The History of Science: 1700–1900
Part I
Professor Frederick Gregory
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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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 the 19th 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 18\textsuperscript{th} and 19\textsuperscript{th} 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 18\textsuperscript{th} 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 17\textsuperscript{th} century, for example, Isaac Newton, a scientist, when the word was not even coined until the third decade of the 19\textsuperscript{th} 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 18\textsuperscript{th} century.
   A. In Britain, the Royal Society, established in the 17\textsuperscript{th} 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 17\textsuperscript{th} 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:
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.

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

Supplementary Reading:

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.

\[
\text{Magnesia alba + acid} \rightarrow \text{residue}_1 + \text{weight loss} \\
\text{Magnesia alba + heat} \rightarrow \text{residue}_2 + \text{weight loss}
\]

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,

\[
\text{acid + residue}_2 = \text{residue}_1
\]

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:**

**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:

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:

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:

Supplementary Reading:
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.

**Supplementary Reading:**

**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.

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 Maillét’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; Paine’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................................................ Helmholtz’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).

**Karlschule**: 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

**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.
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:


Greene, Mott T. *Geology in the Nineteenth Century*. Ithaca: Cornell University Press, 1982. Although primarily concerned with the period after Hutton and Werner, the author does use a revised understanding of their work as a background for his later considerations.


Laudan, Rachel. *From Mineralogy to Geology: The Foundations of a Science, 1650–1830*. Chicago: University of Chicago Press, 1987. One of the few studies to include the German mineralogical community of the 18th century, this work was a major contributor to a revised understanding of the role of Werner in the history of geology.


**Supplementary Reading:**

Badash, Lawrence. “The Completeness of Nineteenth-Century Science,” *Isis*, 63 (March 1972), pp. 48–58. Documents the notion that some physicists believed that physics was nearing an end as the century came to a close.


Burchfield, Joe D. *Lord Kelvin and the Age of the Earth*. Chicago: University of Chicago Press, 1990. Careful analysis of Kelvin’s debate with Lyell and the evolutionists about the differing estimate of available time for evolution to have taken place from thermodynamical considerations and that of evolutionary theory.


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.


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.


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.

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 19th 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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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 the 19th 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 Thirteen
Biology is Born

Scope: In the closing years of the 18th century, a fundamentally new view of life arose among natural philosophers. In this lecture, we first look ahead to the 12 lectures of the series “Life and Its Past” to get a general idea of where the new subject of “biology” will take us over the course of the 19th century. We’ll then return to the beginning of the century and examine how the new view of life contrasted with the conception of natural history in the 18th century. After examining how the continuing development of the idea of epigenesis, encountered earlier in the Haller-Wolff debates, provided the context in which a science of biology could be born, we follow the innovative work of Karl Friedrich Kielmeyer as he attempts to identify the natural laws governing vital phenomena. Finally, we’ll inquire how a biological science might give rise to a differing vision of natural science.

Outline

I. In the last lecture, we saw how the new science of electricity became involved with life itself.
   A. Luigi Galvanni’s claim that there was “animal electricity” was regarded by some as so sensational that it superseded even such accomplishments as those of Galileo and Newton.
   B. It would not be long before the intimate link between electrical force and life itself was exploited.

II. In this lecture, we embark on a new venture, a survey of 19th-century encounters with the subject of “Life and Its Past.”
   A. In this first lecture of the survey, we’ll take a brief look ahead at the whole series before commencing our consideration of the birth of biology.
   B. The beginning of the era marks a turning point, because natural philosophers came up with a new way of regarding living things that required new forms of knowledge.
   C. A whole new organic approach to nature emerged among those calling for an alternative vision of natural science.
   D. Europeans encountered prehistoric beasts and had to explain how they came to be and what they meant for our understanding of ourselves.
   E. A sensational book that tried to summarize how the latest natural science challenged traditional understanding of humankind’s place in nature, written anonymously, rocked England in 1844.
   F. At the same time, Charles Darwin was quietly preparing another bombshell for the age.
   G. Louis Pasteur in France addressed the question of life’s origin.

III. In this lecture, we want to see how the question of life gave rise to a fundamentally new viewpoint among natural philosophers.
   A. According to the French philosopher Michel Foucault, “life” did not exist before the 19th century.
      1. Foucault means that for the natural history of the 18th century, living beings took their place alongside other natural entities to be classified.
      2. The fact that they were living merely grouped them together.
      3. The goal of natural history was to incorporate living things and nonliving things into a larger order—to create a taxonomy of all being.
      4. In this scheme, there was nothing more special about living things than nonliving things.
   B. Foucault suggests that this mode of understanding changed around the turn of the 19th century.
      1. In this new understanding, living things manifested a special quality—life—which was something qualitatively different from everything else.
      2. To understand “life” required new forms of knowledge.
      3. The creation of these novel forms of knowledge emerged as a new science of life, biology.
   C. Biology differed from natural history in a fundamental way.
1. Natural history sought to understand through classification—by organizing the diversity of living things.
2. Biology sought to understand the unique features living things possessed by regarding them as manifestations of higher natural laws.

IV. The context in which “life” was subjected to law occurred in the aftermath of the Haller-Wolff debates, examined earlier in Lecture Eight.
   A. A consensus emerged among German thinkers in the waning decades of the 18th century that the embryo developed from a formless mass, as Wolff had said, as opposed to a preformed entity, as Haller maintained.
   B. But there were still unanswered questions, and German natural philosophers began to explore development beyond that of the embryo.

V. An early attempt to explore a science of life came with the investigation of organic forces.
   A. Karl Friedrich Kielmeyer was a pioneering investigator of organic forces.
      1. He worked in an unusual institution of higher learning—the Karlschule near Stuttgart.
      2. In February of 1793, Kielmeyer addressed an assembly at the Karlschule with a lecture entitled “On the Relations of Organic Forces Among Each Other.”
      3. Kielmeyer insisted that organic forces could not be described quantitatively, as those governing nonliving masses could.
   B. Kielmeyer explored different levels—parallel levels—at which he believed organic forces operated.
      1. He argued that the operation of organic forces governing species was the same as that governing the developmental states of the individual.
      2. A complex individual passes through stages of increasing complexity in its development from embryo to adulthood; a similar sequence of increasingly complex stages can be seen in the arrangement of species in the scale of being.
      3. This meant that animals higher in the scale of being passed through stages of individual development that paralleled the stages of the ascending scale of being itself.
      4. This is to say that the scale of being itself exhibited epigenetic stages, just like those evident in the embryo.
      5. Kielmeyer came to believe that the stages of the scale of being actually developed over time.
   C. After the turn of the century, there were a few who developed these ideas further into what became known as recapitulation.
      1. Several noted that the fetal development of higher animals passes through, or recapitulates, the organizational stages of classes below it.
      2. In 1806, Johann Friedrich Meckel in Halle studied six human fetuses of various ages.
      3. Two years later, physiology professor Friedrich Tiedemann observed that at five months, the eye of the human embryo resembled that of a fish.
   D. Recapitulation theory emphasized the conviction that life was governed by natural laws.
      1. One law governed the development of the individual and the development of the species that made up the scale of being.
      2. These natural philosophers understood this law as an expression of nature’s inner purposefulness.
      3. As such, the laws of biology were different from the mechanical laws of physics.
   E. The birth of “biology” as the new science that subjected life to natural law was one indication of the presence of a different vision of natural science.
      1. We are entering here into the sequel to the Enlightenment, a period known as the Romantic era.
      2. This different vision of natural science emphasized organism over mechanism.

Essential Reading:

Supplementary Reading:
Questions to Consider:

1. Do you think organic forces exist that are qualitatively different from inorganic mechanical forces?
2. How do you think the idea of recapitulation fared in later 19th-century biological science? In 20th-century biology?
Lecture Fourteen
Alternative Visions of Natural Science

Scope: The new outlook reflected in the science of biology was one marker of the end of the Enlightenment and the beginning of a new era. Where natural science was concerned, the Enlightenment culminated in the work of the philosopher Immanuel Kant, whose analysis of reason celebrated the power of natural science at the same time it confined scientific knowledge within carefully described limits. After discussing Kant’s assertions, this lecture considers the reaction against his restriction of the knowledge of nature by a younger generation that was defining a new, post-Enlightenment outlook on nature. The Romantic understanding of nature, evident in the works of the nature philosopher Friedrich Schelling and the novelist, poet, and playwright Johann Wolfgang von Goethe, stood as alternative visions of natural science to the Kantian outlook.

Outline

I. In the last lecture, the new science of biology opened up an innovative view of nature to natural philosophers.
   A. They saw the development of living things as subject to a natural law that operated simultaneously at several levels.
   B. This fundamental law governing living things came to have even wider application. The metaphor for nature itself became organism.
   C. The rejection of nature as mechanism in favor of the new metaphor of organism was, in some ways, a return to the earlier view, but it also served as a major characteristic of an alternative vision of natural science in the immediate post-Enlightenment period called the Romantic era.

II. The Enlightenment view of natural science culminated in the work of the philosopher Immanuel Kant.
   A. Kant’s analysis of reason celebrated its power so much that he turned it on itself, using reason to determine the limitations of reason.
      1. In Kant’s scheme, natural science, beginning as it did with the data of the senses and dependent as it was on causal law, represented what could be known.
      2. Kant, therefore, endorsed the experimental search for the mechanisms of natural process that characterized the Newtonianism of his day, examined in Lecture Two.
      3. But he also said that true scientific explanation was restricted by the structure of the mind itself.
      4. We see this structure in, for example, the capacity to link things together in cause-effect relationships and the ideas of space and number that make mathematical description possible and were all built into the mind itself—like the read-only memory (ROM) in a computer chip.
      5. Kant made clear what humans could not know scientifically.
      6. Kant specified the limits of knowledge beyond which lay a reality that was, in his view, as important for humans to acknowledge as it was off limits to scientific exploration.
   B. The effect of Kant’s analysis was to separate human experience of reality into two nonintersecting parts.
      1. One part—that accessed by our senses—could be made subject to cognition (the phenomenal realm). This was the realm of natural science.
      2. Another part lay outside cognition (the noumenal realm). Here, we encounter the supernatural, which can be apprehended only through faith.
      3. One implication of Kant’s position was that natural science and religion must be kept completely separated from each other.
      4. Throughout the late 1790s and on into the post-revolutionary era, natural philosophers in German universities continued to promote the investigation of nature along the lines Kant had set down in his works on natural science.

III. Some among the younger generation that came after Kant reacted against his fracturing of human experience into two separate and nonintersecting realms.
   A. The Revolution in France brought, in its aftermath, a time of political ferment that was matched by intellectual openness to new possibilities.
B. Among the young natural philosophers of the early Napoleonic period was Friedrich Schelling.
   1. Schelling was impressed with the work Kielmeyer had done on organic forces.
   2. In two works, Schelling expressed fundamental dissatisfaction with the cause-and-effect explanations Kant had required.
   3. Because Kant assumed that one could regard nature as a machine whose parts interacted, as machine parts do, by passing their effects from one part to another, his analysis applied to external nature, as if one were observing nature from outside.
   4. To Schelling, living things were more basic than machines; nature must not be regarded as a machine but as an organism.
   5. An important quality of organism was the way in which it unified disparate parts.
   6. By viewing our approach to understanding reality in this way, Schelling promised to overcome Kant’s fracturing of human experience into two separate realms.
   7. Schelling’s treatment of nature was called Naturphilosophie, or “nature philosophy.”

IV. The Romantic vision of natural science stood as an alternative to the continuing Kantian view during the first two decades of the 19th century.
   A. There was no established “scientific community” in our sense of the term during this period.
      1. Although there were academies and societies of science, in Germany, the word for science, Wissenschaft, has a much broader meaning than “natural science” alone.
      2. German, French, and English did not yet have terms for a practitioner of natural science.
   B. The great attraction of Naturphilosophie to many young minds of Schelling’s generation lay in its insistence that nature be given its own integrity and not be made overly dependent on the formal structure of our minds, as Kant was seen to have done.
      1. Schelling’s objection to Kant did not mean that he had no respect for experimentation or the empirical data of the senses.
      2. For Schelling, it is not that we know nature because our minds are structured a certain way, but because we are part of nature.
      3. The nature that is known by human souls is best comprehended as itself a world soul.
   C. Schelling’s new vision for natural science won him important admirers from many quarters, including numerous scientific disciplines.
   D. By the beginning of third decade of the 19th century, Naturphilosophen found themselves more and more on the defensive.
      1. The followers of Kant naturally tried to defend their mentor’s position from Schelling’s criticisms.
      2. Schelling’s opponents achieved some success in misrepresenting his claims as hostile to empirical investigations.
      3. An increasing number of natural philosophers resisted Schelling’s call to reformulate their mission to include philosophical issues.

V. One more manifestation of Romantic science in this period is the work of the novelist, poet, and playwright Johann Wolfgang von Goethe.
   A. By the turn of the century, Goethe already enjoyed great literary fame and a celebrated position in the court of Duke Karl August in Saxe-Weimar.
   B. His passion for natural science showed itself first in his work on morphology.
      1. Like others, Goethe looked for regularities operating at different levels in the phenomena he observed.
      2. He insisted that through practiced careful observation, one could identify the basic forms lying behind the differentiated structures by which things are often classified.
   C. The other scientific subject that fascinated Goethe was optics, where he took on no less than Isaac Newton himself.
      1. He knew of Newton’s explanation of colored light.
      2. Goethe concluded that Newton had been wrong in his explanation of color.
      3. Goethe’s objection to Newton’s disregard of the subjective experience of the observer, including nature’s aesthetic impact, meant that there would be no meeting of minds.
      4. In the course of his writings on color theory, Goethe raised a number of important and enduring questions.
Essential Reading:
Richards, *Romantic Conception of Life*, chapters 1 and 3 (pp. 116–151), chapters 10–11.

Supplementary Reading:
Sepper, *Goethe Contra Newton*, chapter 2.

Questions to Consider:
1. Is there such a thing as Romantic science?
2. Why do many regard nature philosophy as an outgrowth of the Kantian heritage?
Scope: Although trained in the German school where Karl Friedrich Kielmeyer was also a student, Georges Cuvier’s fame as a natural philosopher was made in Paris during the first three decades of the 19th century. Cuvier’s careful study of fossil remains of vertebrates convinced him that there had been a past age in which life forms different from those known at present existed. Cuvier was among the first to present convincing evidence of extinction of species. By comparing the anatomical features of the fossil remains, Cuvier was able to determine the structures and habits of the prehistoric beasts and even to formulate an important new system of classification. Opposed to the possibility that present-day life had evolved from these earlier forms, Cuvier appealed to a series of violent catastrophes to explain the history of life on Earth.

Outline

I. The alternative vision of natural science we examined last time did not entice everyone exposed to it.
A. Among the students at the Karlsschule in Württemberg was a younger student named Jean-Leopold-Nicholas-Frédéric Cuvier.
   1. Cuvier came from the French-speaking, Lutheran principality of Montbéliard, politically united to the Grand Duchy of Württemberg.
   2. As an adolescent, Cuvier was fascinated by natural history.
B. Cuvier’s education at the Karlsschule was decisive in several ways.
   1. Kielmeyer taught Cuvier how to dissect and introduced him to philosophical natural history.
   2. Cuvier soon learned that he preferred dissection and careful empirical observation to Kielmeyer’s philosophical views.
   3. Cuvier’s exposure to a mix of students from across central Europe afforded him a more diverse education than he would have had in the French institutions of higher learning available to him at the time.
   4. Cuvier took a position as a tutor in France and continued his study of natural history.
C. Cuvier moved to Paris sometime relatively early in 1795, where by the end of the year, his career had begun to take off.
D. Cuvier’s aversion to Romantic biology became clear again in his opposition to Lennaeus’s system of classification.
   1. Cuvier agreed with Etienne Geoffroy Saint-Hilaire, a friend he had made early among the Parisian naturalists, that Linnaeus’s classification was inadequate.
   2. But Geoffroy responded by searching for what he called the “unity of composition,” the common plan of organization, that nature had followed in producing living things.
   3. Cuvier reacted against this philosophical approach, which resembled the philosophical anatomy he had found uninteresting in Kielmeyer.
   4. He began work on a new functional system of classification based on how the nervous system in animals relates to organs of motion.
   5. Cuvier opposed the idea of a “scale of being,” in which one organism was seen as more perfect than another.

II. Cuvier’s work with fossil remains created a stir in Paris around the turn of the century and throughout the reign of Napoleon.
A. The years right after the Revolution proved a favorable time for Cuvier’s work on fossils.
B. The idea of extinct prehistoric beasts may have been implied in the work of Cuvier’s predecessors, but it was he who introduced this realm to the popular imagination.
   1. In a public lecture in 1796, he first used anatomical differences in African and Indian elephant remains to establish that they were, in fact, two different species of elephant.
   2. He then used the same criteria to show why other remains were different from both of these species.
III. Over the next decade, Cuvier fired the imaginations of his listeners as he established that some species no longer existed today.

A. He introduced French natural philosophers to two new ideas: interrelated conditions of existence and what he called the “subordination of characters.”
   1. The “conditions of existence” in a given location were so interconnected with organisms that came into existence there that only certain relations among the anatomical parts of living things were possible.
   2. Cuvier determined to become so familiar with the correlations among the parts of organisms (both living and fossil) that he could then use what he learned to make inferences when all he had to go on was a few remains.

B. The obvious question was: What has become of these animals from before recorded history given that there is no living trace of them today?
   1. Cuvier argued that they had been “destroyed by some kind of catastrophe.”
   2. In a classic publication of 1812, *Investigations on Fossil Bones*, Cuvier insisted that extinction could not have been caused by forces at work in the present.
   3. From carcasses of large quadrupeds encased in ice, he inferred that catastrophic events must have been sudden and violent.
   4. An inundation of water or a sudden elevation of land must have wiped out the forms of life whose remains were then preserved.

IV. A major motivation of Cuvier was to oppose ideas of evolution, or “transformism.”

A. Ideas of transformism had existed for some time.
   1. In the 18th century, the transformation of species was implied in the Earth history of de Maillet and Buffon, which we examined in Lecture Three.
   2. These ideas were also implied in the work of the Englishman Erasmus Darwin.
   3. More immediate for Cuvier were the transformist ideas of Jean-Baptiste Lamarck, whose evolutionary system, published in 1809, is examined in Lecture Sixteen.

B. Cuvier had to explain how creatures became extinct.
   1. He asserted that God had originally created all species that had ever lived or would ever live.
   2. Over time, catastrophes had winnowed out numerous species, which became extinct, while others had avoided elimination.

**Essential Reading:**

**Supplementary Reading:**
Outram, *Georges Cuvier: Vocation, Science, and Authority*.

**Questions to Consider:**
1. Why did it take longer to acknowledge the idea that some species had become extinct than that new species had originated in time (Linnaeus)?
2. Is there a place for catastrophism in natural science?
Lecture Sixteen
Evolution French Style

Scope: During the first two decades of the 19th century, Cuvier’s position on natural history did not go unchallenged. Jean-Baptiste Lamarck, 25 years Cuvier’s senior, objected to the idea that species had become extinct by the action of catastrophes. He proposed that species had, instead, changed over time to their present forms, and he spelled out a detailed explanation of how evolutionary change had occurred. Because his ideas were regarded as overly speculative and because they appeared to encroach on divine prerogatives where life was concerned, Lamarck’s later career suffered in comparison to the earlier respect his work had enjoyed.

Outline

I. In the last lecture, we learned about the world of prehistoric beasts that Georges Cuvier opened up to the educated public of Paris during Napoleon’s reign.

II. Lamarck held a respected place among French natural philosophers before the Revolution changed after 1789.
   A. Under the Old Regime, Lamarck had become a member of the circle of botanists and students at the Jardin du Roi.
      1. In 1777, at age 33, he completed a work on the flora of France that received recognition from Buffon, who arranged to have it published.
      2. Not long thereafter, Buffon assisted Lamarck in obtaining a position in the botanical section of the Academy of Sciences.
      3. In 1781, Buffon created for Lamarck the position of correspondent of the Jardin et Cabinet du Roi.
   B. The coming of the Revolution profoundly disrupted French science.
      1. As the Revolution progressed, there was growing concern about whether the pursuit of scientific knowledge by elites was compatible with the democratic spirit.
      2. Under the guise of educational reform, the Secretary of the Academy, Marie-Jean-Antoine-Nicolas Caritat de Condorcet, proposed a National Society in the spring of 1792, just at the time when the Revolution began to turn radical.
      3. Eight months later, opponents in the National Convention labeled Cordorcet’s motives “a secret desire to retain citizens under the academic rod.”
      4. In spite of desperate attempts by Lavoisier to save the Academy of Science, it was eliminated, along with France’s other learned societies, by action of the Convention.
      5. Once the Reign of Terror passed the new constitution of 1795, it made a place for research in natural science.
      6. The National Institute, while a replacement for the old Academy, also included sections for moral science and for literature and the arts.
      7. The old Jardin du Roi now became the Museum of Natural History, and several other new institutions were also created.
   C. Lamarck’s status in 1795 was still high, but it soon took a downturn because of disagreements with colleagues.
      1. He was given a chair in the Museum and became a member of the scientific section of the Institute.
      2. By the early 1800s, his relationships with colleagues had clearly degenerated.
      3. Many other natural philosophers disliked Lamarck’s growing tendency to move the careful empirical observations of his earlier work to grand speculations.
      4. Lamarck’s ideas about evolution, increasingly present in his work after 1800, were regarded as more evidence of the spirit of system, with which few found favor.
      5. Lamarck himself began to feel somewhat ostracized from the community of natural philosophers in France.

