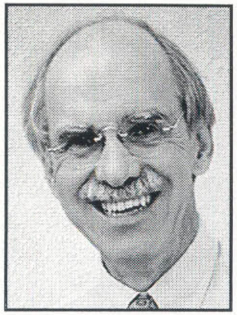

Professor Frederick Gregory is Professor of History of Science at the University of Florida, where he has taught for 25 years. He holds a seminary degree from Gordon-Conwell Theological Seminary, a Master's degree from the University of Wisconsin, and a Ph.D. from Harvard University in the history of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

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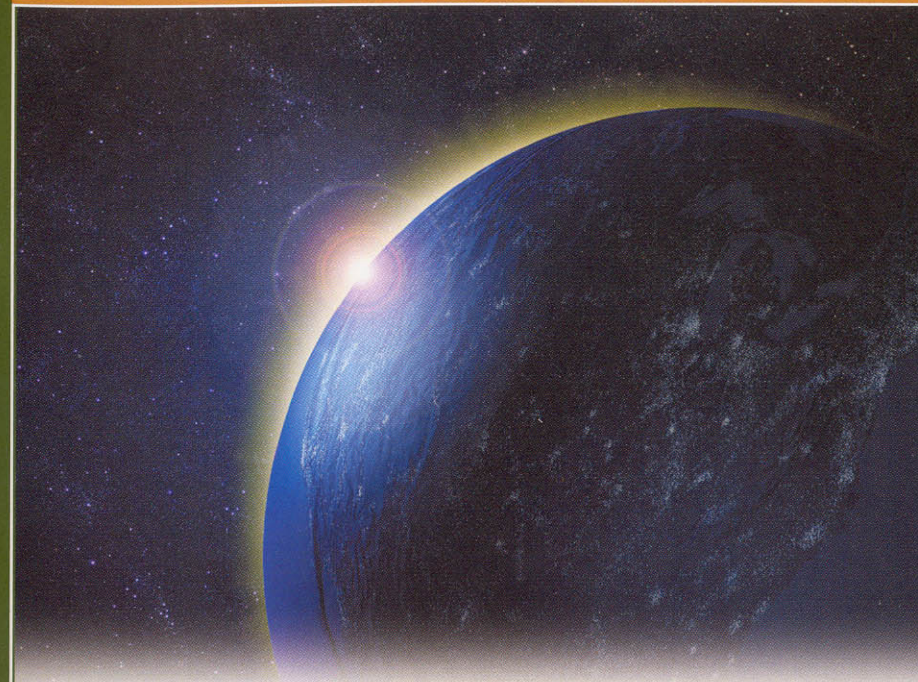

The History of Science: 1700-1900

Taught by: Professor Frederick Gregory,
University of Florida

Part 2

Course Guidebook

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Part II
"Life and Its Past"

The History of Science: 1700–1900

Scope:

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

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

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

Lecture 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 superceded 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 Karlsschule near Stuttgart.
      2. In February of 1793, Kielmeyer addressed an assembly at the Karlsschule 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:

Richards, *Romantic Conception of Life*, chapter 6.

Supplementary Reading:

Lenoir, *Strategy of Life*, chapter 1, pp. 37–53; chapter 2, pp. 54–61.

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 *super*natural, 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?

Lecture Fifteen

A World of Prehistoric Beasts

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 19^{th} 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:

Rudwick, *Georges Cuvier: Fossil Bones and Geological Catastrophes*, chapters 2–4, 11, 13–15.

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 after1789.

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 19^{th} 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:

Burkhardt, *Spirit of System*, chapters 6–7.

Supplementary Reading:

Jordanova, *Lamarck.*

Questions to Consider:

1. Lamarckian evolution proved to have great staying power throughout the 19^{th} and well into the 20^{th} century. What about it was so attractive?
2. Did Lamarck represent more of an 18^{th}- or a 19^{th}-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:

Botting, *Humboldt and the Cosmos*, chapters 8–13.

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:

Secord, *Victorian Sensation*, chapters 1–5.

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:

Browne, *Charles Darwin: Power of Place*, part I.

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 19^{th} 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.
  2. Many French thinkers failed to appreciate the role of natural selection.
- **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:

Bowler, *Evolution*, chapter 10, pp. 285–291.

Supplementary Reading:

Gregory, *Scientific Materialism in Nineteenth-Century Germany*, chapter 9.

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:

Lindberg and Numbers, eds., *God and Nature*, chapter 15.

Supplementary Reading:

Gregory, *Nature Lost?*, chapters 1 (pp. 17–23), 4–5, 7.

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?

1797 .... Schelling's *Ideas for a Nature Philosophy* opens his program to move beyond Kantian limits of knowledge.

1800 .... Volta invents the *pile*, or battery; von Humboldt departs for a four-year scientific expedition to explore the new world; Herschel discovers infra-red "light."