III. Lamarck’s account of life’s past was among the first systematic expositions of evolution.
   A. What was Lamarck’s incentive to consider evolutionary development?
1. In addition to his willingness to consider grand speculative ideas, he also disliked what the young Georges Cuvier was telling Parisians about extinct prehistoric beasts.
2. Lamarck believed in a well-ordered universe, visible for example, in the wonderful balances that functioned to keep nature in equilibrium.
3. That a species might become extinct was, to Lamarck, equivalent to a violation or disruption of nature’s order, something her wisdom would not permit.
4. He specifically rejected Cuvier’s appeal to special intervening events—catastrophes—to explain extinction. They were, in Lamarck’s view, too “convenient.”
5. Lamarck argued that Cuvier’s older species still existed but in forms that had changed over time.
6. Many of Lamarck’s ideas were in place by 1802. They appeared full blown in 1809 in his book Zoological Philosophy.

B. Lamarckian evolution began with something Lamarck called the “power of life.”
1. Lamarck believed that as a consequence simply of being alive, living things became more complex.
2. Although obvious in an organism’s growth, the power of life also manifested itself through the constant movement of internal fluids that exerted a continual pressure on the internal structure of living things, gradually altering the organization.
3. Taking a cue from the discussions of galvanism at the time, Lamarck asserted that the simplest forms of animal and plant life originated by spontaneous generation as a result of the combined action of heat, light, electricity, and moisture.

C. Interaction with the environment also influenced the forms of life over time.
1. If the environment experienced alterations, it follows that the needs of the animals living in the environment would also change.
2. If the new needs became permanent, then the animals adopted new habits that lasted as long as the needs that evoked them.
3. Lamarck’s theory here was thoroughly mechanistic—the organism’s reaction to the changed environment was automatic—a stimulus-response reaction.
4. If these new habits led the animal to use one of its parts in preference over another part, or to neglect the use of some organ altogether, then a part could be gradually strengthened or weakened over time.
5. Lamarck’s most famous example was that of a giraffe, which had developed the permanent habit of constantly stretching its neck to reach the leaves of trees on which it fed, thereby slightly lengthening its neck over its lifetime.
6. Such alterations in bodily parts produced by use and disuse were passed down to the offspring of the organism that acquired them—the inheritance of acquired characteristics.
7. In this way, the characteristics of the species itself were affected; for example, over generations, the giraffe had evolved an elongated neck.

IV. What was the response to Lamarck’s theory?

A. For the most part his work was ignored, but there were those who opposed its endorsement of evolution.
1. The speculative nature of Lamarck’s conclusions confirmed for some that his system had little merit.
2. Predictably, Cuvier and other opponents of transformism criticized the book.
3. Later, in the 1820s, Lamarck’s evolutionary ideas were appreciated within limited circles in France, England, and Germany.
4. For the most part, however, Lamarck’s influence as an evolutionist would not be felt until much later in the 19th century.

B. Reaction against Lamarck was also brought on by his extension of deism to include the living world.
1. His account of the creation of life did not acknowledge a direct role for a divine spark.
2. Lamarck was not an atheist. He believed that God had created an order of things that, on its own, produced the diversity of living things we see today.
3. It was as if God had created the hardware of the universe, installed in it the ROM of natural law, then written a software program that expressed his divine intent for the historical evolution of living things.
4. These ideas were too much for most Frenchmen, including Cuvier, to stomach.
Essential Reading:

Supplementary Reading:
Jordanova, *Lamarck*.

Questions to Consider:
1. Lamarckian evolution proved to have great staying power throughout the 19th and well into the 20th century. What about it was so attractive?
2. Did Lamarck represent more of an 18th- or a 19th-century mentality?
Lecture Seventeen
The Catastrophist Synthesis

Scope: The issue of life and its past in Britain grew less out of a concern with biology, a science of living things, than it did from two uniquely British developments. First, during the first decade of the century, British natural philosophers created an opposition between the ideas of Abraham Werner and those of James Hutton from the 18th century. This led to the celebrated clash between Neptunists and Vulcanists. Second, beginning in the middle of the second decade of the century, William Buckland led a movement to bring geological issues into the study of world history at Oxford. By 1830, the controversies over life and its past were placed front and center in Britain, just as they had been on the Continent. This lecture examines the British route to that result.

Outline

I. The situation in Britain was a bit different from that in France regarding new ideas about life and its past in the early decades of the 19th century.
   A. British thinkers came at the subject from a different direction than those on the Continent.
   B. In Britain, the encounter with life and its past is best understood against the two regional backgrounds of north and south.

II. At the beginning of the century, a small group of thinkers in Scotland created a new debate about the geological past that was unlike discussions taking place on the Continent.
   A. Continental writers, including Cuvier, drew on the detailed empirical observations of the mineral composition of local regions studied by Abraham Werner in Germany.
   B. Cuvier, in particular, contrasted Werner’s approach to the older literary genre commonly known under the phrase “theory of the Earth.”
      1. Theories of the Earth used observational evidence to support grand, high-level explanations of the structure and history of the Earth in terms of a few natural causes.
      2. We have met examples of this tradition in the works of de Maillet, Buffon, and Hutton.
   C. Some Scots proceeded to transform Werner’s empirical “geognosy” into a theory of the Earth, then to compare it to the theory of their countryman James Hutton.

III. The series of exchanges between those who championed Werner against the followers of Hutton has become known as the debates between the Neptunists and the Vulcanists.
   A. The debates began with the appearance of two books in 1802 by men from Edinburgh, John Playfair and John Murray.
      1. Playfair made it clear that he was not interested in geognosy, because it did not deal with causes, as Hutton’s approach did.
      2. Playfair placed his own stamp on Hutton’s work by removing as much as possible Hutton’s theological concern to demonstrate God’s action and replacing it with sound geological theory.
   B. Murray was not about to permit Playfair to claim the field of sound geological theory for Hutton.
      1. Murray was one of several in Scotland who were familiar with Werner’s work.
      2. Murray made Werner’s empirical work into a causal theory of the Earth.
   C. In Britain, the debates of the first decade of the century would be largely over which cause was correct, heat or water, with each side asserting that its claims resulted from empirical observations.
      1. Vulcanists emphasized the slow action of heat and the uniformity of action in the past and present.
      2. Neptunists emphasized the dramatic action of moving water, which for many Englishmen, was easier to reconcile with direct divine superintendence of history.
   D. Between 1810 and 1820, however, the situation became more complicated.
      1. Both Vulcanists and Neptunists came to agree that, although erosion and dislocation caused by the action of water played a part in the formation of present rocks, so, too, did heat and chemical action.
      2. Attention began to shift away from the formation of rocks and toward the fossils embedded in them.
3. William Smith utilized the fossil remains in rocks as markers of their age in a map of the geological strata of England and Wales that he had been working on for more than 20 years.

E. We must keep in mind that the debate between Vulcanism and Neptunism was largely a British phenomenon.
   1. Many on the Continent did not regard Werner’s approach as a causal theory.
   2. Even within Britain, the replies to Playfair’s elucidation of Hutton’s theory were largely a regional matter.
   3. Historians have overstated the impact of Hutton’s thought in the history of geology.

IV. In southern Britain, a different issue developed during the second decade of the century that involved an attempt to reform the discipline of world history at Oxford.

A. British scholars assumed that humans determined world history; thus, classical scholarship in this field focused on written documents from the ancient past.
   1. Primary credentials of the world historian included a knowledge of the languages of antiquity.
   2. Information bearing on the Earth’s physical past, although desirable, was only meaningful as it fit into the reconstruction of human history.

B. British world history changed when Cuvier’s 1812 work on fossil bones became available to English readers in translation in 1813.

C. In this context, William Buckland attempted to bring natural science more centrally into the study of world history at Oxford.
   1. Buckland endorsed Cuvier’s idea that human history was just the last in a series of periods of Earth history.
   2. He campaigned to make geology a worthy academic subject in the university.

D. Buckland’s defense of the Earth’s catastrophic past had an enormous impact, bringing geology to center stage in Britain during the 1820s.
   1. In 1821, Buckland learned about some fossil remains that had been discovered by quarrymen in a cave in Yorkshire.
   2. He argued from bones of hyenas and from markings on the remains of elephants, rhinoceroses, and other animals found in the cave that the hyenas had dragged parts of the other animals into the cave before Noah’s flood had occurred.
   3. Cuvier himself said good things about Buckland’s theory, securing his rising fame.

E. The appearance of Buckland’s work had three effects.
   1. It created a synthesis between British and French ideas about the Earth’s history.
   2. Buckland’s rejection of a strictly literal reading of the Bible called forth a spate of works opposed to his theory.
   3. His understanding of the past categorically rejected the deistic vision of Erasmus Darwin, James Hutton, Jean-Baptiste Lamarck, and others.

F. By arguing that classical world history should be expanded to include geology, Buckland appeared as a progressive force within British academe.

Essential Reading:
Greene, Geology in the Nineteenth Century, chapter 2.

Supplementary Reading:
Rupke, Great Chain of History, part I.
Gillispie, Genesis and Geology, chapters 2–4.

Questions to Consider:
1. How did the British Neptunists alter Werner’s view when they turned it into a causal explanation of the history of the Earth?
2. Once the discipline of world history acknowledged the existence of prehistoric beasts, how do you think that idea affected the conception of human history?
Lecture Eighteen
Exploring the World

Scope: Carrying on in the tradition of such 18th-century explorers as James Cook, naturalists in the 19th century also committed themselves to find out what lay in the world’s unknown regions. Europeans were eager to learn about Alexander von Humboldt’s journey to South America, as they were about the voyage Charles Darwin took around the world aboard HMS Beagle. Darwin took with him the first volume of a new book on geology by Charles Lyell, whose work would later prove influential on Darwin’s thinking. This lecture introduces these two voyagers and analyzes the significance of their journeys for the travelers themselves and for the natural science that they influenced.

Outline

I. From a concern with life of the past, we turn to those interested in the life of the present.
   A. Two individuals in the early 19th century who set out to explore the world of the present were Alexander von Humboldt and Charles Darwin.
   B. Voyages of exploration had been going on well before the 19th century.

II. Alexander von Humboldt became Europe’s leading international “man of natural science” during the first half of the 19th century.
   A. Son of a nobleman and officer in Frederick the Great’s Prussian army, Alexander was born in 1769 to wealth and privilege.
      1. His education came from several sources, including exposure to the Enlightenment Jewish intellectual community of the Berlin salons.
      2. After serving as a mining administrator, he pursued independent scientific research on various problems.
      3. He spent considerable time in Jena and Weimar, where he got to know Goethe, Schelling, and other prominent figures of the Jena Romantic circle.
   B. Von Humboldt imagined a trip to the Americas for the purpose of scientific research, the first such venture undertaken solely for that purpose.
      1. He became acquainted with the French botanist Aimé Bonpland, whom he invited to join him in an expedition to the Spanish colonies.
      2. His main purpose was “to find out how the forces of nature interact upon one another and how the geographic environment influences plant and animal life.”
   C. The journey took the travelers to Venezuela, where they spent a year exploring the coast and the interior.
      1. Von Humboldt and Bonpland set out in February of 1800 to explore the relatively unknown region of the Upper Orinoco.
      2. With Bonpland, von Humboldt confirmed the reality of the Casiquiare Canal, whose existence as a link between the two great river systems of the Orinoco and the Amazon was in dispute.
   D. After a brief trip to Cuba, the pair embarked on a two-year exploration of the Andes of Columbia, Ecuador, and Peru.
   E. The final stage of the trip lasted another year and a half, taking von Humboldt to Mexico and the United States.
   F. Von Humboldt’s adventures, which had been reported during his absence, established him permanently on his return to Europe as a celebrated man of science wherever he went.
      1. He made his home in Paris until 1827, when he was finally recalled to Prussia by the king.
      2. Among von Humboldt’s many writings, his multivolume Cosmos of 1845 was a widely read book.

III. Charles Darwin’s voyage around the world was the decisive event of his life.
    A. Darwin also was born to wealth and privilege.
       1. His finished his degree at Cambridge University in January of 1831 and developed the idea of taking a trip to the Canary Islands before settling down as a country parson.
2. A letter from his favorite professor, John Henslow, asked if Darwin was interested in an exploratory voyage to Terra del Fuego.
3. Darwin departed with the HMS *Beagle* in December of 1831 for what would be a five-year circumnavigation of the globe.

B. Darwin’s accomplishments during the voyage mark him as a skilled observer.

C. Darwin encountered different sources of new ideas.
   1. During the voyage, he read Charles Lyell’s *Principles of Geology*.
   2. Lyell believed that nature’s processes acted gradually, requiring an enormous period of time, and that the Earth’s condition had always been basically the same—a steady state.
   3. Darwin visited the Galápagos Islands, where he made observations of the birds and tortoises, but he was primarily interested in volcanic geological features.
   4. Leaving these islands, the *Beagle* traveled to islands in the South Pacific, to New Zealand and Australia, to South Africa, a jaunt over to Brazil, and back to England by way of the Azores.

D. Encounters with life on the Galápagos Islands provided the occasion for the idea of evolution to make an appearance near the end of the voyage.
   1. While rearranging his notes, Darwin found that he wasn’t sure how to sort the Galápagos birds and tortoises—as varieties or different species.
   2. If they were, in fact, different species, it “would undermine the stability of species.”

E. The idea of evolution germinated and began to blossom after Darwin’s return home.
   1. In March of 1837, Darwin learned from an ornithologist, whom he had asked to examine specimens of finches from the Galápagos, that they were definitely different species.
   2. Darwin began to allow himself to conclude that species transform over time, although that assumption raised several questions.
   3. For the next several years, he worked hard on developing what he began to call “my theory” once he had come upon the idea of natural selection.

**Essential Reading:**
Browne, *Charles Darwin: Voyaging*, part II.

**Supplementary Reading:**

**Questions to Consider:**
1. Why did Alexander von Humboldt’s trip to the New World make him more famous than earlier travelers just before him?
2. It has been said that Darwin’s voyage was the most important shaping event of his life, yet he did not come to the insights for which he is famous until after his return. Exactly what did the trip do for him?
Lecture Nineteen

A Victorian Sensation

Scope: In 1844, the publication of The Vestiges of the Natural History of Creation took Britain by storm. It was, in the minds of many, an outlandish and irresponsible assertion that the best natural science of the day implied that all of creation, including the world of living things, had developed gradually in accordance with natural law. It endorsed the popular science of phrenology, which claimed that the mind, too, was subject to the rule of natural law. Because it was published anonymously, it stimulated enormous public interest and became a sensation. Although it was denounced on many fronts, still, the debates it sparked contributed to the tumultuous 1840s and helped to establish the context in which the subject of evolution entered the British scene.

Outline

I. In the last lecture, we met two travelers from the early 19th century who brought a great deal of attention to natural science.
   A. Darwin’s publication of his Journal of Researches in 1839 was widely acclaimed and made him famous.
   B. Von Humboldt remained famous throughout his life.

II. In 1844, there appeared another book in England that immediately became a sensation: Vestiges of the Natural History of Creation.
   A. Everything about the book created interest in it.
      1. It was claimed to be “the first attempt to connect the natural sciences into a history of creation.”
      2. The message was: The old traditionally religious way of thinking about our past and the Earth’s past simply will not do any longer. Natural science says otherwise.
      3. It was fuel to a fire already burning in north Britain, where a year earlier, the so-called Great Disruption in the Church of Scotland had occurred.
      4. The book was published anonymously, raising curiosity about its author.
   B. The book was read by a great diversity of people in a variety of different settings.

III. What was in this book that caused so great a reaction?
   A. Above all, it was a defense of deism supposedly based on the truths of natural science.
      1. The author celebrated the rule of law in nature.
      2. A major motivation, not made explicit in the book itself, was the author’s enthusiasm for phrenology, the science of reading the localized mental functions of the mind from external anatomical features of the skull.
      3. The author urged that the solar system, the Earth, and life had come about as the result of what he called “creation by law.”
      4. For people of traditional faith, the book undermined God’s superintendence of nature and history.
   B. What specific claims did the anonymous author make about the formation of the cosmos and life within it?
      1. The author explained the emergence of solar systems and of our Earth as the result of a process of natural development from primitive nebulous matter.
      2. Life originated and slowly developed naturalistically, without God’s direct involvement, from primitive to more complex forms over immense periods of time.
      3. The author insisted that his naturalistic vision of life and its past, although apparently deterministic, was in the end, benevolent.

IV. What reception greeted this Victorian sensation?
   A. What one thought of the book correlated nicely with one’s position in Victorian society.
      1. Discussion of the book and of such subjects as phrenology and mesmerism was, for many aristocrats, a form of entertainment that allowed them to test uncertain borders of appropriateness.
      2. Members of the Whig reform movement liked the idea that nature was lawful and progressive but disliked such views being associated with a disagreeable evolutionary cosmology.
3. Members of the established Anglican Church confronted the *Vestiges* as a misunderstanding of the true relationship between religion and science.
4. Evangelicals tended to think that the *Vestiges* led to atheism.
5. Some from all quarters of society, including literate workers, found that reading the *Vestiges* contributed to their loss of faith.
6. Those associated with the radical movement for free thought latched onto the *Vestiges*. As a more moderate appeal to progress than their usual message, they saw its association with natural science as an opportunity to bring them respectability.
7. The *Vestiges* was a problem for the great majority of Victorian society.

**B.** What kind of person had written this outlandish book?
1. Educated “gentlemen of science” were not supposed to be given to extreme positions, yet the learning reflected in the book suggested one of them might have written it.
2. Several women were suspected of being the author.
3. After a few years, the opinion settled on the Scottish publisher Robert Chambers, although the controversy raged on into the 1850s.
4. Chambers was a liberal Whig reformer, opposed to aristocratic privilege as much as he was to what he thought of as evangelical hypocrisy.

**C.** Knowing about the impact of *Vestiges* revises the usual view of evolutionary history that centers on Darwin.
1. Darwin did not create the crisis over evolution and evolutionary cosmology. It was everywhere in Britain well before Darwin’s book came along, 15 years after the *Vestiges*.
2. Given that Darwin’s idea of natural selection was rejected by almost all readers for the first 75 years after he made it public, his significance was not the result of revealing a compelling new truth to his age.

**Essential Reading:**

**Supplementary Reading:**
Chambers, *Vestiges of the Natural History of Creation*.

**Questions to Consider:**
1. Why was deism, which acknowledged God as creator of nature, not more palatable to the British mind of the 1840s?
2. How does a better understanding of the sensation surrounding *Vestiges* alter your view of Darwin’s later achievement?
Lecture Twenty

The Making of The Origin of Species

Scope: After returning home from the voyage of the Beagle in 1836, Charles Darwin relatively quickly came to the idea of natural selection. This lecture traces the path Darwin followed in creating and developing his theory in the years after his voyage and in producing the hurried compendium we know as The Origin of Species. Darwin set out to establish as firm a scientific foundation as he could for his views. Surviving personal loss and constant illness, Darwin struggled to overcome the many roadblocks facing anyone who wished to challenge the special creation of species by God with a theory of evolution. By examining the structure and content of the Origin, we will acquire a better understanding of why the work made such a powerful impression on the age.

Outline

I. In Lecture Nineteen, we saw how preoccupied early Victorian Britain became with the demands of natural science in the 1840s.
   A. The celebration of the rule of law in nature was not the prerogative of just one understanding of natural science.
   B. The young Charles Darwin experienced all this with mixed emotions.

II. A closer look at Darwin’s efforts after he came home from his trip around the world reveals that his understanding contained many new implications.
   A. Having become convinced of transmutation soon after his return, he then came to natural selection, “a theory by which to work.”
      1. The seminal idea was born from reading Thomas Malthus’s argument about the rate of increase in human population far outstripping that of agricultural food production.
      2. Malthus observed that something must be curbing the rate of increase in the population, because at most times, there was a broad balance between the population and food supply.
      3. Darwin generalized this logic from humans to all plant and animal life.
   B. His earlier plan for the ministry abandoned, Darwin settled down to a life of research, publication, and personal challenges.
      1. Darwin realized that the implications of his new theory were incompatible with traditional Anglican religion.
      2. He was under great pressure in these post-voyage years. He experienced the first episodes of the illness that would plague him his whole life.
      3. He shared his views with a small number of people.
      4. He was quick to say that the means by which he thought evolution occurred were wholly different from Lamarck’s idea.
      5. Given the outcry against the publication of the Vestiges, Darwin determined that he would have to do a lot more work on his theory before he could make it public.
   C. Darwin abandoned the writing of his species book and escaped into close observation, especially of barnacles.
      1. He found that where most barnacles were hermaphrodites, there were some in which a separate male organism lived as a parasite inside the carapace of a female.
      2. Darwin concluded that he was seeing evolution in action here—the birth of sexuality.
      3. Everything was once hermaphroditic, but once nature had stumbled onto sexuality, the production of variation was enormously enhanced, which in turn, produced a richer array from which nature could select.
   D. The late 1840s and early 1850s were a trying time for Darwin personally.
      1. He continued to suffer from the sickness that plagued him.
      2. He inherited more than £50,000, a huge sum that he managed well, guaranteeing him the life of a country gentleman.
3. In 1849, Darwin began taking the water cure, a regimen of cold showers and steam baths, which appeared to work for him.
4. His eldest daughter, 10-year-old Annie, who had been unwell for some time, became ill enough in the spring of 1851 that he took her to receive the cure as well.
5. Annie’s death a month later marked the death-knell for Darwin’s Christianity, which had been decaying for some time.

III. Darwin returned to the species manuscript in 1856.

A. Increasingly convinced that his theory of natural selection was correct, Darwin began preparing the way among his friends.
1. He invited several to Down in April of 1856, including the marine scientist Thomas Huxley.
2. The main subject of discussion was about the possibility of transmutation.
3. Darwin earlier had told Lyell about natural selection. Although impressed, he worried about its implications for the dignity of the human species.
4. Still, Lyell urged Darwin to write up his ideas, which he began to do in 1856.
5. In June of 1858, a letter from Alfred Russell Wallace arrived, outlining a new idea that was remarkably similar to Darwin’s natural selection.
6. Lyell and Hooker suggested that Wallace’s letter and a short précis of Darwin’s theory both be presented to the Linnean Society’s June meeting.

B. Darwin’s book, with the new title *On The Origin of Species by Natural Selection*, appeared in November of 1859, an abstract of the work Darwin had planned to publish.
1. Readers of the book were drawn along by its logic, which moved from the variation that breeders of plants and animals could produce to the inference that nature, with enormous time at its disposal, could do the same.
2. After reminding the reader of the struggle for existence that went on in nature, Darwin introduced his idea of natural selection.
3. The continuous operation of natural selection over vast time produces changes in species so substantial that they have been transmuted into different species.
4. What makes the book so credible and persuasive is Darwin’s candid admission of problems with his idea, which he does his best to solve.
5. The book is filled with specific information about plants and animals that illustrate his theory. Darwin wishes to give the impression that his theory rests on facts.
6. What made it different from Chambers’s evolutionary scheme was that Chambers emphasized the idea of evolution without specifying how it occurred, while Darwin focused on the mechanism of evolution—natural selection.

C. The reception of the *Origin* made clear what Darwin’s achievement had been.
1. The quality of the work was evident to almost everyone.
2. Many of his friends praised the work highly in reviews and lectures.
3. Others objected that Darwin’s inductive reasoning was too loose, that the work did not prove its case, and that it remained, in the end, an unsubstantiated hypothesis.
4. The greatest objection was that Darwin viewed nature as something outside providence; that what one reader called his “law of higgledy-piggledy,” took the place of divine superintendence of life.
5. Darwin had sharpened the issue of the relationship between science and religion by asserting that his scientific understanding of nature existed apart from the traditional religious view.
6. Unlike Chambers, Darwin broke with the past by not attempting to support or justify his theory through reference to developmental cosmology.
7. Darwin’s work stood as an argument that specialized research, not philosophical disposition or religious leaning, should drive the scientist.
8. Such an argument was enormously threatening to his age for many scientists, as well as many nonscientists.

Essential Reading:
Supplementary Reading:
Desmond and Moore, *Darwin*, chapters 20–32.

Questions to Consider:
1. How does Darwin’s theory of evolution differ from Lamarck’s?
2. Darwin’s book on evolution appeared 15 years after that of Chambers. How is it that Darwin’s book was immediately taken seriously while Chambers’s was almost universally condemned?
Lecture Twenty-One

Troubles with Darwin’s Theory

Scope: During the first decade after the appearance of Darwin’s *Origin*, a number of scientific difficulties were raised by members of Britain’s now organized scientific community. Problems with how natural selection could get started, why it had produced nonadaptive characteristics, and why it appeared inconsistent with the new sciences of statistics and thermodynamics represented a few of the issues debated in the aftermath of Darwin’s book. Add to these the difficulty of harmonizing the theory with the common understanding of the fossil record and the sum of objections led to what has been called an eclipse of Darwin’s theory. If Darwin’s own account of how evolution occurred was not persuasive to many, he had nevertheless convinced most that evolution had, in fact, occurred. The ground was prepared, therefore, for the revival of Lamarckian ideas of evolution.

Outline

I. Last time, we saw how Darwin’s book, long in the making, was quickly sold out when it appeared in 1859.
   A. Known as a respected naturalist and as a world traveler, people were eager to learn what Darwin had to say about the question raised by his title—how species originated.
   B. The situation was different in 1859 from what it had been 15 years earlier when the anonymous *Vestiges* had weighed in on this question.
      1. Failed revolutions on the Continent in 1848 had first raised the hope, then dashed it, that a new social order was dawning.
      2. Among those identified with natural science, more and more were associating themselves with nontraditional positions.
      3. The relationship between religion and natural science had become more complicated than it had been in the past, when science was regarded as an obvious ally of faith.
      4. As a result, it was no longer fashionable to make dogmatic public pronouncements about science and religion.
   C. In this lecture, we’ll see that Darwin’s theory did not fare well in the 19th century.

II. An initial consideration of Darwin’s ideas in 1860 has been frequently misinterpreted.
   A. An encounter occurred between Bishop Samuel Wilberforce and Thomas Huxley at the June 1860 meeting of the British Association in Oxford.
   B. The debate was a minor incident whose significance has been overblown.
      1. The relationship between science and religion was not the most pressing religious issue of the day in Britain.
      2. British theologians were more concerned about questions concerning the interpretation of the Bible.
      3. The event has become significant because of the way it has sometimes been interpreted.
      4. Darwin’s book did not enter Victorian society like a plough running into an anthill.

III. Scientific difficulties with Darwin’s theory began to emerge in the 1860s.
   A. Among the first was the claim that there had not been sufficient time for evolution by natural selection to occur.
      1. The Scottish physicist William Thomson (later Lord Kelvin) articulated how and why the cosmos (including Earth) was running down, a different conclusion from that of Charles Lyell’s steady-state Earth.
      2. Thomson concluded that the Sun and Earth were not old enough to permit evolution.
   B. A review of Darwin’s book raised a pressing problem about why natural selection simply wouldn’t work.
      1. In 1867, Fleeming Jenkin, a Scottish engineer, reviewed the *Origin* critically by saying that advantageous variations would be swamped by normal traits.
      2. Jenkin appealed to Victorian racial assumptions to illustrate his claim.
      3. Because many in Darwin’s day accepted that heredity resulted from a blending of the traits of the parents, Jenkin’s critique made great sense.
4. Darwin tried to respond by means of a theory of heredity he had created.

C. The Duke of Argyll emphasized an instance of inheritance that seemed to escape natural selection.
   1. The coloration in hummingbirds, for example, did not help them survive.
   2. Darwin appealed to a variation of natural selection in reply: Color functions to attract mates.

IV. Philosophical and religious difficulties with natural selection also made their appearance.
   A. Some found Darwin’s method objectionable.
   B. Many, including some of Darwin’s friends, just could not accept that natural selection operated on variations produced by chance.
   C. Chance variations also appeared to undermine morality.

V. Although natural selection did not fare well, the general acceptance of evolution increased.
   A. Darwin’s ironic achievement in the 19th century was to have promoted evolution at the expense of his own theory of natural selection.
   B. Darwin himself had acknowledged that natural selection was not the exclusive means by which evolution occurred.
      1. His hereditary theory contained aspects that bore similarities to Lamarck.
      2. He acknowledged that use and disuse played a role, although less in his view than natural selection.
      3. The blurring of the difference between his and Lamarck’s understanding of evolution was as annoying to Darwin as it was difficult for him to prevent.
   C. Neo-Lamarckian ideas flourished in the waning decades of the 19th century.
      1. The attraction of Lamarckian evolution was that it could be easily reconciled with divinely controlled evolution.
      2. Because evolution became more and more popular, invariably, it was some form of neo-Lamarckian evolution that held wide appeal.
      3. This led, by the end of the century, to what one historian has called the “eclipse of Darwinism.”

VI. Darwin avoided the claim that life itself had arisen naturalistically.
   A. He allowed that the creator had “breathed” life into the original life form or forms.
   B. What natural science had to say about life’s origin became an issue in France.
   C. Louis Pasteur’s contribution to the debate must be viewed in the context of his overall achievement as a man of science, as we will see in the next lecture.

Essential Reading:
Bowler, Evolution, chapters 7–9.

Supplementary Reading:
Burchfield, Kelvin and the Age of the Earth, chapters 3–5.

Questions to Consider:
1. Why do you think Darwin’s theory was (and remains) so threatening to many?
2. Is there a way to make Darwin’s theory compatible with a religious view of history and the world?
Lecture Twenty-Two
Science, Life, and Disease

Scope: Around the time that Darwin’s *Origin* appeared in England, in France, another controversy was brewing. Based on experiments from the late 1850s, the director of the Museum of Natural History in Paris claimed to have proof of the spontaneous generation of microorganisms. This claim was soon opposed by the French chemist Louis Pasteur. The debate between Félix-Archimède Pouchet and Pasteur took on both religious and political implications, especially in light of the apparent association of Darwin’s theory with spontaneous generation. Pasteur’s fame was enhanced further by his development in the 1880s of vaccines to combat anthrax and rabies, living proof of the new idea of experimental medicine that had been called for by the French physiologist Claude Bernard.

Outline

I. Controversies other than those examined in the last lecture surrounding Darwin’s theory also surfaced in the 1860s.
   A. Darwin’s achievement captured public attention most thoroughly in Britain.
   B. In France, evolution did not cause as great a stir as elsewhere.
      1. French people had lived with the idea of evolution for a long time.
   C. But another controversy arose that focused attention on a specific issue: the origin of life itself.
      1. The question was whether the appearance of life could occur naturalistically, without the direct and intentional participation of God.
      2. The controversy involved a young French chemist named Louis Pasteur, who had emerged into the public eye.

II. Pasteur came on the scene of French science with his work with crystals.
   A. As a young professor of chemistry in the late 1840s, Pasteur became interested in crystals, particularly the interaction of crystals and light.
      1. He discovered a rather dramatic fact: Some crystals were identical in every respect except that they were mirror images of each other.
      2. Pasteur extended the work of others on the general optical activity of natural substances.
      3. Pasteur boldly declared that optical activity was associated with life itself, while optical inactivity was associated with death and decay.
   B. From fermentation, Pasteur was led to the subject of spontaneous generation.
   C. A debate on spontaneous generation began in France in 1859.
      1. Félix-Archimède Pouchet conducted experiments in which microorganisms had appeared in boiled hay infusions in a mercury trough after exposure to artificially produced oxygen.
      2. No preexisting germs could survive the temperatures produced, and the oxygen, being artificially produced, introduced none. The microorganisms had, thus, spontaneously appeared from organic debris.
      3. Pouchet also defended the doctrine with arguments from philosophy and religion.
   D. Pasteur began a series of experiments in 1860 that resulted in a public lecture on spontaneous generation early in 1864.
      1. In the lecture, he asked where in Pouchet’s experiments, if spontaneous generation had not occurred, the microorganisms had come from.
      2. Pasteur then declared that there had been dust on the surface of the mercury Pouchet had used.
      3. Pasteur linked spontaneous generation to larger questions of evolution. In his mind, it was equivalent to materialism.
   E. Pasteur’s celebrated rejection of spontaneous generation served a larger agenda in 19th-century France.
1. Spontaneous generation had been urged earlier in the century by Lamarck and was associated in France, therefore, with evolution, which had been discredited by the authoritative voice of Georges Cuvier.

2. It had also been urged by some of the followers of Friedrich Schelling, whose pantheistic nature philosophy was regarded in France as atheism.

3. In the period of the Second Empire following the failure of the Revolution of 1848, France entered an era of conservatism.

4. In 1864, Pope Pius IX issued the Syllabus of Errors, which condemned pantheism, naturalism, and overdependence on human reason.

5. Commissions of the Academy of Sciences backed Pasteur’s position over Pouchet’s, and members of the scientific elite argued against Darwinian evolution based on Pasteur’s treatment of spontaneous generation.

III. Later in his career, Pasteur turned to the study of vaccines, earning even greater fame as a hero of natural science.

A. Using an analogy between fermentation and disease, Pasteur was predisposed to believe that disease and immunity could be understood as the activity of microbes.

B. Pasteur soon became involved in a race to create a vaccine for anthrax, a disease fatal to farm animals.
   1. He was apparently beaten by a rival, who announced creation of an anthrax vaccine in 1880.
   2. Pasteur announced creation of his anthrax vaccine early in 1881.
   3. A public test demonstrated that his vaccine was effective.
   4. His fame grew while any claims of his rival dropped from sight.

C. What elevated Pasteur to mythical status in history of science was his use of a vaccine for rabies in 1885.
   1. Pasteur found that the virulence of the rabies could be increased or decreased for certain animals by passing it successively through a series of appropriately chosen animals.
   2. By 1884, he found that he could attenuate (“weaken”) the rabies virus in dogs by passing it successively through monkeys.
   3. In a series of cases, Pasteur became known for saving lives.

IV. Pasteur’s use of vaccines on human subjects involved him in debates over the intersection of scientific and human interests.

A. Although his actions precipitated criticisms at the time and among historians since, the criticisms have done little to soil Pasteur’s general reputation as a researcher.

B. Another arena in which natural science intersected with specifically human concerns involved social and political organizations.
   1. Did new scientific claims, specifically about humankind’s past, have implications about how we should organize ourselves socially and politically?
   2. The controversies surrounding these questions will be the subject of the next lecture.

Essential Reading:
Geison, Private Science of Louis Pasteur, part III.

Supplementary Reading:
Farley, Spontaneous Generation Controversy, chapter 6.

Questions to Consider:
1. What do you think Pasteur’s basic motive was in arguing against spontaneous generation?
2. Do you think Pasteur behaved ethically in his use of untested vaccines to treat patients?
Lecture Twenty-Three
Human Society and the Struggle for Existence

Scope: The idea of evolution had already been in the air before Darwin published his famous book. After Chambers wrote the *Vestiges* in 1844, Herbert Spencer had latched on to the “development hypothesis” in 1852. Further, the notion that life in nature was red in tooth and claw made Darwin’s use of the idea of a struggle for existence palatable. Although Darwin had deliberately neglected in the *Origin* to associate human beings openly with the animal world, it did not take long for others to do so. The claim that humans should draw lessons from this new knowledge of the natural world for themselves was then inevitable. But it was possible to derive different ideas about how human society should be organized from the lesson evolution supposedly contained.

Outline

I. In this lecture, we look at two different conclusions drawn from the increasing acceptance of evolution in the late 19th century.
   A. Note that these were not conclusions drawn from an acceptance of evolution by natural selection.
      1. We saw earlier that one effect of Darwin’s work was growing acceptance of evolution, even though natural selection was widely criticized.
      2. Given Darwin’s emphasis on natural selection, the most commonly understood evolution in the late 19th century was neo-Lamarckian, not Darwinian.
   B. The application of evolutionary concepts to social and political questions in the post-Darwinian period is often known as social Darwinism.
      1. This is really a misnomer, because Darwin’s evolution is not necessarily progressive.
      2. But even Darwin understood progress to have occurred in certain areas.
      3. We will continue to use the phrase social Darwinism to refer to the application of evolutionary ideas to social and political questions.
   C. Progressive evolutionary ideas inspired two different applications to social and political questions in the 19th century.
      1. Most well known is the view that of Herbert Spencer in Great Britain, our first example of so-called social Darwinism.
      2. Another example occurred in Germany with the work of Ludwig Büchner.
      3. The quite different conclusions drawn by these two individuals show that attempts to apply natural science to society depend on who is making the application.

II. Herbert Spencer’s social Darwinism reflects his particular English background.
   A. Spencer’s family set him apart from many of those upper-middle-class figures with whom he later associated.
   B. Spencer associated with Darwin’s theory when it appeared, even though he valued Lamarckian use and disuse far more than Darwin did.
      1. Spencer coined the phrase survival of the fittest as a replacement for natural selection.
      2. Darwin’s use of the phrase blurred the difference between himself and Spencer.
   C. Spencer used biological evolution to support a laissez faire philosophy he already held.
   D. Spencer’s views found resonance in certain quarters of American society and among some British liberals.

III. On the Continent, a very different inference from evolution to society was drawn.
   A. The author of this second brand of social Darwinism was the German physician Ludwig Büchner.
      1. Büchner came from a liberal German family, three of whose children became well known in the 19th century.
      2. Büchner’s fame came from a book he wrote in 1855 called *Force and Matter*.
      3. His major ideas on evolution and society came later in the century.
   B. Büchner’s understanding of evolution’s significance for human society was quite different from Spencer’s.
1. Büchner acknowledged that human *origins* were tied to animals but rejected the notion that what reigned in the animal world was, in general, good for humans.

2. He believed that while humans were products of evolution, they were unique products, because in them, nature had produced a species that was aware of its own past.

3. Consequently, to guarantee continued progress, humans had to decide to distinguish themselves from animals and to take charge of their own future.

C. Büchner’s attitude resulted in a number of practical proposals for society.

1. The social and political implication of our evolutionary past was, for Büchner, a modified form of capitalism.

2. He argued against rights of inheritance, for state health insurance, and against ground rent.

IV. Neither Spencer’s nor Büchner’s recommendations carried the day where actual practice was concerned.

A. In their own way, the issues Spencer and Büchner raised brought public attention to evolutionary ideas.

B. As evolution became more and more a public issue, the question of its relation to religion became increasingly important.

**Essential Reading:**

**Supplementary Reading:**

**Questions to Consider:**

1. Would the phrase *social Lamarckism* more accurately or less accurately reflect Spencer’s attempt to merge evolution and social thought than *social Darwinism*?

2. Büchner called natural selection an impossibility (*ein Unding*). Why was Büchner unwilling to accept natural selection?
Lecture Twenty-Four
Whither God?

Scope: If scientists could not agree about the veracity of natural selection as the means by which evolution occurred, theologians felt no obligation to accept it. A fundamental problem was God’s relationship to the cosmos. It was not impossible to modify one’s conception of God to accommodate the reality of evolution, but evolution by natural selection was another matter. Darwin’s theory sharpened the theological problem, because it removed God the greatest distance from his earlier role as the superintendent of natural history. The response one took to Darwin, then, depended on the manner in which one depicted God’s relationship to the cosmos. This lecture examines the theological responses to the flourishing of evolutionary theory during the second half of the 19th century, which ranged from outright rejection to warm embrace.

Outline

I. Disagreement over the meaning of evolution for humankind’s understanding of itself was not confined to the social and political questions we examined in the last lecture.
   A. An intriguing implication of Darwin’s idea, especially given the various ways it was understood, was that it forced the issue on religion.
   B. In this lecture, we will inquire how Darwin was understood by three different groups of theologians and what their understanding meant to their religious beliefs.
   C. Lurking behind these questions lay the issue of the relationship of God to nature, a question that has been with us since the beginning of the course.

II. A preliminary consideration to our investigation here concerns the understanding of truth in these different responses to the development of natural science in the 19th century.
   A. How one understood truth conditioned the kind of answer one would accept to the question of God’s relationship to nature.
   B. In the classical understanding of truth, widely assumed in the 19th century, the task was to establish a correspondence between the way things are and our ideas about them.
      1. Originating with the Greeks, this approach involves the metaphysical claim that nature is rational.
      2. This conception has been called the correspondence theory of truth. It was embraced by most theologians and natural scientists of the 19th century.
      3. Because truth consists in getting it right, there can only be one truth.
   C. At the end of the 18th century, a new conception of truth emerged in the aftermath of Kant’s achievement—the coherence theory of truth.
      1. This theory of truth was revived among Kantian theologians at the end of the 19th century.
      2. Kant argued that our minds affect the ideas we have about nature; therefore, he regarded the acquisition of classical metaphysical truth as impossible.
      3. Because our minds affect the knowledge we have of the world, the coherence theory of truth does not make the metaphysical claim that there is only one truth.
      4. Our knowledge of the world is merely useful—it does not confirm nature’s final rationality.
   D. Although new ways of understanding truth would appear after the turn of the 20th century, they do not play a role in our story.

III. Conservative theologians, who assumed the correspondence theory of truth, believed that Darwin could not be ignored. They displayed some variation in their responses.
   A. Those who held to a strict interpretation of the Bible simply declared that evolutionary scientists were wrong about animal and human origins.
      1. Theologians, such as the American Charles Hodge, read Darwin’s book and understood his emphasis on natural selection.
      2. Hodge’s verdict about Darwinism, rendered in his book of 1872 called What Is Darwinism?, was that it was atheism.
B. Some conservatives permitted evolution while insisting on the central importance of the Bible and God’s role in directing evolution.

IV. Liberal protestant theologians, who also accepted a correspondence theory of truth, believed that their theology had to be updated to accommodate new scientific truth.
A. Because they believed that science had shown evolution to be true, they argued that religious doctrine had to change to reflect the new truth.
B. Liberal theologians thus retained a belief that God was in control of nature and history.
   1. By and large, these theologians did not view evolution as Darwin did, as a process governed primarily by natural selection.
   2. They saw evolution as something directed by God, not by random variations selected by nature.

V. More radical theologians on the Continent, operating on a coherence conception of truth, did not agree that religion and science had to be reconciled.
A. The Kantian theologian Wilhelm Herrmann announced in a book of 1876 that aspiring to metaphysical truth should not be part of a theologian’s task.
   1. He argued that because metaphysical truth was unattainable, its pursuit did not belong in theology.
   2. Science and religion should be kept separate, with religion concerning itself with ethics, morality, and the practice of living an authentic life.
B. In a later book, Herrmann discussed the nature of our knowledge of the world and its place.
   1. Pursuit of knowledge of nature should be left to the natural scientist, and religion should not place restraints on science.
   2. At the same time, scientists should realize that they, too, are unable to attain metaphysical knowledge of nature.

VI. As the century drew to a close, a variety of positions were available on the question of God’s relationship to nature.
A. The frequent portrait of a pitched battle between science and religion in the post-Darwinian era has been overdrawn.
B. That portrait applies to America in the 1920s but not much elsewhere.
C. In the great majority of places and times, there have been serious attempts to engage science and religion without presuming at the start that they are mortal enemies.