1802 .... Playfair and Murray champion Vulcanism and Neptunism, respectively; Young's first slit experiments establishing the wave theory of light.

1806 .... Goethe formulates his critique of Newton's theory of color.

1807 .... Dalton's *New System of Chemical Philosophy* revives interest in atoms.

1809 .... Lamarck's *Zoological Philosophy* lays out a systematic theory of evolution.

1811 .... Avogadro distinguishes atoms of an element from molecules, which may have more than one atom of an element.

1812 .... Cuvier elaborates his theory of catastrophes to explain the history of fossils.

1817 .... Founding of *Isis* by Oken, one of the first journals of natural science intended to educate the public.

1818 .... Fresnel's prediction of a bright spot based on the wave theory of light shown correct.

1820 .... Oersted discovers electromagnetism as a "circular" force surrounding a current-carrying wire; Ampère interprets magnetism as electricity in motion.

1822 .... Founding of the first modern scientific society, the German Society for Natural Investigators and Physicians; Fourier's theory of heat, in which heat flow is irreversible, is finally published after several years of unacceptance.

1823 .... Buckland's analysis of cave fossil remains brings the Earth's physical past into the study of world history.

1824 .... Carnot's theoretical analysis of the steam engine opens a new science of thermodynamics.

1831 .... Darwin leaves for a five-year trip around the world on HMS *Beagle*; Faraday demonstrates that cutting magnetic lines of force produces electricity; founding of the British Association for the Advancement of Science, modeled on the earlier German society; Somerville's translation of Laplace's *Celestial Mechanics.*

1841 .... Feuerbach's *Essence of Christianity* argues that religious doctrines are projections of human needs.

1842 .... Mayer's paper on the indestructibility of force.

1843 .... Joule begins experiments that will show that heat has a mechanical equivalent; the Great Disruption of the Scottish Church divided those unhappy with modernism from those happy with the latest science.

1844 .... Anonymous publication of the sensational book *Vestiges of the Natural History of Creation*; Darwin tentatively shares his ideas on transmutation with Lyell and Hooker.

1845 .... World's largest telescope resolves the nebula in Orion into stars, a blow to the nebular hypothesis.

1846 .... Vogt's *Physiological Letters* portrays thought as a secretion of the brain; Leverrier successfully predicts the location of a new planet, Neptune, winning the race with English astronomers.

1847 .... Helmholz's classic announcement of the conservation of force.

1848........Revolution breaks out in Paris, followed later by revolutions in other European capitals.

1850........Clausius agrees that heat has a mechanical equivalent but argues that it is proportional to the fall in temperature—not all heat is converted into work; Moleschott's *Theory of Nutrition: For the People* continues to popularize scientific materialism.

1851........Thomson affirms that "energy" cannot be lost but that it can become unavailable to humans.

1853........Whewell's *Of the Plurality of Worlds* shocks Britain with its rejection of extraterrestrial life.

1854........Helmholtz describes the heat death of the universe to a Königsburg audience.

1855........Büchner's *Force and Matter*, the Bible of scientific materialism, appears.

1857........Spencer articulates his *laissez faire* application of general evolutionary ideas to social and political questions; Clausius's use of statistical means to measure speed of molecules advances study of the kinetic theory of gases.

1859........Darwin, whose hand was forced by a letter from Wallace containing ideas similar to his own, rushes his *Origin of Species* into print.

1860........Maxwell's mechanical model relates electrical and magnetic phenomena. A mathematical depiction of the model led to the incorporation of light as an electromagnetic phenomenon.

1861........Thomson begins his critique of evolution on thermodynamic grounds.

1864........Pasteur critiques Pouchet's defense of spontaneous generation based on experiments.

1867........Jenkin's review of *Origin* raises major problems with Darwin's theory.

1869........Mendeleev arranges elements according to atomic weights in a periodic table.

1870........Büchner's ideas on evolution and society attempt to merge individual freedom and social responsibility; German states unite into a nation under Prussian leadership.

1872........Hodge's *What Is Darwinism*? answers that it is atheism.

1877........Schiaparelli's map of Mars identifies "canals" on the surface.

1879........Herrmann calls for the radical separation of science from religion, arguing that neither supplies metaphysical truth.

1881........Pasteur dramatically demonstrates a vaccine for anthrax; in 1885, he cures two patients with a vaccine for rabies.

1887........Michelson collaborates unsuccessfully with Morley to measure the relative velocity of the Earth through the ether.

1894........Michelson predicts that no original far-reaching discoveries in physics will be made over the next hundred years.

1900........Planck introduces the idea that energy is radiated and absorbed in discrete amounts he called *quanta*.

1905........Einstein formulates his theory of special relativity.

Glossary

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Pluralism: Belief in the existence of other worlds.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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 Maillet, Benoit (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 Maillet'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 18^{th} 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 19^{th} 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 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.