Essential Reading:

Supplementary Reading:

Questions to Consider:
1. How well do the conservative, liberal, and radical categories fit today’s attempts to relate science and religion?
2. Has the issue of science and religion historically ever been a matter of the complete antagonism between the two as is often portrayed?
### Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tr>
<td>1686</td>
<td>Newton completes <em>Principia</em>; Leibniz publishes critique of Descartes’s measure of the force of motion.</td>
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<td>1702</td>
<td>Stahl introduces the imponderable substance phlogiston to explain combustion.</td>
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<td>1727</td>
<td>Death of Newton.</td>
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<td>1733</td>
<td>Voltaire’s <em>Philosophical Letters</em> praises all things English, including Newtonian philosophy.</td>
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<td>1735</td>
<td>First edition of Linnaeus’s <em>System of Nature</em>, containing his scheme of classification based on plant sexuality. Edition of 1766 removes the claim that no new species have originated.</td>
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<td>1741</td>
<td>Trembley observes regeneration in freshwater polyp and uses it to criticize the widely accepted idea that adult forms are preformed in the embryo.</td>
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<td>1746</td>
<td>Leyden jar for storing electrical charge invented in Holland.</td>
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<td>1748</td>
<td>De Maillet’s <em>Telliamed</em> 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.</td>
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<td>1749</td>
<td>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.</td>
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<td>1756</td>
<td>Black’s experiments with magnesia alba underscore the importance of weighing reagents.</td>
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<td>1757</td>
<td>Haller affirms his conversion to the preformation theory, setting off his debate with the epigeneticist Christian Wolff.</td>
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<td>1774</td>
<td>Priestley produces a dephlogisticated gas from mercury calx and communicates his result to the French during a visit.</td>
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<td>1775</td>
<td>Lavoisier argues that combustion consists of the addition of oxygen, not the release of phlogiston.</td>
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<td>1778</td>
<td>Buffon reasserts his prolonged estimation of the age of the Earth and of life in <em>Epochs of Creation</em>; Mesmer arrives in Paris and begins a campaign to have his theory of animal magnetism accepted.</td>
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<td>1781</td>
<td>First edition of Kant’s <em>Critique of Pure Reason</em> sets limits on human knowledge of the world; Herschel discovers the planet Uranus.</td>
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<td>1783</td>
<td>Berlin journal poses prize question on “What is Enlightenment?” reflecting public awareness of an enlightened era.</td>
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<td>1784</td>
<td>Paris Commission rules against Mesmer’s theory.</td>
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<td>1786</td>
<td>Werner publishes his classification of rocks based on his theory of consolidation from primal fluid.</td>
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<td>1789</td>
<td>Beginning of the French Revolution with the convening of the Estates General.</td>
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<td>1791</td>
<td>Galvani announces his theory of animal electricity.</td>
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<td>1793</td>
<td>Kielmeyer endorses the notion that laws governing organisms differ from the mechanical laws of the inorganic; Paine’s <em>Age of Reason</em> attacks Christianity’s acceptance of extraterrestrial life.</td>
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<tr>
<td>1795</td>
<td>Hutton communicates his ideas on prolonged gradual geological change to the Royal Society.</td>
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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................................................... Helmholtz’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.

1857................................................... Büchner’s *Force and Matter* shocks Britain with its rejection of extraterrestrial life.

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................................................... Hermann 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.


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**).

**Karlschule:** 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 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.
Biographical Notes

**Ampère, André Marie** (1775–1836). French mathematician and physicist who, before 1820, had established a modest reputation in French scientific circles through work in chemistry and mathematics. On hearing about Oersted’s discovery of electromagnetism, he determined, through experiments, that two wires situated parallel to each other with current flowing in the same direction exerted a magnetic force of attraction to each other. Ampère suggested that magnetism was electricity in motion. He postulated that there was a circular flow of electricity around each molecule of a magnet, so that each molecule was made into a miniature magnet in the same way that an iron bar is made into a magnet. His elaborate mathematical depiction of the forces that moving electricity exerted, which he assumed to be in straight lines perpendicular to the direction of the current’s flow, established the field of electrodynamics.

**Bonnet, Charles** (1720–1793). Swiss naturalist, most well known for his assertion that God had originally created a multitude of seeds or germs, each one of which contained, within it, a miniature organism that carried all the traits the organism would have as an adult. Further, the miniature organisms contained, encapsulated in them, yet more germs, and they, in turn, more. In all, there were enough encapsulated germs to account for all the organisms that would develop up to the Second Coming. Known as the theory of preformation, it solved the nagging question of how to explain that embryos knew in advance what form to assume as they developed to adulthood.

**Büchner, Ludwig** (1824–1899). German physician and popularizer of natural science during the second half of the 19th century. In the period after the failed Revolution of 1848, Büchner wrote the highly successful book *Force and Matter*, in which he defended a materialistic interpretation of reality. He appealed to the methods and results of natural science in defense of his scientific materialism and in attacks on religion, whose defense of an immaterial soul he felt was unacceptable to a modern mentality. In his ideas on the implications of natural science for society, he argued that because evolution revealed humans to be nature’s highest product, humans should take charge of their own future and guarantee basic human values.

**Buckland, William** (1784–1856). Professor of geology at Oxford, he had been a student of the classics there in the early years of the 19th century. He took holy orders and became a fellow of Corpus Christi College in Oxford in 1808. His first position in mineralogy at Oxford in 1813 paid so poorly that a new position was created for him in 1818, a readership of geology. From this vantage point, Buckland, who with his eccentric personality and engaging style as a lecturer was one of the most colorful academic figures of his day, exerted a major influence on British classical learning by bringing the study of geological features and fossil remains into the classical discipline of world history. He endorsed Cuvier’s idea that the Earth’s history extended well beyond the Noahic Flood and included a period in which prehistoric beasts lived.

**Buffon, Georges-Louis Leclerc, Comte de** (1707–1788). Greatest French naturalist of the 18th century, he presided over the Jardin du Roi from 1739 until his death in 1788. Author of the multivolume *Natural History*, which began appearing in 1749, Buffon’s thought ranged widely over knowledge of nature. He had been trained in Newtonian philosophy and did not hesitate to include the Earth’s physical past under his conception of natural history, speculating even on the natural means by which the Earth had originated. He accepted the notion that present-day organisms were descendants of more primal forms, which he explained through a process of degeneration brought about by changing external conditions.

**Carnot, Sadi** (1796–1832). French engineer and natural philosopher who determined to provide a theoretical analysis for the steam engine, in particular, to investigate if there was a maximal amount of motive force that could be obtained using a certain amount of heat and whether some substances were better than others in producing a given amount of motive force. His answers to these questions were contained in his influential treatise of 1824, *Reflections on the Motive Power of Heat*. For Carnot, the production of motive force from heat in heat engines was accomplished by taking excess heat from a hot body and delivering it to a cold body; in other words, it is necessary for there to be a fall in temperature from a hot temperature to a colder one for motive force to be produced. This aspect of his analysis proved to be important in the thinking of later physicists studying the laws of thermodynamics.

**Chambers, Robert** (1802–1871). Anonymous author of *The Vestiges of the Natural History of Creation*, which created a sensation in Victorian Britain when it appeared in 1844. In writing this accessible naturalistic narrative of the development of the cosmos and life on Earth, Chambers drew on recognized experts in various scientific
disciplines to establish his deistic account of creation. The anonymity of the book only added to its fame, because the author’s identity became a subject of much speculation and included as possibilities many highly respected men and women. The tremendous interest in a naturalistic account of the history of the cosmos and of life within it reveals that Darwin’s work, rather than shocking the British by daring to challenge traditional views of history, took its place in an atmosphere already well prepared for such sentiments.

Clausius, Rudolph (1822–1888). German physicist whose work in thermodynamics integrated the results of both Carnot and Joule when the two were thought by some to be mutually exclusive. In 1850, Clausius confirmed Joule’s claim that heat had a mechanical equivalent, but he indicated that some of the heat involved was merely transferred from a warm to a colder one, as Carnot had said. Later in the decade of the 1850s, his paper “On the Nature of the Motion We Call Heat” (1857) initiated the modern phase of the kinetic theory of gases. Clausius simplified things greatly when he defined the mean free speed of molecules in a gas, thus devising a means by which physicists could correlate the many individual speeds of gas molecules with the overall temperature, pressure, and energy of the gas.

Cuvier, Georges (1769–1832). Known as the father of comparative anatomy, he was born in the French-speaking, Lutheran principality of Montbéliard, a small independent region between east central France and Switzerland, politically united to the Grand Duchy of Württemberg. Educated at the academy of the grand duke, Cuvier learned natural history from German scholars before taking up residence in France during the years of the Revolution. After a precipitous rise in natural science near the end of the 18th and beginning of the 19th centuries, Cuvier became the grand old man of French science. He was among the first to persuasively demonstrate the reality of extinct species and became known for his principle of subordination of characters, by which he could extrapolate from anatomical remains of contemporary organisms or fossil remains to the makeup and behavior of the whole organism. He also was famous for his theory of repeated catastrophes that, in his view, had periodically eliminated species.

Dalton, John (1766–1844). Son of a Quaker weaver, he grew up to become an instructor of mathematics and chemistry in a dissenters’ school in Manchester until 1800, thereafter serving as a private teacher of the same subjects. Dalton’s interests ranged from meteorology to color blindness, but his fame stems from his theoretical work in chemistry. Embracing the ancient idea that matter is composed of atoms, he argued that there were different atoms for each elementary substance. In his New System of Chemistry of 1808, he formulated the law of definite proportions, which specifies that the number of combining atoms of different elements that combine to form a compound do so according to simple, definite ratios.

Darwin, Charles (1809–1882). English naturalist and author of The Origin of Species (1859), which introduced his idea of natural selection to the public. After traveling around the world on a five-year voyage from 1831 to 1836, Darwin returned to formulate his theory of descent with modification, according to which those individuals whose characteristics were most well adapted to their environment would tend to survive longer and have more offspring with these same favorable features. The effect over time of nature’s continuing to select these individuals over others was that the makeup of the species was gradually altered until, with sufficient time, a new species had originated. The appearance of the theory did a great deal to promote the idea of evolution, but Darwin’s theory of evolution by means of natural selection did not fare nearly as well. Because of difficulties with the theory, natural selection waned in the decades around the turn of the 20th century.

De Maillé, Benoît (1656–1738). French diplomat and natural philosopher whose observations from travels in Egypt and the Mediterranean area convinced him that the waters of the sea were receding. His theory of the early history of the Earth, based on a gradually diminishing sea level, contained an implicit theory of evolution of life over a long time and was received as scandalous speculation when it appeared in 1748, a decade after he died. De Maillé’s work is an early example of the deistic attitude characteristic of a strain of 18th-century natural philosophy in which the writer assumed that humans should inquire about the natural means God had employed to accomplish his purpose in nature.

Descartes, René (1596–1650). French philosopher whose reflections on nature influenced generations of thinkers after him. His division of reality into thinking things (mind) and extended things (matter) implied that nature should be described in terms compatible with its material reality; that is, nature should not be described in terms of mind or spirit. Descartes imagined nature to behave as a huge machine in which force was transferred by contact only. To permit action at a distance was, to him, equivalent to imposing the qualities of mind on nature, which he had expressly rejected. Newton read and appreciated Descartes’s mechanical philosophy, although in his conception of force, he rejected Descartes’s banishment of spirit from nature.
Einstein, Albert (1879–1955). German physicist and author of the theory of relativity, Einstein is perhaps the most publicly recognizable figure in the history of science. Beginning with Galileo’s assertion that the laws of physics are the same for all observers in uniform motion, Einstein extended this principle of inertia to encompass all the laws of physics, including electromagnetism. In 1905, he realized that, because Maxwell’s description of the behavior of electromagnetism entailed that it travel at the speed of light, light must have this same speed for all observers in uniform motion. The implication of this conclusion was that space and time must change in different frames of reference to accommodate light’s constant speed. Einstein’s theory of special relativity, like Planck’s energy quanta, is an example of the revolutionary changes that some scientists at the end of the 19th century said were no longer to be expected.

Faraday, Michael (1791–1867). English chemist and physicist, he was a dedicated member of the small religious sect of Sandemanians, whose strict adherence to biblical mandate and church discipline formed a central part of daily life. From his initial role as an assistant to Humphrey Davy, he rose from humble social origins to become one of England’s most noted scientists. His interpretation of Oersted’s discovery of electromagnetism as concentric circular lines of force surrounding the current-carrying wire eventually led to the idea of the collection of the lines to form what he called the magnetic field of the current. Faraday’s concept of a field of force has become a mainstay of physics ever since his day.

Franklin, Benjamin (1706–1790). American statesman and natural philosopher, he began experiments on electricity in the 1740s. Theorizing that electrical effects were produced by the presence of a weightless substance that he called “electrical fire,” Franklin explained that an object became “electrified plus” when it acquired more than its normal electrical fire on its surface and “electrified minus” when it became deficient of its normal amount. Using this scheme, he provided a convincing explanation of why the new invention of the Leyden jar could store electricity. Having become convinced that lightning represented electrical discharge, he devised the lightning rod as a means of protecting buildings from strikes. Franklin’s popularity even while serving in France as a diplomat was due, in large measure, to the fame he had acquired as a master of electricity.

Galvani, Luigi (1737–1798). Italian physician who took up the study of electricity as it applied to anatomy and physiology. After stumbling on the effect of electrical discharge on muscle contraction where there was no direct contact with the muscle, Galvani came to the conclusion that muscles contained miniature Leyden jars that could be discharged by signals from the brain. Such “animal electricity” he regarded as a new source of electricity. He became embroiled in a controversy with his countryman Alessandro Volta, who provided an alternative explanation of the source of electricity involved in experiments with muscle tissue. Galvani’s discovery made popular a link between electricity and life that quickly captured the attention of the wider public.

Goethe, Johann von (1749–1832). German novelist, poet, playwright, royal advisor, and natural philosopher, he helped to bring attention to the upsurge in German cultural activity in the latter half of the 18th century. His fame was established with the highly successful novel The Sorrows of Young Werther, in 1774, soon to be followed by more successes. As advisor to the Grand Duke Karl August in Weimar, Goethe assumed a post near what turned out to be the heart of German Romanticism. His interests in natural science were widespread, although he is most well known for his work in morphology and for his criticism of Newton’s theory of color. The latter was motivated by his complaint that, because Newton separated himself from the object he was studying, his conclusion should not be assumed to be the only possible view.

Haller, Albrecht (1708–1777). Swiss physician and journal editor, he was respected as one of the most well-informed men of his day. On learning of the water polyp’s ability to regenerate after having been cut in two, Haller abandoned his acceptance of preformation, which required that the embryo encapsulate whole adult organization, in favor of epigenesis. From later experiments on chickens, however, he concluded that the yolk was but an expansion of the small intestine of the chicken and reconverted to a belief in preformation. In his debate with Caspar Friedrich Wolff, his defense of preformation reflected his appreciation of Newton’s position that it is theologically dangerous to permit matter to possess active forces on its own, as it appeared to do in epigenesis.

Helmholtz, Hermann von (1821–1894). German physician and physicist, he was one of the celebrated figures of German natural science during the second half of the 19th century. Trained in physiology, he expressed an early interest in how the laws of physics affected the world of living things; in particular, he asked how the matter of food is used to enable the body to exert force and what the relationship was between physiological processes and heat. His general conclusions on this subject appeared in 1847 under the title “On the Preservation of Force,” considered
to be one of the earliest statements of the conservation of energy. At the time of its original submission to the German physics journal *Annals of Physics*, it was rejected as overly philosophical.

**Humboldt, Alexander von** (1769–1859). German natural philosopher and explorer, his early studies of natural science included experimentation in electricity, in particular, the interaction of electricity and living organisms. Born to wealth and position, he supported himself on a scientific exploratory trip to South America in 1799. Descriptions of the tropical regions of Venezuela and the varied climates of Ecuador and Peru that he sent back captured the minds of educated Europe, and on his return in 1804, his fame rivaled that of Napoleon Bonaparte. He spent much of his career in France until the king of Prussia called him back to Berlin in 1827, where he assumed the position of symbolic leader of German natural science.

**Hutton, James** (1726–1797). Scottish physician who, early on, abandoned medicine for the life of a country gentleman. From his interest in geology, Hutton formulated a theory, based on the pressure of the internal heat of the Earth, by which our globe came to possess the surface features of the present. He argued that for an indefinite period in the past, the Earth had undergone cycles of decay from erosion above and regeneration from elevation of submerged material that had been fused by the Earth’s heat. Because he emphasized that the process was continuing in the present, just as it had always continued in the past, he demanded that there be a uniformity between past and present causation. His later supporters in Scotland dubbed his position Vulcanism and emphasized its contrast to the agencies of consolidation of rocks in Neptunism. During the 1830s, his emphasis on uniformity was contrasted to the catastrophic agencies of Cuvier’s revolutions of the globe.

**Huxley, Thomas** (1825–1895). British physiologist, anatomist, and zoologist, he is most well known for his effective public advocacy of Darwin’s theory of evolution by natural selection in the years after 1859. Never hesitant to take on issues in philosophy and even ethics, Huxley coined the term *agnostic* in the post-Darwinian debates to characterize his position on numerous aspects of the implications of natural science for religious and philosophical questions.

**Joule, James** (1818–1889). British physicist famous for his experiment that determined the mechanical equivalent of heat by measuring the change in temperature produced by the friction of a paddlewheel attached to a falling weight. Joule was the son of a brewery owner but was forced to take over the brewery, along with his brother, when his father became ill and was unable to attend university. He received instruction in the physical sciences from the chemist John Dalton, who inspired him to pursue his interest in science. Convinced that discovering the laws of nature revealed the mind of God, Joule’s private experiments on heat and mechanical force, which were not initially well received, caught the attention of William Thomson, whose endorsement began a general recognition of their importance.

**Kant, Immanuel** (1724–1804). German philosopher whose early training at the University of Königsberg exposed him to Leibniz’s philosophy. His encounter with Newton’s work during his student years encouraged in him an independent attitude toward Leibniz’s thought, with the additional result that he developed a profound interest in the natural sciences. His 1755 *General History of Nature and Theory of the Heavens* contained his ideas on how a cosmos subject to Newton’s laws of motion might have formed. In 1781, the first edition of his *Critique of Pure Reason* appeared, which challenged the assumption that metaphysics, in the classical sense of determining the nature of reality, was possible. As the founder of what became known at the time as critical philosophy, his achievement stood as a challenge to those who followed him in the Romantic era to transcend the limitations he had imposed on reason.

**Kielmeyer, Carl** (1765–1845). German zoologist educated in the Württemberg academy of Grand Duke Karl Eugen, where he was a senior classmate of Georges Cuvier. He returned to the Karlsschule to teach and, in 1793, delivered his famous lecture on the relations of organic forces among each other. Kielmeyer argued that living things were governed by unique forces that operated at parallel levels. His assertion that the distribution of forces in the scale of organisms follows the same order as the distribution in the different developmental states of the individual was later expressed by the statement that the laws governing the development of the individual recapitulate those governing the development of the species. Although not the first to explore this possibility, Kielmeyer was influential on others who helped to keep the notion alive in German biological thought of the 19th century.

**Kuhn, Thomas** (1922–1996). American historian of science whose 1962 book *The Structure of Scientific Revolutions* introduced the word *paradigm* to American academic culture. Kuhn argued that the context of a
scientific discovery was equally important to its content; if historians are to perform accurate historical evaluation, therefore, they must avoid judging past scientific works on the basis of present-day assumptions and engage in the sympathetic reading of texts. In depicting the historical context, Kuhn referred to a paradigm as the set of assumptions, conscious and unconscious, held in a culture at a given time and profoundly influential on the cognitive meaning of scientific theories. A scientific revolution occurred in conjunction with a shift from an older paradigm to a new one, in which different assumptions either replaced older ones or became more dominant than they had been.

**Lamarck, Jean-Baptiste** (1744–1829). French zoologist who worked in the decades around the turn of the 19th century. Lamarck was among the first to publish a systematic account of the evolution of species over time. In his *Zoological Philosophy* of 1809, he argued that living things possess a power of life, by which they become more complex in physical organization over time. Secondary causes of evolution include the appearance of characteristics resulting from over or under use of parts over a long time, which acquired features are then passed down to offspring. Lamarck’s theory was regarded as too highly speculative to command acceptance and found resonance in only a few quarters during his lifetime. Later in the century, however, it was revived and, in various new guises, enjoyed renewed life until well into the 20th century.

**Laplace, Pierre** (1749–1827). French astronomer and physicist whose naturalistic explanation of the stability of the solar system brought the cosmos independence from the constant divine supervision required in Newton’s conception. His support of this deistic conception was made clearer when, in his nebular hypothesis, he provided a naturalistic explanation of the original formation of the solar system from primal nebular matter. In his *System of the World* of 1796, his incredible confidence in Newtonian mechanics gave rise to a depiction of the deterministic worldview that would become associated with classical mechanics. In that work, Laplace wrote that a mind that could comprehend all the forces of nature and knew all the positions of its masses would be able to predict all of nature’s movements, from atoms to planets, with perfect certainty.

**Lavoisier, Antoine** (1743–1794). Although his training was in law, his real interest lay with the natural sciences. Elected into the French Academy of Sciences for work primarily in geology, Lavoisier turned his attention to the study of heat and chemical change. On learning about a new gas virtually devoid of phlogiston from Joseph Priestley, Lavoisier set out to experiment for himself. Because he paid careful attention to the weights of the reagents involved, insisting that matter could not be created or destroyed, he became convinced that when a metal gained weight during calcination (“rusting”), it was because it fixed in itself the purest part of atmospheric air, Priestley’s “dephlogisticated air,” which Lavoisier named *oxygen*. He is credited with having announced the conservation of matter as a principle of chemical research.

**Leibniz, Gottfried Wilhelm von** (1646–1716). German philosopher and mathematician whose philosophical system contrasted with those of Descartes and Newton. Unlike Descartes, Leibniz did not believe that the ultimate component of the realm of nature was extension; rather, it consisted of units called *monads* that shared features with mind. He was also critical of the idea of action at a distance attributed to Newton, as well as the latter’s defense of the idea of absolute space. His most public opposition to Newton came over the latter’s assertion that God was constantly required to supervise nature in order to guarantee its operation, a notion Leibniz felt demeaning to the deity. In mathematics, he invented the calculus independently from Newton but later became embroiled in a priority dispute over the issue.

**Linnaeus, Carl** (1707–1778). Swedish botanist whose *System of Nature* established a binomial classification for living organisms and earned him the title “father of classification” in the view of many. His early work in classification of plants utilized the idea of plant sexuality, a notion not original with him. A devoted Swede, he undertook experiments to acclimatize plants from other regions of the world to Sweden’s environment as a means of making Sweden more independent. Deeply religious, he nevertheless earned the opposition of some when he concluded that some plants had been “children of time,” that is, that they had originated after the original creation by God through a process of hybridization.

**Lyell, Charles** (1797–1875). English geologist who advocated that the best way to understand the geological past is by means of processes that are observable in the present. As a result, he believed that geological change was extremely slow and that the age of the Earth was enormous. Lyell maintained that if one were transported back in time, the fundamental aspects of the Earth would not indicate a “primitive” state from which the present state developed; rather, the basic features of the early Earth would resemble those of the present. This placed him at odds with the conclusions of the new science of thermodynamics, which suggested that physical processes involved
irreversible change. Lyell’s three-volume *Principles of Geology* (1831–1833) was influential on the young world traveler Charles Darwin, who read the work shortly after it appeared. Lyell was among the few individuals in whom Darwin confided, and although he admired Darwin’s theory in private, he failed to endorse it publicly.

**Maxwell, James** (1831–1879). British physicist who brought clarity to the relationship between electricity and magnetism by viewing it as a mechanical interaction between parts of an ethereal substance. While one aspect of his mechanical model was associated with electrical effects, magnetic effects were correlated with another. He depicted his mechanical model in a series of mathematical equations that had the form of wave equations, suggesting that electromagnetism shared properties with light, which also consisted of waves in the ether. When his theory predicted that the electromagnetic waves would travel at the speed that a French physicist had recently calculated light to travel, Maxwell inferred that an intimate relationship existed between light and electromagnetism. Although confirmed later, Maxwell’s outlook ran into difficulties when motions in the ether relative to the motion of the Earth did not behave as predicted.

**Mayer, Julius Robert** (1814–1878). German physician who was prompted to think about the heat produced by the body while pursuing duties as a ship’s physician in the East Indies. He concluded that the heat produced from oxidation of food was converted into the body’s mechanical motion. Based on this recognition that heat had a mechanical equivalent, as well as his understanding of force as cause, Mayer concluded that force in general was not lost but converted from cause to effect. When he later concluded that force was not created either, he had come to a conception of the conservation of force. By identifying force as cause, he avoided having to acknowledge it as a property of matter, thereby also avoiding materialism, a position he rejected for personal religious reasons.

**Mendeleev, Dimitri** (1834–1907). Russian chemist from Siberia, son of a high school director, who rose from a difficult family situation after the death of his father to study in St. Petersburg and become a university professor. In 1869, Mendeleev formulated a table of the 63 known chemical elements based on their atomic weights. He organized the elements into groups possessing similar properties. Where a gap existed in the table, he predicted that a new element would one day be found and deduced its properties. Although hydrogen was not included in the table because of its unique properties and although his values for the atomic weights of several elements differ significantly from recent values, he was successful in promoting an idea that would continue to be perfected.

**Mesmer, Franz** (1734–1815). Austrian physician who became convinced that forces emanating from the planets, as in the case of light, influenced living things. Later, he focused on the effect of magnetism on living organisms, concluding that there was a flow of animal magnetism that, if blocked, led to disease. Claiming to have learned how to treat such blockages, Mesmer enjoyed some success with several patients, but his unconventional means led to problems, as well. Mesmer took his theory to Paris, where he sought legitimation from the Academy in the days just before the French Revolution. Rebuffed by the Academy, he attracted to his cause others who stood outside the establishment.

**Michelson, Albert** (1852–1931). American physicist whose parents emigrated to the United States from Prussia when he was two years old. He graduated from the U.S. Naval Academy and, a few years later, became an instructor in natural science there until 1881. From 1883, he was a professor of physics, first at Case School of Applied Science in Cleveland, then at Clark University in Massachusetts, and finally, at the newly organized University of Chicago. In his early work, he measured the speed of light with great precision and, while in Europe in 1881, invented a device for the purpose of discovering the effect of the Earth’s motion on the observed velocity, repeating the experiment in 1887 with his colleague E. W. Morley. The null result of the experiment puzzled physicists, because when coupled with other experiments, it implied that the ether was neither stable nor moving with respect to the Earth.

**Moleschott, Jakob** (1822–1893). Dutch physiologist and scientific materialist whose training and early career was spent in Germany. He focused his research on the physical basis of life and nutrition, portraying life as the result of an exchange of matter. Famous for the slogan “without phosphorus, no thought,” he drew out the social implications of his materialistic interpretation in his 1850 *Theory of Nutrition: For the People* by giving advice on what foods were best for the poor and even how they should be cooked. The philosopher Ludwig Feuerbach linked natural science to revolution in a review of Moleschott’s book in which Feuerbach generalized Moleschott’s message in the cryptic phrase “You are what you eat.” His radical views became unpopular with his superiors at the University of Heidelberg, and he left for Switzerland in 1856, where he remained for five years before moving to a permanent home in Italy.
Newton, Isaac (1642–1727). Outstanding English natural philosopher whose 1687 book on the *Mathematical Principles of Natural Philosophy* opened a new era in the history of science. Newton argued that his task as a natural philosopher was to describe, in mathematical terms, the force that he inferred must be present to keep the moon from flying off on a tangent, without having to spell out how the force was transmitted. This he did admirably, but because he did not specify that the force was transferred by mechanical impact, his critics, followers of Descartes, accused him of claiming that the force he claimed existed between matter “acted at a distance.” Because his system made it far more possible than before to understand and predict the motions of heavenly bodies, it defined a new option in the eyes of many.

Oersted, Hans Christian (1777–1851). Danish professor of chemistry who, in 1820, observed that a magnetic needle was deflected in the vicinity of a current-carrying wire. He was sensitive to this possibility, because having been long interested in German nature philosophy, he was convinced that nature’s forces were interrelated. His explanation of the phenomenon was couched in the categories of nature philosophy and found little acceptance. But there was no denying the reality of the phenomenon of electromagnetism, which opened up physical science to a host of new discoveries.

Oken, Lorenz (1779–1851). German morphologist and nature philosopher who rose from peasant origins to become a leading figure of German natural science during the period of restoration after Napoleon’s final defeat in 1815. As founder of *Isis*, a journal for natural science and society in 1817, and as a prime mover behind the formation in 1822 of the Association of German Natural Investigators and Physicians, the first modern association of natural science, Oken stood at the center of the growing public awareness of natural science and its increasingly important role in modern society. More than any other individual, Oken negotiated a place for natural science in the burgeoning public sphere in the German states and beyond.

Pasteur, Louis (1822–1895). One of the national heroes of France, his reputation stems from his invention and dramatic testing of vaccines for the treatments of anthrax and rabies in the 1880s. As a chemist interested in fermentation, Pasteur emerged onto the public scene in French science in the 1860s by opposing a respected director of the Museum of Natural History in Rouen on the question of spontaneous generation. With a certain flair for public performance, Pasteur appealed to experiments he had done that persuaded his listeners that spontaneous generation had not occurred as asserted. At least in part, his motivation in opposing spontaneous generation was philosophical and religious, because the claim that life arose from non-life was associated at the time with the anti-religious scientific materialism of mid-century.

Planck, Max (1858–1947). German physicist responsible for introducing the idea that energy, when radiated or absorbed, does so in discrete amounts he called *quanta*. In trying to account for the pattern of energy given off from a body that, by heating, radiates over a range of frequencies from low to high, two discrepancies with existing knowledge emerged. In the region of high frequencies, the existing model predicted that energy radiation should increase dramatically, a result opposite from what was observed experimentally. In the middle-frequency region, the results appeared too chaotic to be captured by any mathematical description. Planck’s restriction of energy radiation to quanta was able to solve both of these difficulties, although its violation of the classical assumption that energy radiates continuously introduced implications about nature that ran counter to the classical Newtonian world picture. Like Einstein’s theory of special relativity, Planck’s work represented one of the revolutionary changes that some scientists at the end of the 19th century said were no longer to be expected.

Priestley, Joseph (1733–1804). Born into a family of religious dissenters, he received an education from a nonconformist academy in Northamptonshire, where he cultivated his interest in history, philosophy, and the natural sciences. Later, as a minister and instructor in a dissenting academy, Priestley cultivated his own views on politics and religion, some of which antagonized established powers, although he was encouraged in his views by Benjamin Franklin and Thomas Paine, whom he met in London. A staunch defender of Stahl’s phlogiston theory of combustion, he conducted numerous chemical experiments in which he isolated many new “airs,” or gases, describing their properties and giving them names. Among these, his discovery of “dephlogisticated air,” later named *oxygen* by Lavoisier, is most well known. Priestley’s favorable view of the French Revolution and his defense of what might be called Christian materialism led to accusations of atheism and sedition, and in 1794, he decided to leave Britain for Pennsylvania, where he lived until his death.

Schelling, Friedrich (1775–1854). German philosopher and motive force behind the nature philosophy movement of the early years of the 19th century in Germany. Although not the first to address the issue of a philosophy of nature, Schelling’s use of the word *Naturphilosophie* in several works of the waning years of the 18th century and
early years of the 19th century brought him recognition as the founder of a movement. His goal was to demonstrate the unity of mind and nature by tracing characteristics of mind in nature and by deducing nature from mind. In so doing, he hoped to create an alternative to the Kantian separation of the realm of things-in-themselves from what could be known through reason. To guarantee the unity he sought, Schelling rejected the metaphor of mechanism for nature in favor of organism.

**Somerville, Mary** (1780–1872). First woman to be published by the Royal Society, she was the translator, with commentary, of the celestial mechanics of Pierre Laplace from French into English. She was born Mary Fairfax and, like many girls, received a haphazard early education; when she discovered an interest in mathematics, had to learn it largely on her own. She was married at 24 and widowed three years later. Although she had two children, she also received a sufficient inheritance to allow her to pursue her love of natural science and mathematics, which she did through study of astronomy and the work of Isaac Newton. In 1812, she married a navy surgeon, Dr. William Somerville, who was supportive of her work, which included experimentation on the magnetic properties of colored light in the 1820s. She became acquainted with several key natural philosophers, including John Herschel, and followed her translation of Laplace with a book, *The Connexion of the Physical Sciences*, in 1834.

**Spencer, Herbert** (1820–1903). Raised in a family of Methodist dissenters with Quaker sympathies, he adopted the nonconformist attitudes of his father. Largely self-educated, Spencer became a writer for *The Economist* in 1848, which brought him into contact with many leading intellectual figures of early Victorian Britain. In his early writings, he advocated a national policy of laissez faire with regard to economic matters, a position he inherited from his personal background. Spencer’s is among the first names linked to the position known as social Darwinism, allegedly an application of Darwin’s theory of evolution by natural selection to political questions of government’s responsibility in issues of social welfare. Although Spencer defended what he termed the “survival of the fittest,” his belief that a lack of governmental interference in social questions would lead to progress is based more on a Lamarckian than a Darwinian evolutionary footing.

**Stahl, Georg** (1659–1734). Most well known for his promotion and refinement of the theory of combustion originated by Joachim Becher. It was Stahl who named Becher’s combustive principle phlogiston and whose elaboration of phlogiston’s role in calcinations brought it to wider attention in early 18th-century Germany. Trained in medicine, Stahl became the personal physician to King Frederick William I of Prussia. He saw his greater task to be the introduction of rational chemistry in the place of alchemy, of which he was critical. As a rational account of the combustion process, phlogiston theory enriched 18th-century chemistry, lasting to the end of the century, when it was finally replaced by the new French chemistry of Lavoisier.

**Thomson, William** (1824–1907). British physicist whose work in thermodynamics helped to create the new science of energy in the 19th century. Impressed by the conclusion of Carnot that in the production of mechanical force there is a necessary fall in temperature, Thomson nevertheless agreed with Joule that heat was not conserved when used to produce mechanical force. He interpreted the fall in temperature as a “dissipation” of energy, that is, energy that was not destroyed but had become unavailable to produce mechanical force. When it became clear that the amount of unavailable energy was increasing irreversibly over time, Thomson publicly opposed the view of Lyell, who represented the physical conditions of the past as qualitatively similar to those of the present. He also determined, from calculations on the rate of the Earth’s cooling, that there had not been sufficient time for Darwinian evolution to have occurred and became a critic of the theory. He was knighted in 1866 and was raised to the peerage in 1892 (as Baron Kelvin of Largs).

**Vogt, Karl** (1817–1895). German zoologist and scientific materialist, he came from a liberal family whose political positions and activities were unpopular with the local authorities. Eventually forced to flee to Switzerland, Vogt completed a medical degree at Bern and spent the next years with the Swiss naturalist Louis Agassiz in Neuchâtel. Eventually landing a position back in Hesse at the university in Giessen, Vogt’s fiery temperament and radical views kept him embroiled in controversy throughout his life. He exploited his materialistic views in vehement criticism of religion as a delegate to the Frankfurt Parliament during the uprisings of 1848, where he urged the separation of church and state.

**Volta, Alessandro** (1745–1827). Italian natural philosopher whose experimentation with electricity led to the invention of the battery. He argued that contact between two dissimilar metals could be made to produce a sustained electrical discharge. By bringing the two metals into contact when both were also touching a moist substance, Volta was able to show that a continuous discharge of electricity resulted. He asserted that this explained what happened in Galvani’s experiments with electricity and muscle tissue, arguing that Galvani’s explanation through “animal
electricity” was false. Volta’s position was not universally accepted, because others were able to show contraction in a muscle when only one metal was present.

**Werner, Abraham** (1750–1817). German mineralogist whose lectures in Freiberg drew students from all over Europe to learn his classification system. Keying on the time when rocks were formed rather than on their mineralogical content, Werner identified as a “formation” all rocks that had been formed in the same period. His method was to emphasize careful field observation over speculation and to integrate diverse information about the region, position, orientation, and fossil content when determining the time of formation. He explained the history of the formation of rocks based on their consolidation from a primal gelatinous fluid and classified rocks as primitive, transition, stratified, and recent. Because of the central role of the primitive ocean, his view was later dubbed Neptunism and assumed a catastrophic dimension among his British followers that was foreign to Werner himself.

**Whewell, William** (1794–1866). Master of Trinity College, Cambridge University in England, Whewell was a highly respected natural philosopher and author. His careful thinking about natural science, which reflected an influence from his acquaintance with German thought, was evident in volumes on both the history and philosophy of the inductive sciences. It was Whewell who coined the word **scientist** as a term for the practitioner of the natural sciences, a development that marked the growing role scientists were assuming in British society. He shocked the educated world in 1853 when it was learned that he was the anonymous author of the work *Of the Plurality of Worlds*, in which the possibility of extraterrestrial life was rejected in favor of a single story of redemptive history on Earth.

**Wolff, Caspar Friedrich** (1733–1794). German physician who became the champion of epigenesis, the view that the embryo developed from previously unorganized matter into the organized adult forms of living things. Wolff is most well known for his debate with Albrecht von Haller, who defended the view that the embryo developed from preformed matter. Wolff’s view became more widely accepted in German circles with the emergence of biology as a science of living things whose laws operate in a different manner from those of the inorganic realm.
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 19th and 20th 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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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 the 19th 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 extra-terrestrial 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.

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Lecture Twenty-Five
Forces, Forces Everywhere

Scope: After introducing the new series of lectures on “Physical Science and Culture in the 19th Century” with a survey of its contents, this lecture reviews the heritage of 17th- and early 18th-century treatments of motive force, forces that cause matter to move. Before the 19th century, the motive forces that received the most attention were gravitation and the mechanical force exerted in collisions. We’ll look at an enduring controversy from this earlier heritage about the proper way to measure the quantity of motion God had invested, and would preserve, in the universe. During the late 18th and early 19th centuries, natural philosophers undertook careful examination of other ways that nature exerts pushes and pulls on matter and causes it to move. The forces associated with heat, electricity, chemical change, magnetism, and light led investigators to explore the links among these forces. In the process, many new phenomena were uncovered, raising the general question about the interrelationships among nature’s forces.

Outline

I. With this lecture, we enter our final series of lectures in the course, “Physical Science and Culture in the 19th Century.”
   A. We begin with a brief survey of what we will cover in the last 12 lectures.
   B. Our first three lectures will be concerned with discoveries about nature’s forces and new theories to explain them.
      1. We’ll look at the ideas about force that were inherited and follow the discovery of the ways in which many forces were interconvertible.
      2. The conversions raised the question of a fundamental force, of which all the individual ones were manifestations.
      3. Here is an early concern with unification of forces so prevalent in today’s physics.
   C. After a look at the creation of new institutions of science that resemble those of our own day, we’ll follow the story of energy.
   D. Two major controversies will occupy us, one about the materialism natural science allegedly demanded and another involving the issue of extra-terrestrial life.
   E. Finally, we’ll follow James Maxwell’s ideas about the ether and their implications for the understanding of light and for the nature of scientific theory itself.

II. We begin our consideration of physical science and culture in the 19th century with a look back at the old theological problem of God’s relation to the cosmos.
   A. In his Principles of Philosophy, Descartes had asserted that because God was unchangeable, he “conserves the world in the same action with which he created it.”
      1. With this idea of “action,” Descartes gave to natural philosophy a problem that would take a long time to solve, but that contained dividends rich beyond anyone’s imagination in the 17th century.
      2. The problem Descartes uncovered was: If all the individual actions in the world always add up to the same total, how are we to think about these individual actions?
   B. How did Descartes measure what he called the “quantity of motion” of a given piece of matter?
      1. He reasoned that it depended on two factors: how big the matter was and how fast it was moving.
      2. In a collision, whatever velocity was given up by one piece of matter was given to the other one; thus, the total sum of the masses times their velocities remained the same.
   C. Adjustments to this view soon cropped up.
      1. What happens if two equal blobs of clay move directly toward each other at equal velocities?
      2. When they collide, they do not rebound at the same velocity but stick together, and the motion, as well as the motive force, is lost. It would appear that the total sum of motion and motive force has been diminished because the velocities, being opposite in sign, cancel each other.
      3. The German Gottfried Leibniz published a critique of Descartes’s view in 1686.
   D. Although Leibniz did not convince everyone right away, his vis viva shifted the focus of the issue.
1. Leibniz was thinking of a different kind of measure of motive force. The focus was on the effect the moving object produced, not just the force, the push or pull, it exerted.

2. Natural philosophers continued to argue about the precise nature of the motion and motive force that God would not permit to erode away.

III. In the late 18th century, natural philosophers were exploring other ways in which nature caused matter to move.

A. For example, clearly, heat could move matter.

B. Electricity and magnetism could exert a force that caused motion in matter.

C. Once Volta had invented his battery, a whole new field of electrochemistry was opened.

D. Light became the subject of renewed interest around this time, as well.
   1. In 1800, the German-born British astronomer William Herschel noticed that if he placed his thermometer in the region just below the red end of the spectrum, it registered the hottest temperature of all.
   2. One year later in Germany, Johann Ritter found that if he exposed silver chloride to the individual colors, it was darkened to a decreasing degree.

E. These many connections among forces raised the question about how they might all be interrelated.
   1. Electrical current was always accompanied by heat and sometimes light, when the wire glowed.
   2. Heat and light were intimately related, as Herschel had demonstrated, and light and chemical force were related, as Ritter showed.
   3. Electricity and chemistry were interrelated, as Davy persuasively argued.
   4. Most of these forces could also be used to produce motive force to move matter in one way or another.
   5. Could they all be related to each other? Might there be one fundamental force of which all these individual forces were mere forms?

Essential Reading:

Supplementary Reading:
Holton and Brush, *Physics, the Human Adventure*, chapter 17, section 1.

Questions to Consider:
1. If, for 17th-century natural philosophers, God’s immutability was the ultimate guarantee that mechanical force was conserved, what guarantees later laws of conservation?

2. What is the relationship, historical and conceptual, between the search for unity among nature’s forces at the beginning of the 19th century and that present in the contemporary dream of unifying nature’s four fundamental forces?
Lecture Twenty-Six
Electromagnetism Changes Everything

Scope: Persisting in his conviction as a follower of Friedrich Schelling’s nature philosophy that the forces of nature were somehow interrelated, the Danish natural philosopher Hans Christian Oersted uncovered in 1820 the manner in which a magnet was affected by the flow of electric current. It involved an instance of nature not behaving in Newtonian fashion. Although Oersted’s philosophical explanation of his experiments failed to persuade most natural philosophers, André Marie Ampère in France and Michael Faraday in England soon produced approaches to the new phenomena that advanced the study of electromagnetism and led to the creation of new electrical machines that would directly affect society.

Outline

I. Last time, we explored the numerous ways that nature’s forces seemed to interact with one another.

II. In fact, this question was not confined to those who saw themselves as investigators of nature. It was also a major concern among the nature philosophers we met in Lecture Fourteen.
   A. There, we met Friedrich Schelling, who rejected the notion that nature was a machine in favor of viewing it as an organism.
      1. An implication of this viewpoint was that all of nature was an organized interdependent unity, held together by a world soul, just as the human organism is a coherent whole unified by a human soul.
      2. This meant that all of nature’s forces were interrelated, as well, because they were all parts of the larger organized whole.
      3. Where electricity and magnetism were concerned, Schelling taught specifically that, philosophically speaking, they were one and the same dynamic activity.
      4. Schelling’s basic approach inspired those who were influenced by his thought to be ready to find interconnections among nature’s forces.
   B. One important figure who was influenced by German philosophy was the Danish natural philosopher Hans Christian Oersted.
      1. Soon after earning a doctoral degree in philosophy in 1799, Oersted made an extended trip to Germany and France, where he met Schelling.
      2. Oersted appreciated Schelling’s insistence that all of nature must be regarded as an organized whole that was able to be grasped by our reason.
   C. Oersted became interested in pursuing the link between electricity and magnetism.
      1. Oersted persisted in this endeavor after he returned to Denmark and became a professor of chemistry in 1806 in Copenhagen.
      2. Oersted showed that if current flowed through a wire, then a circular magnetic force existed around the wire. That was not like Newton’s forces, which acted in straight lines.
      3. Oersted’s discovery caused a great stir and stimulated other experimenters to investigate this strange circular force.
      4. Oersted’s appeal to nature philosophy to explain what he’d discovered was not persuasive to most of his contemporaries.

III. Two different approaches to understanding how electromagnetism was produced emerged soon after Orested’s announcement.
   A. One was presented by André Marie Ampère, who prior to 1820, had established a modest reputation in French scientific circles through work in chemistry and mathematics.
      1. Ampère assumed that any force, magnetic or otherwise, could not really act along a circular path, as Oersted’s description of the magnetic force around the current-carrying wire seemed to indicate.
      2. Rather, like all the forces known up to that time, Oersted’s apparent circular magnetic force had to be the resultant sum of central forces.
      3. Ampère wound a current-carrying wire around a bar of iron and found that he could create a magnet in the iron bar.
      4. Ampère came to the conclusion that magnetism was electricity in motion.
5. Ampère suggested that even in the case of a permanent bar magnet, there was electricity in motion. He postulated that there was a circular flow of electricity *around each molecule of the iron*.

6. Ampère wrote the complicated mathematical equations that described the forces that moving electricity exerted. He assumed the forces acted in straight lines perpendicular to the direction of the current’s flow.

7. His achievement marks the beginning of *electrodynamics*—the forces produced by electricity in motion.

B. A completely different approach to the phenomena of electromagnetism was taken by Michael Faraday in England.

1. Where electromagnetism was concerned, Faraday simply accepted the notion that some forces in nature may act along curved rather than straight lines.

2. Faraday produced lines of magnetic force using one wire, then used them to try to produce an electrical current in a second wire.

3. He found that electrical current was produced when the magnetic lines of force were interrupted, which he learned to do by physically moving a bar magnet that had been wrapped with a wire.

IV. Discoveries like this by Faraday and others made possible new inventions that had significant impact on 19th century society.

A. The electric generator, in which a loop of wire turned between two poles of a magnet to produce current in the wire, represented a new source of power to the 19th century.

B. The electric motor used current to make an electromagnet rotate. The motion of this rotating armature could then be used to do mechanical work.

C. Both of these inventions contributed to the growing awareness of the importance of natural science in modern life.

D. These inventions also illustrated that mechanical force could be converted into electrical force, and electrical force could be converted into mechanical force.

E. In the next lecture, we’ll investigate more about conversions of force and more challenges to Newtonian ideas, this time starting with the ubiquitous force of heat.

Essential Reading:

Supplementary Reading:

Questions to Consider:
1. Faraday’s and Ampère’s approaches to electromagnetism were vastly different, yet from each came productive continuing research programs. What complementary aspects of natural science were they addressing?

2. Do you think it merely coincidental that both Faraday and Ampère were extremely religious men in their private lives?
Lecture Twenty-Seven
French Insights About Heat

Scope: Of all the forces of nature, that of the motive force of heat proved to be one of the most intriguing during the early decades of the 19th century. Two French natural philosophers made fundamental contributions to the beginnings of a new science of heat. Joseph Fourier’s mathematical description of heat flow contained an implication that ran counter to the understanding of the French Newtonians encountered in an earlier lecture. No one realized that it was an early sign that Newtonian assumptions might not be sufficient to understand how nature worked. In addition, Sadi Carnot’s careful analysis of heat engines offered valuable insight into their efficiency and, more important, provided a manner of thinking about what happens when heat is used to produce the motion of matter that would reap great benefits in the next generation of physicists.

Outline

I. The inventions made possible by electromagnetism contained an interesting question about the interrelationships among forces.
   A. In a generator, by turning a coil of wire mechanically, one can obtain electrical current.
      1. Is mechanical force here merely made use of to produce the electrical force of a current?
      2. Or is mechanical force converted to, does it become, electrical force?
   B. In an electric motor, one starts with electrical current and ends up with the rotating mechanical motion of the armature.
      1. Here, is the electrical force of the current merely made use of in obtaining the mechanical rotation?
      2. Or does the electrical force become mechanical force?

II. The use of heat to obtain motive force was centered on the invention of the steam engine.
   A. The steam engine was a major symbol of the shift from animal power to inanimate power that accompanied industrialization.
   B. The invention of the steam engine is an example of technology leading science.

III. Among the first to consider heat from a theoretical, as opposed to a practical, point of view was the French mathematician Joseph Fourier.
   A. Born into humble social status in 1768, Fourier exhibited natural sympathies for the Revolution when it came.
      1. He survived the Revolution and became a teacher at the newly established École Polytechnique, where he soon acquired an important position in mathematics.
      2. He was a technical adviser to Napoleon for the famous expedition to Egypt that Napoleon undertook in the summer of 1798 and was later Napoleon’s appointed prefect of Grenoble.
   B. During the first decade of the 19th century, Fourier devoted himself to the study of heat; in particular, he investigated how heat flowed through solid bodies.
      1. The brilliance of the mathematical techniques he developed to express his results was not recognized until later.
      2. Like Oersted, Fourier introduced a non-Newtonian element into physics. In his case, the laws he formulated for the conduction of heat implied that heat flow was not reversible.

IV. Another Frenchman around this time had also become fascinated by the theoretical study of heat—this time, in the steam engine.
   A. Sadi Carnot received the benefit of an excellent education from his father.
      1. His father, Lazare Carnot, had been a member of the Directory and active in various representative bodies during the French Revolution.
      2. Sadi completed his studies in engineering and entered the military.
   B. Carnot wanted to know answers to some important practical questions about heat engines:
1. Was there a maximal amount of motive force that could be obtained using a certain amount of heat?
2. Were some substances better than others in producing a given amount of motive force?

C. In the course of answering his questions, Carnot came upon an important insight whose implications would take some time to appreciate.

D. Carnot realized that if heat were going to be used to produce motive force, then the only way that could happen was if heat at a higher temperature fell to a lower temperature.

V. How are we to understand Carnot’s explanation of his crucial insight?

A. Carnot thought of the production of motive force from heat as nature’s response to a disturbance in a normally balanced state.
   1. Carnot viewed the steam engine as another way of disturbing a normal state, then presenting nature with an opportunity to restore the original state.
   2. The heat engine he imagined was an ideal engine; that is, he did not consider heat lost by conduction or by friction of the moving parts, which were viewed as weightless.
   3. Carnot did not commit himself in his book to a particular view of what heat was, but his readers took him to mean that heat was a weightless fluid called caloric, which was present in or attached to all matter.

B. With these assumptions, Carnot proceeded to analyze how a steam engine works by disturbing, then restoring an equilibrium state.

C. What are the implications of Carnot’s analysis for our question about using one form of force to obtain another, as opposed to converting one kind of force into another?
   1. First, heat can be used to move a piston up and down provided that it could be given to a body that was colder.
   2. Second, and crucially, for Carnot, the production of motive force from heat in heat engines is accomplished by taking excess caloric from a hot body and delivering it to a cold body.
   3. This means that for Carnot, the heat is merely used to produce motive force in the piston; it is not converted into motive force.

D. Carnot’s analysis allowed him to draw other extremely important conclusions.
   1. If motive power depended on the difference in temperature between the hot body and the cold body, then the substance used to supply the heat was not important.
   2. A second conclusion was even more surprising because it was based on the understandable assumption that some heat engines are more efficient than others.
   3. His heat engine was an ideal one, so he imagined that it was reversible, unlike the flow of heat in Fourier’s understanding.
   4. Carnot imagined that he could use the motive force he got from a more efficient heat engine to drive a second, less efficient one in the reverse direction.
   5. Carnot concluded that all ideal reversible heat engines must have the same efficiency.

E. These remarkable conclusions about heat were just the beginning of the new science of thermodynamics. We will learn just how important they were when we come to the famous Second Law of Thermodynamics in Lecture Thirty.

Essential Reading:

Supplementary Reading:
Questions to Consider:
1. If steam technology was a stimulation to the creation of scientific theory, can one generalize about the direction of the causal relationship between technology and scientific theory?
2. In the first four decades of the 19th century, there was disagreement about the nature of heat itself. How did scientists come to the impressive insights about heat they did without agreeing about what heat was?
Lecture Twenty-Eight

New Institutions of Natural Science

Scope:  The emergence of a middle-class public sphere in Europe and, with it, an increasingly significant role for something called “public opinion” made autocratic actions of monarchs more and more subject to open scrutiny. This was particularly true in the German states in the period after the defeat of Napoleon, when ideals of fatherland and truth circulated widely. In this context, the nature philosopher Lorenz Oken founded a new journal of natural science as an open forum for the free exchange of ideas. Oken took the lead six years later in the establishment of the first German association of natural science, which served as the inspiration for the creation in Britain of the British Association of Science in 1831. With the establishment of these modern associations, the idea of a practitioner of natural science began to emerge, as did a wider concern to distinguish the methodology of natural science from the older broad approach of natural philosophy.

Outline

I.  In this lecture, we examine the beginnings of the congealing of a scientific community in the history of Western science.

   A.  In Lecture Fourteen, where we considered alternative visions of natural science from those associated with a mechanical conception of nature, we observed that there was no one “scientific” approach to the investigation of nature.

   1.  There were those, such as Georges Cuvier, who insisted on gathering empirical information, from which generalizations about nature could be formed, as the primary responsibility of the investigator of nature.

   2.  In the German states, nature philosophers urged that the mere accumulation of information about nature was seeing nature only from the outside, when one also needed to include the special knowledge humans possessed because they were a part of nature.

   3.  In France, Jean-Baptiste Lamarck complained that the mere gathering of facts ignored the need to bring ideas to the interrogation of nature.

   B.  All this was taking place at a time when Europe had been turned upside down. Something called “public opinion” eroded the king’s authority by inquiring if the king’s actions had been reasonable.

   1.  The Old Regime in France had been dismantled by the Revolution, giving rise in its aftermath to Napoleon Bonaparte.

   2.  With the final defeat of Napoleon in 1815, Europe tried to put itself back together.

   3.  To complicate the situation, the continuing Industrial Revolution provided its own disruption of the social order and contributed to the working class’s increasing awareness of its own unfavorable circumstances.

   4.  Accompanying all this was the emergence of what has been called a public sphere in the middle class, a defining feature of which was the acknowledgment that argument, not status, should determine authentic social authority.

   5.  It is in this fluid situation that a new idea of a scientific community began to take shape.

II.  The founding of a journal of natural science marked an early step in the process of solidifying the scientific community.

   A.  The nature philosopher Lorenz Oken, who was also politically active in the post-Napoleonic era, determined to found a new journal of natural science.

   B.  The founding of Isis in 1817 proved to be an immediate success.

   1.  Although the focus of the articles was natural science, political issues began to appear, as well, forcing the authorities to intervene.

   2.  Oken was given a choice: Cease publication of Isis or lose his professorship at Jena University.
III. The founding of a society for natural science greatly accelerated the congealing of a scientific community.

   A. Up to this point, gatherings of those interested in the study of nature were local groups, often with a narrow focus within the natural sciences.
      1. Exceptions, of course, were the Royal Society in England and the Académie des Sciences in France.
      2. But these were exclusive societies, not open to anyone interested in natural science.

   B. Again, Lorenz Oken took the lead in creating a new society for German science.
      1. The first meeting was held in Leipzig in September of 1822 to organize the Gesellschaft Deutscher Naturforscher und Ärzte (Society of German Investigators and Physicians).
      2. The participants decided to meet annually in a different city of Germany, alternating between southern, northern, eastern, and western locations.
      3. One of Oken’s goals was to bring together those working in closely related fields to stimulate collaboration among individuals who might otherwise be unaware of one another.
      4. Oken insisted that social gatherings become an essential feature of the meetings of the society to promote informal interchange.

   C. The idea of a national society with an annual conference open to all was a tremendous success.
      1. The 1828 meeting was held in Berlin, where the king of Prussia attended an evening social occasion of some 1,200 people.
      2. Although not yet professionalized, those who pursued research in natural science had acquired a greater social visibility than they had ever had before.

IV. The German success served as a model for British investigators of nature to organize their own society.

   A. During the 1820s in Britain, there was concern that Britain was falling behind in natural science.
      1. In 1830, Babbage published Reflections on the Decline of Science in England, which caused a great stir because of its attempt to expose English science as second class.
      2. In addition, Babbage openly criticized the Royal Society of London for being dominated by members who were far more interested in aristocratic status than in scientific achievement.

   B. The German meetings inspired the British to create the British Association for the Advancement of Science.

   C. As in Germany, the new society focused attention on an emerging social identity.
      1. During the Cambridge meeting of 1833, the poet Samuel Taylor Coleridge, long-time friend of those who sought to encounter and understand nature, was honored.
      2. He forbade members of the BAAS to call themselves philosophers, as some traditionally still referred to themselves.
      3. In response, William Whewell, master of Trinity College, coined the word scientist as a term that designated those who studied material nature.
      4. It would take some time for the new name to catch on, but its presence signaled a shift away from natural philosophy toward an enterprise that was more narrowly focused.

Essential Reading:
Purrington, Physics in the Nineteenth Century, chapter 2, pp. 9–19.

Supplementary Reading:
Thackray and Morrell, Gentlemen of Science, chapter 2.

Questions to Consider:
1. How were the new institutions of natural science discussed here different from older associations, such as the British Royal Society and the French Academie des Sciences?
2. How would you characterize what the new name scientist connoted that was not captured by the older term natural philosopher?
Lecture Twenty-Nine
The Conservation of What?

Scope: In the 1840s, the continuing investigation of the interrelationships among nature’s forces led to inquiries about conversion of one kind of force into another and to the general question of the possible creation and destruction of force. In Germany, Robert Mayer became convinced that it was impossible to destroy force, at first leaving open the question of whether new force was created in certain contexts. Around the same time, in Britain, James Joule argued experimentally against conceiving heat as something that was conserved in steam engines. Joule showed that when heat was used to produce mechanical motion, a portion of the heat actually became mechanical force. These and other considerations led to the announcement in July of 1847 by Hermann Helmholtz that although force can be converted from one form into another, it can be neither created nor destroyed. But even at the moment of its announcement, there remained confusion about the meaning and merits of the claim of conservation.

Outline

I. The new institutions of natural science and the emerging identity of the natural scientist we encountered in the last lecture occurred on the eve of a period of major scientific achievement.
   A. One key episode in the natural science of this period was the development of ideas about what would eventually be called energy.
   B. This story illustrates one of history’s ironies.
      1. One of the historians who has written about this subject is Thomas Kuhn, whose central concern revolved around the idea that energy conservation was discovered by several people at the same time.
      2. It is much more likely that, had we been alive in these years, we would not have observed simultaneous discovery of this concept.
      3. Many historians of science today depict this episode as a protracted struggle to understand nature that only gradually produced a consensus.
   C. In this lecture, we will choose three from among the contributors, all under 30, to the construction of this consensus.

II. We first need to review what heat was thought to be.
   A. The caloric theory of heat, which assumed that heat was an inherently light substance that permeates gross material bodies, originated with Aristotle’s identification of fire as one of the four basic elements.
      1. In this conception, temperature could be associated with the amount of caloric that occupied a given volume.
      2. The observed evening-out over time of the temperature of two bodies originally at different temperatures could be visualized easily as the flow of caloric from the hotter to the colder body until the density of caloric in each is the same.
   B. An alternative explanation was that heat was the motion of the ultimate particles making up a specific mass.
      1. This view was entertained at least as early as the 17th century to account for the creation of heat through friction.
      2. At the turn of the 19th century, Benjamin Thompson (Count Rumford) undertook a series of experiments in Germany that involved boring canons.
      3. Rumford’s conclusion was that the only way his results made sense was if heat was the result of the motion of the particles in the metal.
   C. Each theory of what heat was also had severe weaknesses.
      1. How could the caloric theory account for the inexhaustible heat produced in the boring of canons if the heat were due to a set amount of caloric in the metal canons that was somehow set free during the boring process?
      2. How could Rumford explain the transfer of the Sun’s heat to the Earth on the assumption that it was a mode of motion of the corpuscles of gross matter?
3. As the decade of the 1840s dawned, both ideas about heat were still appealed to, depending on the context.

III. One of the routes to conservation came by way of physiology. It was undertaken by a young German physician named Julius Robert Mayer.
   A. Mayer signed on as the ship doctor for a Dutch expedition to the East Indies in early 1840, where he observed something unexpected.
      1. He records being surprised by the “uncommon redness” of the venous blood he drew—it looked like that from an artery.
      2. He explained this by invoking Lavoisier’s theory of animal heat, according to which animal heat results from oxidation going on in the blood.
   B. Mayer next made another inference about the heat produced by the body.
      1. He believed that mechanical motion could not be generated out of nothing.
      2. He argued that the heat produced by the oxidation in the blood, while in part supplying the heat the body needs to keep warm, must also be related to the mechanical motions the body makes.
      3. In asserting that heat became mechanical motion, Mayer was arguing that there was a mechanical equivalent of heat.
   C. Mayer’s publications on his return to Germany were unusual in several ways.
      1. An 1842 paper cast his assertions in a philosophical mode that many did not appreciate.
      2. Further, Mayer was a religious man who was vehemently opposed to godless materialism; thus, he refused to regard forces as properties of matter.
      3. By arguing that force was cause, he eventually came to the notion of the conservation of force.

IV. A more concrete argument about force conversion occurred in the experimental work of James Joule from Manchester in England.
   A. Joule had no knowledge of Mayer’s work but had become convinced on his own that when mechanical motion produced heat, there is a constant ratio of the work done by the motion to the heat produced.
   B. Joule attempted to establish this conclusion through a series of experiments, which he reported at the British Association meetings beginning in 1843.
   C. His most well known experiment involved a paddlewheel that was turned in an insulated bucket of water by a slowly falling weight.
   D. He was able to measure the rise in temperature of the water and correlate it with the amount of work done by the descending weight, thus obtaining a precise measure of how much heat equated to how much mechanical work.

V. One of the earliest announcements of the general result implied by Mayer’s and Joule’s work, the conservation of force, was given in Germany in July of 1847 by another young medical doctor, Hermann Helmholtz.
   A. Helmholtz began his medical studies in Berlin, working with a group of students who were wrestling with the problem of vital force, which they thought could be reduced to mechanical forces acting on matter.
   B. In 1847, Helmholtz wrote a paper entitled “On the Preservation of Force,” which many regard as the first general statement of energy conservation.
      1. He imagined a system of bodies, each body in a specific position relative to the others and all the bodies subject to various forces acting among them.
      2. If, after a time, the bodies moved to different positions because of the forces acting on them and if they were subsequently moved back to their original positions, Helmholtz argued that any work gained by the first motions would be exactly lost by the movements back to the original position.
   C. Helmholtz’s analysis was general. It was not limited to a single cause of motion, as in the example just given, but could include many acting simultaneously.
   D. There are two kinds of force in Helmholtz’s analysis, and each can be converted into the other.
      1. One he calls the “tensive force,” because it is exerted without motion resulting.
      2. The other is the “living force,” vis viva, or the force the weight exerts by virtue of its being in motion.
      3. At any time, then, one has all tensive force and no living force, all living force and no tensive force, or some combination of part tensive and part living.
4. What stays the same here is the total of the two forces, the sum of the tensive and the living force.

VI. Although we have arrived at a general result, there was not yet clarity about what was conserved.
   A. The word Helmholtz used was force, not energy.
   B. It is easy to see why we should avoid characterizing these developments as simultaneous discoveries of the conservation of energy.

Essential Reading:

Supplementary Reading:
Caneva, Robert Mayer and the Conservation of Energy

Questions to Consider:
1. Why did scientists continue so long to use the word *force* for what they would eventually call *energy*?
2. Exactly how does the concept of energy differ from that of force?
Lecture Thirty

Culture Wars and Thermodynamics

Scope: Carnot’s insight that the production of motive force from heat involved a “fall” from a higher to a lower temperature, combined with Joule’s recognition that heat is transformed into motive force in the process, led to the realization that mechanical force, or as William Thomson called it in 1852, mechanical energy, could become dissipated. Dissipated energy was energy that was present but had become unavailable to produce motive force. On the Continent, Hermann Helmholtz drew out the ominous implications of a heat death of the universe in a public lecture of 1854. In light of the Great Disruption in the Scottish church, in which traditionalists, unhappy with the growing liberalism of the day, broke away to establish their own church, Thomson and fellow Scotch Presbyterian physicists used their new understanding of energy to steer a middle course between scientific naturalism on the one hand and traditional literalists on the other.

Outline

I. In Lecture Twenty-Nine, we followed the stories of three individuals, Robert Mayer, James Joule, and Hermann Helmholtz, as they struggled with the question of how heat was converted into mechanical motion.
   A. Mayer, Joule, and Helmholtz all agreed that Carnot had erred in assuming that heat was merely made use of, but not used up, when steam engines produced motive force.
   B. In this lecture, we want to explore how scientists came to the conclusion that these interconversions back and forth could not just go on forever.

II. For those who were trying to understand heat in the 1840s, the choice appeared to be between Carnot and Joule.
   A. If Carnot was right, then heat was made use of in steam engines (as water is used in the example of a mill wheel in Lecture Twenty-Seven), but it was not converted into force.
   B. If Joule was right, then heat became mechanical motion; it disappeared as mechanical motion appeared. Here, heat was converted into mechanical force.
   C. In Germany, a young physicist named Rudolf Clausius challenged this way of seeing things in 1850. Clausius suggested that there were important aspects of both physicists’ works that should be retained.
      1. He regarded Carnot’s assertion that the fall in temperature was proportional to mechanical work as valid.
      2. He also thought Joule was correct that heat was converted into mechanical motion.
      3. His solution was to suggest that when heat was used to produce motive force, only some of the heat was turned into mechanical work, while some was merely transferred from a warm body to a colder one.

III. Similar conclusions were made the following year by the young Scotsman William Thomson.
   A. Like Clausius, who he acknowledged, had stated it first, Thomson believed that both Carnot and Joule were right.
      1. Like Clausius, Thomson concluded that when heat is used to produce motive force, some of it becomes motive force and some is moved from a higher temperature to a lower one by conduction.
      2. Carnot had not considered heat flow by conduction, because his heat engine was an ideal heat engine.
      3. But in the real world, there would always be heat conducted though the sides of the boiler of any heat engine.
   B. Thomson drew an interesting conclusion from this analysis.
      1. He was impressed that the part of the heat during this process that was conducted could not be converted into mechanical work.
      2. He reasoned that some of the heat during this process became unavailable to do work. It was, in Thomson’s word, “dissipated.”
      3. Thomson now appropriated the word energy instead of force to focus on the motion of matter, as opposed to the mere push of the steam on the piston.
      4. The word energy, referring to the work done, only slowly replaced force in these treatments of thermodynamics.
C. In 1854, Hermann Helmholtz made clear the cosmic implications of Thomson’s dissipated energy.
   1. He pointed out that the store of dissipated heat in the cosmos must be constantly increasing, because it could not be reconverted.
   2. He concluded that the store of dissipated heat would grow until, eventually, all force had been converted into it: “Then all possibility of a further change will be at an end, and the complete cessation of all natural processes must set in.”

IV. The new vision of the future of the physical world had an impact on religious assumptions.
   A. This would not be the case for the irreligious scientific materialists we will meet in the next lecture.
   B. A heat death would, however, clash with the old Laplacian cosmos we encountered in Lecture Two.
   C. The new view based on the dissipation of energy had a particular impact on those who held more traditional religious positions.
      1. One such individual was William Thomson, who had been raised in the Presbyterian Church of Scotland.
      2. Thomson seemed to be caught in the middle between the biblical literalists of the Free Kirk and the liberal compromisers with deistic naturalism.
   D. Thomson crafted his own religious position in conjunction with his new understanding of energy.
      1. The irreversibility of all physical processes suggested an end to the world, which opposed Laplacian naturalism and was consistent with his Presbyterian faith.
      2. Thomson, therefore, opposed such writers as Lyell, who suggested that the Earth’s past was a steady state, with no progression at all.
      3. Thomson declared that “everything in nature is progressive,” by which he meant that nature developed irreversibly.
      4. On the other hand, Thomson did not think that the end times were close at hand, as more traditional Presbyterians did.

V. This early work of Clausius, Thomson, and Helmholtz did not create the public stir that the controversy over materialism was making around the same time. That will be the subject of our next lecture.

Essential Reading:

Supplementary Reading:
Holton and Brush, *Physics, the Human Adventure*, chapter 18.

Questions to Consider:
1. For you, is the idea of a heat death of the universe compatible with religious faith (as it was for Thomson), or does it undermine a religious view of the future?
2. How does the running down of the universe jibe with current ideas of the universe’s expansion?
Lecture Thirty-One

Scientific Materialism at Mid-Century

Scope: The 1840s was a tumultuous decade on the Continent. Sensational writings in theology by the left-wing Hegelian Ludwig Feuerbach introduced an intellectual defense of materialism that found political expression in the years leading up to and following the revolutions of 1848. As his inspiration, Feuerbach specifically cited natural science, whose new institutions and discoveries imparted to it a growing visibility in society by mid-century. Among natural scientists themselves, “the unholy trinity” of Karl Vogt, Jacob Moleschott, and Ludwig Büchner proclaimed radical assertions about the self-sufficiency of the material realm over the ideals of philosophy and, especially, religion. When it appeared in 1859 in England, Darwin’s *Origin of Species* merely added fuel to an already raging fire on the Continent about the relationship between natural science and religion.

Outline

I. In the last two lectures, we have followed physicians and physicists as they have tried to sort out ideas about energy.
   A. We observed what a challenge it was to sort out the meaning of conversions of force from one kind to another, especially where the force of heat was concerned.
   B. The controversy over scientific materialism, which arose around the same time, caught the attention of the educated public.

II. The 1840s was an active time in Europe, intellectually, economically, socially, and politically.
   A. Apart from the scientific ideas we have already met, there were other intellectual achievements.
      1. Paralleling the sensation of the *Vestiges of the Natural History of Creation* in Britain, on the Continent, Ludwig Feuerbach’s *Essence of Christianity* of 1841 purported to expose religion as a mere projection of human needs.
      2. Humans had invented a domain of divine existence, which they then claimed transcended our ordinary experience of the material world.
      3. Feuerbach identified with natural science, claiming to be “a natural investigator [Naturforscher] of the mind.”
      4. The young Karl Marx found Feuerbach’s materialism to represent an inspiring inversion of the Hegelian idealism that had been dominating the philosophical scene.
      5. Marx’s new dialectical materialism claimed to be a philosophical foundation for social change.
   B. Industrialization was in full sway, producing social unrest in its wake.
      1. The age of railroads, begun a decade earlier, began to take off on the Continent in the 1840s.
      2. This was one important factor that helped France and Germany begin to catch up to England’s achievement in industrialization.
      3. The horrendous working conditions in factories and pollution produced monstrous public health challenges in the decade, leading to calls for reform.
   C. Politically, rulers found the situation increasingly unstable as the 1840s progressed.
      1. In France, all the political exiles and malcontents from elsewhere in Europe seemed to have gathered in Paris, where they clamored for the creation of a new age.
      2. Revolution broke out in Paris in February of 1848, precipitating revolutions in other major cities on the Continent.

III. The use of natural science to promote materialism became very visible around mid-century.
   A. Among the first proponents of scientific materialism was a fiery young professor of zoology from Giessen in Germany.
      1. Karl Vogt completed a medical degree in 1839, then spent five years studying fossils and geology under the direction of the noted Swiss naturalist Louis Agassiz.
      2. He then spent three years in Paris in the middle of the tumultuous 1840s before accepting a position in zoology at Giessen University in Germany.
3. His *Physiological Letters* contain his most famous statement, made to support his materialistic view of mental activity, that “thoughts stand in the same relation to the brain as gall does to the liver or urine to the kidneys.”

4. After revolution broke out in Germany, Vogt was elected a representative to the Frankfurt Parliament, where he continued to take radical stances.

5. He defended revolution as something sanctioned by nature and depicted scientists as necessary revolutionaries.

6. He also attacked religion and its institutions, declaring unrestrained war against church and religion.

B. Vogt’s sounding the materialistic alarm found an echo in the work of a young Dutch physiologist, Jakob Moleschott.

1. Moleschott was educated in Germany in physiology, where he met Ludwig Feuerbach and impressed him with a study of the physiological chemistry of food.

2. He proclaimed that because life was merely an exchange of matter, differences in diet determined differences in thought and character.

3. The book was reviewed by Feuerbach, who endorsed Moleschott’s materialistic explanation of human character in a phrase that has been famous ever since: “You are what you eat.”

4. In 1852, Moleschott’s book *The Cycle of Life* declared again that life was not the result of a special force; rather, it was the result of the forces of matter: heat, light, electricity, and mechanical motion.

5. His radical ideas caused such a stir that he soon lost his position and left Germany for Switzerland.

C. The most well known of the scientific materialists was Ludwig Büchner, a young German physician working in Tübingen.

1. Büchner came from a family of gifted children. His brother Georg had penned two plays that have stood the test of time, and his sister Luise became a leader in Germany’s nascent women’s movement.

2. He was inspired by the 30th anniversary meeting of the German Society of Natural Scientists and Physicians in 1853.


4. Büchner’s slogan, “No force without matter, no matter without force,” aggressively proclaimed that there was no such thing as immaterial spirit.

5. He set out on a campaign to eliminate every kind of supernaturalism and idealism from the explanation of natural events.

6. His strong conviction that the empirical method of natural science was the only route to knowledge led to the conclusion that philosophy must adopt its approach.

7. Büchner celebrated the conservation of force, which he interpreted as the “immortality” of force in 1857, as a confirmation of his materialistic vision.

8. Büchner’s summary statement of scientific materialism became the symbol of the movement.

IV. The materialistic controversy that began at mid-century established an assertion that has found many advocates and detractors since.

A. The strong political agenda associated with it betrays that it embraced an idealistic vision of its own.

1. The conviction that natural science supported materialistic metaphysics was held with an emotional commitment rivaling that of religious individuals.

2. Büchner’s rejection of the inevitability of universal heat death betrays an optimistic vision of the future not warranted by his materialistic beliefs.

B. It was clear that an age of Realism had replaced the Romantic spirit of earlier decades.

1. The new spirit of Realism was evident elsewhere in the culture, as well as in the materialistic controversy that flowed from natural science.

2. It was visible in the *Realpolitik* pursued by Otto von Bismarck, who used it to successfully unite the German states into a new Reich by 1870.

3. It was evident in the school of Realism in art and in the literature of the period that attempted to “tell it like it is,” rather than to focus on edifying the reader.

4. After mid-century, Karl Marx abandoned the exhortation of his *Communist Manifesto* and sat down in the British Museum to examine economic data.
Essential Reading:

Supplementary Reading:

Questions to Consider:
1. Why is it that natural science frequently carries a public image of being materialistic?
2. Why was it so hard to mount an effective public reply to the popular materialism of mid-century?
Lecture Thirty-Two
The Mechanics of Molecules

Scope: In the aftermath of the achievements in chemistry at the end of the 18th century, John Dalton went in a new direction when he successfully summarized experimental results involving chemical reactions, using the ancient assumption that there was a smallest unit, an atom, of elemental substances. Modifications of Dalton’s hypothesis soon occurred when Amedeo Avogadro introduced the distinction between an atom and a molecule of a single element. More modifications were introduced to accommodate both the discovery of new elements and the increasing body of experimental information gathered as the century progressed. By the 1860s, chemists began to arrange elements in various tables based on similarities observed. Around the same time, physicists enjoyed increasing success in describing the behavior of gases by treating them as collections of molecules moving in a confined space. In the course of doing so, they introduced a statistical style of thought that contained fascinating implications for the behavior of nature in general.

Outline

I. One of the assumptions of the scientific materialists was that molecules in motion determined the nature of reality.
   A. Once we know the laws governing the motion of molecules, we will know all that can be known.
   B. What scientists were to begin finding out was that there were unsuspected obstacles lying in the path to knowledge of molecular motion.
   C. In this lecture, we’ll survey the knowledge of matter from where we left it back in Lecture Six with Lavoisier.

II. Already in the early 19th century, there were hints that the laws of matter might be different from those Newton had found for the heavens.
   A. In the 18th century, much of chemistry was dominated by what historians have called the Newtonian dream.
      1. The idea was to proceed in chemistry the same way Newton had described the laws of planetary motion—to find mathematical expressions of the forces involved.
      2. In spite of various attempts to quantify short-range chemical forces, no one had been successful in realizing the Newtonian dream in chemistry as the century came to a close.
   B. The appearance of a basic question, about how chemical substances combined, led chemists in France and England to pursue a different course in chemistry at the turn of the 19th century.
      1. The question was: When chemical substances combine to form a composite, do they always combine in the same proportions, or can the proportions vary?
      2. In France, a debate arose on the issue, with Joseph Proust asserting that the proportions were fixed, while Claude Berthollet argued that they could combine in an infinite variety of proportions to produce composites with different properties.
   C. A few years later in England, John Dalton was fascinated with the different gases that made up the atmosphere: Why did they remain mixed instead of separating out in layers?
      1. He assumed that the gases were composed of particles that, because they repelled themselves selectively, without repelling the atoms of other gases, resulted in a general mixture.
      2. He determined to establish the number and weight of the elementary chemical substances that entered into combination.
      3. Studying instances in which different compounds resulted from the same elementary substances, Dalton came to the conclusion that the proportions in which they combined were not only fixed, but in many cases, were simple multiples of one another.
      4. He formulated what has become known as the law of definite proportions: When atoms combine to form a compound, the number of combining atoms of the different elements form simple, definite ratios.
      5. Dalton was now able to determine the relative weights of the atoms that combined.
III. Additional insights strengthened atomic theory over the course of the century.

A. New ideas in atomic theory in France and Italy created controversy.
1. In France, Joseph Gay-Lussac argued, based on experiments, that when gases act on one another (as in the formation of water), the volumes of the combining gases exhibit simple ratios.
2. This seemed to Dalton to imply that atoms might be of equal sizes, an idea he did not believe.
3. Amedeo Avagadro in Italy suggested that gases are not necessarily made up of single atoms. They may be composed of two or more similar atoms, united into what he called a *molecule*.
4. Again, Dalton opposed this result, because Avagadro did not explain what held diatomic molecules together without causing the gas to condense.
5. Avagadro nevertheless concluded that equal volumes of gases under the same conditions possess equal numbers of molecules, a law that still bears his name.

B. Chemists also sought regularities among the growing list of elementary substances.
1. In the second decade of the century, the English physician William Prout suggested that the atom of hydrogen was the true fundamental particle.
2. This implied that atomic weights should be whole multiples of hydrogen’s weight, a result that seemed to be confirmed by Dalton’s work, early on.
3. As the years passed, however, more and more experimental results indicated that very few atomic weights were exact multiples, and the hypothesis was dropped.
4. Others, however, began looking for similarities in chemical properties among different elements.
5. In 1869, Dimitri Mendeleev published a book on principles of chemistry in which he arranged elements according to increasing atomic weights, forming a new row when he came to elements that displayed similar properties to an earlier element.
6. Sometimes, he had to leave gaps and, sometimes, his values for atomic weights were at odds with those determined by others.
7. Because no one understood why Mendeleev’s table worked as well as it did, he had to endure criticisms.

IV. By mid-century, the kinetic theory of gases brought chemical atomic theory together with physics, yet another instance of the extension of physics beyond the classical Newtonian outlook.

A. Rudolph Clausius, whom we met in Lecture Thirty, is a key figure in the development of kinetic theory.
1. Born the son of a minister in a part of Prussia that is now Poland, Rudolph received his doctoral degree in 1848 and worked on the mechanical motion of the particles of gases in connection with his studies in thermodynamics in the early 1850s.
2. Clausius published what became a fundamental paper entitled, “On the Nature of the Motion We Call Heat.”
3. In addition to their motion of translation, he said that the molecules were also rotating and even oscillating with respect to each other. Once equilibrium was established, the total energy of the system is made up of these various kinds of motions of the molecules.
4. He used his model to explain pressure and evaporation of liquids.

B. In 1860, James Maxwell contributed to the further development of kinetic theory.
1. He applied the emerging mathematical study of statistical variation to kinetic theory.
2. Although Maxwell’s proposal became part of kinetic theory, it was not until the 20th century that experimental proof was obtained.

C. The success of kinetic theory contributed to the introduction of a new style of thinking about nature.
1. The work of Clausius, Maxwell, and others showed that one can be productive in describing nature as the aggregate of variations around a mean, rather than insisting that there is only one true manner in which nature behaves and that scientific law must express.
2. If scientific laws can be statistical, that fact has implications for the nature that is being described.
3. Nature is no longer best envisioned as a well-oiled machine that always gives the same output when presented with the same input.
4. Nature’s regularity is guaranteed overall by the statistical law, but individual outputs cannot be predicted with complete accuracy.
5. The old completely deterministic order announced by Laplace back in Lecture Two, in which a perfect Newtonian mind could know all of nature with certainty, had been replaced.
Essential Reading:

Supplementary Reading:
Holton and Brush, *Physics, the Human Adventure*, part F.

Questions to Consider:
1. Can there be any real object in nature that corresponds to the notion of an atom as something that cannot be divided?
2. Do you agree that, to the extent nature insists on being described in statistical terms, nature’s behavior resembles that of people more than it does that of machines?
Lecture Thirty-Three
Astronomical Achievement

Scope: The 1796 book by Pierre Simon Laplace entitled *System of the World* asserted more than just the claim examined in Lecture Two, that the cosmos was a stable machine that would run eternally. Laplace also drew on new telescopic observations of William Herschel, a German-born astronomer who had come to live in Britain. Herschel’s revelation of new nebulae, structureless masses of a finely distributed substance, some of which displayed apparent condensation in the center, inspired Laplace’s nebular hypothesis to explain the origin of the solar system. The core of Laplace’s compendium of Newtonian celestial mechanics, published between 1799 and 1825, came to Britain through the self-taught woman of science Mary Somerville in the early 1830s. The widely celebrated discovery of the new planet Neptune, in 1846, both kept the public’s focus on the heavens and contributed to the growing visibility of natural science in the century. Neptune’s discovery also represented a continuation of the nationalistic rivalries in science that marked this period.

Outline

I. Paralleling the realm of the very small, examined in the last lecture on atomic theory, was the realm of the very large—the world of astronomy.

A. While Berthollet and Proust were arguing over whether proportions of chemical reagents were fixed or infinitely variable, the nebular hypothesis of Pierre Simon Laplace began to exert influence.
   1. Nebulae, or fuzzy-shaped objects in the heavens, had been known since antiquity, but they had proliferated in number in the 18th century.
   2. Laplace’s nebular hypothesis, about the origin of the solar system from a nebulous fluid, appeared to exhibit what came to be known as *creation by natural law*; that is, the laws of matter produced a solar system from a primitive homogeneous fluid.
   3. This idea was extremely attractive to anyone disposed toward deism.
   4. Between 1799 and 1825, Laplace established himself as the Newton of the 19th century by accumulating his astronomical researches into five volumes under the title *Celestial Mechanics*.

B. Laplace’s *Celestial Mechanics* came into English in a translation of 1831 by a remarkable woman, Mary Somerville.
   1. Born Mary Fairfax, she was the daughter of an officer in the English navy who took responsibility for her own education in mathematics and natural science.
   2. A second husband, William Somerville, proved to be supportive of her interest in mathematical studies.
   3. Through her husband, Somerville became acquainted with numerous English literary and scientific figures.
   4. She translated and commented on the Laplacian achievement in astronomy, establishing her authority as a scientific figure in Victorian Britain.
   5. Somerville’s characterization of Laplace’s cosmos celebrated science as a support for basic Victorian values.

II. The nebular hypothesis enjoyed supporters and detractors in the first half of the century.

A. Two popular authors championed the nebular hypothesis in Britain.
   1. Laplace’s scheme was given a central place in the *Vestiges of the Natural History of Creation* of 1844.
   2. John Nichol wrote on astronomy and observed that the great truths in astronomy were being discussed in almost every popular periodical, as if they had already become common knowledge.

B. The nebular hypothesis was not without its detractors.
   1. Many regarded it as proof of atheism, because it replaced God as creator with natural law.
   2. Some argued that the supposed primal fluid that made up nebulae was not really a fluid at all.
   3. One of the nebulae that had attracted attention was the Great Nebula in the constellation Orion.
   4. The issue became focused when the Earl of Rosse completed construction of the world’s largest telescope, a gigantic reflector nicknamed the “Leviathan of Parsonstown,” and turned it on Orion in 1845.
5. Lord Rosse’s telescope resolved the grand nebulae into stars. He also was able to show, for the first time, that some nebulae had spiral arms, which he conjectured to be rotating masses of stars.

C. Lord Rosse’s resolution of the Orion nebula did not destroy the nebular hypothesis.
   1. Some, including the author of the famous *Confessions of an Opium Eater*, Thomas De Quincey, regarded Lord Rosse’s resolution of the nebula as the death knell of the nebular hypothesis.
   2. Defenders of that hypothesis, such as John Nichol and Robert Chambers, simply argued that nebulae came in two varieties: those that could be resolved and those that were genuinely nebular fluid.
   3. As a result, the hypothesis continued to be debated throughout the century.

III. Another major discovery in astronomy around the same time involved a new planet.
   A. The only addition to the planets since ancient times had come in the late 18th century, when William Herschel discovered Uranus, whose motion provided the occasion for yet another new planet.
      1. In 1781, William Herschel noticed an object he first took to be a comet. The object had been cataloged before, but its motion had not been detected.
      2. Eventually, Herschel recognized it as a new planet circling the Sun. After several years, astronomers were reasonably sure that they had established the orbit of the new planet, named Uranus for the Greek god of the heavens.
      3. As interest in Uranus waned, it was observed sparingly in the early 19th century.
      4. In 1820, more ancient observations of Uranus were uncovered, and they raised a problem, because they were at variance with the orbit that had been established.
      5. Various hypotheses were offered in the 1830s to account for the difference.
      6. Astronomers settled on the idea that an unknown planet, beyond the orbit of Uranus, was causing it to deviate from the established orbit.

   B. Discovery of the new planet was a story of frustration.
      1. Both a Frenchman and an Englishman took up the problem in the 1840s.
      2. The problem was to identify the mass and position of a planet that would exert the gravitational pull on Uranus to pull it out of its orbit as observed.
      3. Solutions to the problem were offered, but astronomers failed to actually look for the new planet.
      4. The Frenchman Urbain Leverrier wrote to a German astronomer in Berlin, instructing him where to look for the new planet, Neptune.

   C. The discovery of Neptune illustrates several interesting things about natural science at the time.
      1. It confirmed once again the power of science, because Leverrier had deduced the existence of a new planet by making calculations on paper and instructed observers where to look.
      2. The implication was that natural science can unearth nature’s secrets, if one has the ability and patience to employ the methods of science.
      3. It made clear that natural science was not immune to the effect of distinct national rivalries. Leverrier’s discovery was heralded as an example of the prestige of French science.
      4. In an attempt to win credit for English science, John Herschel observed that Adams had had the solution earlier than Leverrier; the French were outraged.

Essential Reading:
Neeley, *Mary Somerville*.

Supplementary Reading:
Grosser, *Discovery of Neptune*.

Questions to Consider:
1. Did the nebular hypothesis promote ideas of organic evolution, or did evolution stimulate interest in the nebular hypothesis?
2. Why might the French and English be particularly sensitive about the respective glories of their scientists in the 1830s and 1840s?
Lecture Thirty-Four
The Extra-Terrestrial Life Fiasco

Scope: At the end of the 18th century, the longstanding consensus that the likely existence of extra-terrestrial life presented no challenge to the historical drama of Christian redemption on Earth was shattered by Thomas Paine. His attack precipitated a spate of responses defending the compatibility of life on other worlds with Christianity. At mid-century, there appeared an anonymous pamphlet on the plurality of worlds, soon recognized to be from the pen of the highly respected natural philosopher William Whewell, master of Trinity College in Cambridge University. Whewell concluded that the uniqueness of the Christian salvation story prohibited its being reenacted elsewhere. This denial of the possibility of extra-terrestrial life for theological reasons, at a time when more and more secrets of the cosmos were being unraveled, set off a furor of reaction.

Outline

I. Last time, we saw the enormous interest astronomers created with their talk of a new planet and the nebular hypothesis.

II. The issue of other worlds and extra-terrestrial life has roots deep in the Western past.
   A. The issue was made particularly significant when the theologian Thomas Aquinas was reprimanded for heretical teachings in the condemnations of 1277.
      1. Aquinas had explored Aristotle’s views, among which was his conclusion that the Earth, being the center of the cosmos, was the only place where life existed.
      2. In 1277, the Catholic Church officially permitted the idea that life might exist elsewhere, a position that Christian theologians before that time had rejected as pagan.
      3. Within 150 years, the question arose whether creatures who lived elsewhere were covered by the redemptive sacrifice of Christ or whether Christ would have to go to other worlds and die again.
   B. Between the medieval period and the end of the 18th century, a consensus emerged among theologians and natural philosophers that extra-terrestrial life was likely.
      1. Reformers and later natural philosophers of the 17th century saw no problem with extra-terrestrial beings.
      2. In the 18th century, the growing field of natural theology embraced other worlds as a testimony to God’s greatness.
      3. Numerous others also regarded extra-terrestrial life as possible, some even as a testimony to God.
   C. Into this comfortable consensus fell the bombshell of Thomas Paine’s Age of Reason of 1793.
      1. Paine mocked what he regarded as a conceit of Christianity to believe in extra-terrestrial life and, at the same time, to insist on the universality of Christ’s redemptive sacrifice.
      2. Paine threw down the gauntlet to Christians: Either give up belief in Christ’s redemptive role, or give up belief in extra-terrestrial life.
   D. The reaction to Paine was quick in coming and lasted for years.
      1. Most reactions were to reassert belief in both Christ’s redemption and the existence of other worlds.
      2. New works on extra-terrestrial life continued to appear over the first half of the century.

III. At mid-century, a new bombshell exploded on the scene.
      1. The author asked what to make of the other worlds science shows to us as far as redemption is concerned.
      2. The author was, in effect, agreeing with Thomas Paine: Either give up universal redemption or give up extra-terrestrial life.
      3. This author chose to give up extra-terrestrial life.
   B. The denial of the existence of extra-terrestrial life was regarded as scandalous by many.
1. When the author of the book was found to be William Whewell, the master of Trinity College, Cambridge, and known defender of natural science, astonishment was everywhere.

2. How could such a progressive figure take such a backward-looking position?

IV. The ensuing debate exposed a variety of opinions on the question.
   A. The great majority appeared to oppose Whewell’s position.
      1. Historian Michael Crowe has determined that 70 percent of the books written during the debate that followed opposed Whewell.
      2. Eighty percent of scientists favored pluralism, thus opposing Whewell.
      3. Even among Anglicans, more than 71 percent opposed Whewell’s conclusion.
   B. Among all religious writers, however, the split was approximately half and half, indicating a sizable group of Victorian society that still had doubts about the existence of extra-terrestrial life.

V. As the century wound down, a new debate over extra-terrestrial life emerged.
   A. The Italian astronomer Giovanni Schiaparelli tested a new telescope’s capacity to observe a planetary surface.
      1. He observed dark lines that he dubbed “channels” (canali), opening a debate on Martian canals that would last into the 20th century.
      2. Schiaparelli favored the view that the channels were natural waterways but did not oppose the idea that they could have been intentionally constructed.
      3. By this time, a growing number of celestial bodies had been eliminated as fit sites of possible life. The new technique of spectral analysis permitted scientists to determine the elements that made up many heavenly bodies.
      4. Although some doubted that the lines on Mars represented anything real, new observations near the end of the century confirmed that the lines were undeniable.
      5. Camille Flammarion in France and Percival Lowell in the United States popularized the notion that Mars could well be inhabited, to the delight of the general public.
   B. Eventually, scientists concluded that the atmosphere of Mars was unable to support life, with the possible exception of microbes or primitive plants.
   C. Nevertheless, belief in the possibility of extra-terrestrial life has continued unabated to the present day and is now as strong as ever.

Essential Reading:
Crowe, Extraterrestrial Life Debate, chapters 5–7, 10.

Supplementary Reading:
Whewell, Of the Plurality of Worlds.

Questions to Consider:
1. Why has the history of concerns with extra-terrestrial life been intimately associated with the history of religion?
2. Given that consideration of extra-terrestrial life has never depended on an actual encounter with other life forms, it is really a reflection about ourselves. What does this story from the 19th century tell us about ourselves as human beings?
Scope: At the beginning of the 19th century, Thomas Young in England and Augustin Fresnel in France successfully employed a wave conception of light to describe aspects of its behavior. Later in the century, the Scotch physicist James Clerk Maxwell envisioned electrical and magnetic effects as the result of rotations in an imponderable medium of great elasticity and subtlety believed to permeate the whole of planetary and stellar space. His mathematical description of the distortions took the form of wave equations that not only provided a new level of clarity about electricity and magnetism but also led to the discovery of startling results about light and the development of an entire spectrum of electromagnetic radiation. Measurements of light’s speed occurred in the 1880s when Albert Michelson improved a technique of Jean-Bertrand-Léon Foucault. This he repeated later, with Edward Morley, in an attempt to explore the role of Maxwell’s ether in transmitting light. The surprising results sharpened the question about the status of hypothetical models, because the ether possessed properties that defied the imagination. Did the ether really exist?

Outline

I. We ended our investigation of the question of extra-terrestrial life with sensational claims about life on Mars.
   A. By the end of the 19th century, telescopes had improved to the point at which distinct features on Mars could be detected.
      1. The meaning of these features was, of course, subject to a great diversity of opinion.
      2. But telescopes could focus light from distant objects better than ever before.
   B. The question of what light itself was and how it moved had been the subject of inquiry since the Middle Ages.
      1. In the 17th century, a Danish astronomer, Olaus Roemer, demonstrated that the speed of light was not infinite, as some had assumed.
      2. In the same century, René Descartes explained light as pulses, or waves in a medium that existed between the object and the eye, that were propagated by mechanical means.
      3. Newton believed, however, that this pulse theory of light could not account for a newly discovered property—polarization.
      4. By the beginning of the 19th century, no consensus had emerged about the best explanation of what light was.
   C. In this lecture, we will see that this changed with the establishment of a new wave theory.

II. In the early years of the 19th century, the wave theory of light received new backing.
   A. The English physician Thomas Young was a remarkable man, whose interests and abilities carried him well beyond the medicine he practiced for a living.
      1. He was broadly educated in languages, including some ancient languages of the Near East, and played a key role in deciphering the ancient Egyptian writing known as hieroglyphics.
      2. As a physician, he was curious about the connection between the body and sensation.
      3. In 1801, he set out to conduct his own experiments in the investigation of what light was.
   B. Young did an experiment from which he concluded that light was made of waves, but not the kind of waves Descartes had envisioned.
      1. He passed a beam of light through two holes and examined how the emerging light fell on a screen.
      2. What he saw was a pattern of bright and dark regions, something that did not make sense if light consisted of a ray of particles, as Newton imagined.
      3. Young imagined that light moved through an ethereal medium that existed between an object and the eye, somewhat like waves moving through water.
      4. He then explained the bright regions of the pattern he observed as the places where the crests of the waves emerging from the two slits coincided and the dark regions as the places where the crest of one wave coincided with the trough of another, thus canceling each other.
      5. Young figured out a way to explain polarization using his waves, as well.
C. Young’s wave theory was developed and confirmed in France during the second decade of the century.
   1. Augustin Fresnel provided a mathematical description of how waves could be used to explain the way light bends around obstacles.
   2. Fresnel’s mathematical wave theory implied that a small disk placed in the path of a beam of light would cause the light to bend around the edges and converge toward the center to produce a bright spot in the middle of the shadowed region, an implication that was confirmed in 1818.
   3. Light would be regarded as waves in the ether for the remainder of the century.

III. In the middle of the century, James Maxwell discovered something new about light while trying to decipher why electricity and magnetism were related, as Oersted, Ampère, and Faraday had found them to be.
   A. We saw the basics of electromagnetism back in Lecture Twenty-Six.
      1. The work of Oersted, Ampère, and Faraday uncovered various aspects about the intimate relationship between electrical and magnetic force.
      2. But no one felt that they understood why this relationship existed.
   B. In 1860, Maxwell made a mechanical model that related electrical and magnetic force.
      1. He visualized the relationship between electrical and magnetic force in a current-carrying wire as a mechanical interaction between parts of an ethereal substance.
      2. He postulated that there were rotating vortices or eddies in this ether that penetrated the wire and that they were separated by tiny spheres rotating in the opposite direction to act as ball bearings between the vortices.
      3. The circular-acting magnetic forces were represented by the rotating vortices, while the electrical charges were represented by the little ball bearings.
      4. Because the system was interlocked, rotating motion in one produced motion in the other.
      5. Maxwell generalized his result by suggesting that the ether, which was present in but not confined to the wire, had vortices and ball bearings everywhere, not just when it penetrated the wire.
      6. This implied that, just as rotating magnetic vortices produced electrical force in the ball bearings of the ether in the wire, they could also do the same in regions of space where no wire was present.
      7. In space, these changes produced electromagnetic waves traveling through space and appeared as a real current if a wire or conducting substance was encountered.
      8. Maxwell proceeded to depict his mechanical model in a series of mathematical equations.
   C. Maxwell’s model and the equations that arose from it held several revealing implications.
      1. The equations depicting the model were equations that described waves.
      2. His theory predicted that these waves shared properties of light waves—they could be reflected and refracted by appropriate substances.
      3. Startlingly, Maxwell’s theory predicted that the electromagnetic waves would travel at about $3 \times 10^8$ m/sec, the speed that a French physicist had recently calculated light to travel!
      4. Maxwell concluded that light consisted in the transverse waves of the same medium that was the cause of electric and magnetic phenomena.
   D. Developments after Maxwell confirmed that his theory represented a fundamental insight, although it took some time for confirmation to come.

IV. Maxwell’s theory, although successful, also introduced problems.
   A. This occurred when Albert Michelson and E. W. Morley attempted to confirm the relative velocity of the Earth through the ether in 1887.
      1. Assuming that the Earth created a “wind” as it traveled through the ether, they sent two beams of light from one point in the direction of the wind and perpendicular to that direction.
      2. Both beams were reflected back to the point, where they were expected to arrive at slightly different times because of the differing effects of the ether wind on their journeys.
      3. The interference pattern produced was expected to change as the perpendicular beams of light were placed in different orientations, but no difference in the interference pattern was detected.
      4. Some assumed that the ether was dragged along with the Earth, an idea that was discredited by experiments.
      5. Scientists were left with a conundrum: The ether was neither stable nor moving with respect to the Earth!
B. The other problem was that properties of the ether were hard to grasp.
   1. Light could be blocked by matter. Yet, as electricity and magnetism showed, the ether penetrated wires and other conducting matter.
   2. It turned out that the elasticity of the ether had to be greater than that of steel.
   3. The overarching question for those immersed in an age of Realism was: Is there really an ether with vortices and wheel bearings as Maxwell originally envisioned?
   4. If it was only a heuristic model, why did it work so well in explaining electricity and magnetism and in uncovering their relationship to light and other kinds of radiation?
   5. It is an old problem: How realistically is the scientist to take the model?

C. As the century concluded, the problems that had been mounting were overlooked in favor of the incredible advances that had been made.

Essential Reading:

Supplementary Reading:

Questions to Consider:
1. If modern-day physicists no longer accept the existence of an ether yet do accept electromagnetic waves, what for them is waving?
2. Given the contradictions that existed in the highly successful program of classical physics, is it reasonable for scientists to insist that their explanations possess complete coherence?
Lecture Thirty-Six
The End of Science?

Scope: As the 19th century neared its end, the accumulation of recent, startling achievements concerning matter, force, and energy, plus the new ideas about life and its past, confirmed in the minds of some scientists that their mechanical understanding of nature was closing in on a complete description of the material world. In this lecture, we will summarize the worldview that had emerged over the two centuries since the beginning of the course and indicate the warning signs that would soon, in the work of Max Planck and Albert Einstein, deflate the overconfidence and naïveté of the late 19th century.

Outline

I. In the last lecture and throughout this series, we have seen a number of occasions when scientists encountered results that appeared to be inconsistent with the mechanical model of nature they had been perfecting.
   A. Most of the warning signs that the so-called Newtonian world machine was insufficient were associated with electromagnetism and heat.
   B. The problem was that all of these innovations, although they led to problems, worked! They permitted scientists to explain more and make accurate predictions.
      1. Scientists certainly learned to understand a great deal about electricity, magnetism, and light as a result of them.
      2. They also applied what they learned to make electrical machines that began to supply useful energy to society.
      3. Revolutions in communication and lighting were visible evidence of the value of what scientists had learned.
      4. As a result, scientists did not tend to regard the inconsistencies and paradoxes they encountered as fundamental problems.
   C. In this lecture, we’ll look at the growth of the confident attitude about natural science, based on what had been achieved, that appeared among some in the late 19th century.
   D. We’ll end the course with two developments that would challenge this confidence at its core.

II. Accomplishments over the course of the 19th century formed the basis for a growing confidence about the power of natural science.
   A. We’ve seen reason for this confidence in the biological sciences.
   B. The situation was the same in the physical sciences.

III. Some scientists became so confident that they felt they had the tools to finish the work of understanding nature.
   A. They reflected their belief, typical of the Realism of the day, that scientific theory was able to depict nature as it really is.
      1. Some were impressed with how far natural science had come when compared to human understanding of nature in the past.
      2. They were confident that science had identified a method, based on careful observation and experimentation, that would lead humankind ever closer to nature’s truth.
      3. The cosmos was the clockwork universe ruled by deterministic law.
      4. To these scientists, explaining something scientifically meant to take apart nature’s machinery to see how it worked.
      5. Given the success of mechanical models in kinetic theory and electromagnetism, they were confident that persistent problems would someday be resolved.
      6. The unifying power of the concepts of energy and the field convinced many that physical science might be coming to its end.
   B. Confidence in mechanistic natural science grew to impressive levels in some circles during the late 19th century.
1. In 1887, the soon-to-be president of the American Association for the Advancement of Science predicted that no great, original, and far-reaching discoveries or novel and almost revolutionary applications lay ahead.
2. In 1894, Albert Michelson suggested that physicists basically understood the laws of nature. What was left was to make them more precise.
3. Some theologians shared this image of science nearing its end.

C. Not everyone shared this naïve confidence in mechanistic science.
   1. Maxwell, although he certainly believed in an ether that possessed mechanical properties, was hesitant to embrace his particular model of the ether as something that actually existed.
   2. Such physicists as Ernst Mach and Pierre Duhem and the mathematician Henri Poincaré began to reevaluate the nature of scientific theory, each moving away from the simple claim that theory represented nature as it really was.
   3. And there always were those warning signs we’ve identified; these may not have been consciously noticed, but they were, at least, recorded in the sub-consciousness of scientists.
   4. Clearer were inconsistencies about the ether that Michelson and Morley had exposed that could not be easily explained.
   5. Such men as Lord Kelvin referred in 1901 to the “clouds” that hung over physical theory.

IV. As the new century dawned, two major developments, quantum theory and relativity, exposed the overconfidence of these scientists as premature and challenged the foundations of the age of Realism.
   A. The work of the physicist Max Planck challenged a fundamental assumption of 19th-century physics, that is, that changes in energy (when it is given off or taken on) occur continuously.
      1. Our perception of natural processes that, for example, require energy to occur is of smooth or continuous change.
      2. In accounting for the energy radiation that occurs when a body is heated from lower to higher temperatures, it was assumed that the variations of output observed occurred smoothly or continuously.
      3. No one, however, was able to give a complete account of the energy pattern from low to high temperatures. The middle-range temperatures were especially problematic.
      4. Planck eventually solved the problem, but his solution involved abandoning the assumption that energy had to be radiated continuously.
      5. He introduced the idea of quanta, or permissible discrete amounts of energy, in his successful description of the overall energy pattern.
      6. If nature behaved the way Planck described it in this context, then an object seemed to disappear from its first position and reappear at a second position.
      7. When Planck’s idea of quantizing energy found applications in other areas of physics, physicists began to take seriously that perhaps nature did indeed behave in such a bizarre fashion.
      8. Gone was the intuitive idea that nature was a deterministic machinery whose laws were within our grasp.

B. Albert Einstein’s insistence that the laws of electromagnetism were not exceptional led to another major revolution in our view of nature.
   1. His real motivation was concern to show that the laws of electromagnetism were not inconsistent with the laws of motion.
   2. Einstein imagined what the world would look like if he rode on a beam of light by which we obtain information about the world.
   3. If he traveled as fast as light, he would not be able to see anything ahead of him because the light could not get ahead of him to be reflected back from objects.
   4. Because that would happen only when he was going the speed of light, he had a test that would tell him absolutely that he was not at rest.
   5. But the law of inertia said that motion was relative, that one could not tell absolutely if one were moving, only that one was moving with respect to something else.
   6. Thus, the laws of electromagnetism and of moving bodies were at variance with each other, something Einstein did not want to be.
7. To ensure the consistency of all the laws of physics, Einstein declared that light’s speed was absolute, that it would not show differences from one observer to another.

8. This meant that light’s speed did not change to accommodate different frameworks of space and time, but that space and time changed to accommodate the constancy of light’s speed.

9. The idea of changing space and time presented the world of 19th-century physics with its second example of a “great, original, and far-reaching discovery” that had been declared impossible in 1887.

C. The erosion of a comfortable Realism in natural science was accompanied by other breakdowns of Realism around the turn of the new century.
1. Realism in art and literature gave way to new forms that did not strive to depict the world as it really is.
2. In the world of politics and diplomacy, things were beginning to go awry, only to collapse with the outbreak of world war.

D. The decline in the mechanical world picture of the clockwork universe into the exciting and wide-open world of relativity and quantum theory merely confirms an old lesson from the history of science: Natural science is a continuing adventure, in which one ought never to assume that the last word is even close to being spoken.

Essential Reading:
Purrington, Physics in the Nineteenth Century, chapters 8–9.
Cline, Men Who Made a New Physics, chapters 3–5.

Supplementary Reading:
Holton and Brush, Physics, the Human Adventure, chapter 26, pp. 388–398; chapter 30, pp. 462–464.

Questions to Consider:
1. Just as at the end of the 19th century, the end of the 20th century also saw declarations of “the end of science.” Why do these sentiments periodically appear? Is their appearance at the end of centuries significant?
2. Do you think that quantum theory and relativity will ever be abandoned as either incorrect or severely limited approaches?
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 Maillot’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; Paine’s *Age of Reason* attacks Christianity’s acceptance of extra-terrestrial 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............................... Helmholtz’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 the fifth edition of the Origin, but was never satisfied with it as a replacement for “natural selection.” Darwin’s use of the phrase blurred the very real distinction between his understanding of evolution and Spencer’s, especially where the implications for society were concerned.

Theory of the Earth: Speculative theories of causal agencies of terrestrial change, such as those offered by de Maillot (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 mv², 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:**


———. *Charles Darwin: Voyaging*. Princeton: Princeton University Press, 1995. Called the definitive Darwin biography by some, this first volume covers the period in Darwin’s life up to (but not including) the publication of *The Origin*.


Greene, Mott T. *Geology in the Nineteenth Century*. Ithaca: Cornell University Press, 1982. Although primarily concerned with the period after Hutton and Werner, the author does use a revised understanding of their work as a background for his later considerations.


Laudan, Rachel. *From Mineralogy to Geology: The Foundations of a Science, 1650–1830*. Chicago: University of Chicago Press, 1987. One of the few studies to include the German mineralogical community of the 18th century, this work was a major contributor to a revised understanding of the role of Werner in the history of geology.


**Supplementary Reading:**

Badash, Lawrence. “The Completeness of Nineteenth-Century Science,” *Isis*, 63 (March 1972), pp. 48–58. Documents the notion that some physicists believed that physics was nearing an end as the century came to a close.


Burchfield, Joe D. *Lord Kelvin and the Age of the Earth*. Chicago: University of Chicago Press, 1990. Careful analysis of Kelvin’s debate with Lyell and the evolutionists about the differing estimate of available time for evolution to have taken place from thermodynamical considerations and that of evolutionary theory.


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.


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.
