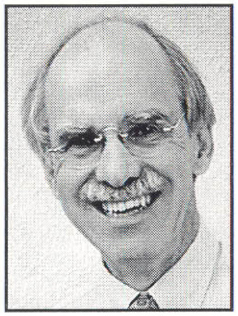

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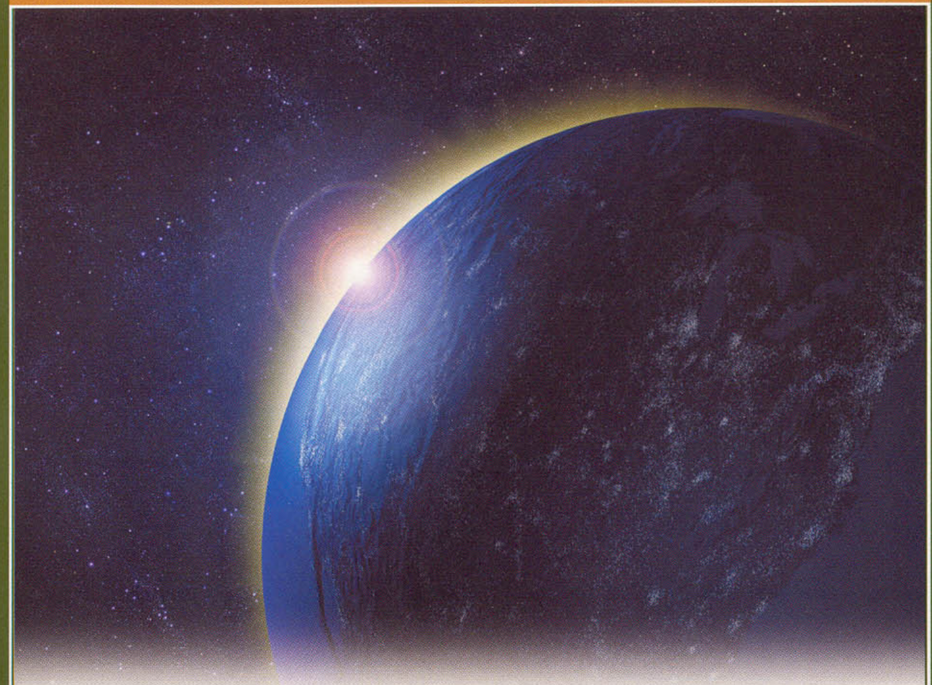

The History of Science: 1700-1900

Taught by: Professor Frederick Gregory,
University of Florida

Part 3

Course Guidebook

THE TEACHING COMPANY®

Frederick Gregory, Ph.D.

Professor of History of Science, University of Florida

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

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

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

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The History of Science: 1700–1900

Part III

"Physical Science and Culture in the 19th Century"

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 extra-terrestrial life erupted before a public already fascinated with the latest observations of new and extremely powerful telescopes. If electromagnetism had introduced curiosities earlier in the century, it continued to mystify in James Maxwell's treatment at mid-century. Not only was light somehow involved, but experiments conducted in the wake of Maxwell's work just did not make sense. Nevertheless, the amazing accomplishments of physical scientists during the century permitted some not only to be undaunted but to predict confidently that the end of science was near. Developments at the end of the century showed, however, that natural science is an ongoing enterprise much bigger than the outlook of any specific era.

Lecture Twenty-Five

Forces, Forces Everywhere

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

Outline

I. With this lecture, we enter our final series of lectures in the course, "Physical Science and Culture in the 19th Century."

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

II. We begin our consideration of physical science and culture in the 19th century with a look back at the old theological problem of God's relation to the cosmos.

A. In his *Principles of Philosophy*, Descartes had asserted that because God was unchangeable, he "conserves the world in the same action with which he created it."

1. With this idea of "action," Descartes gave to natural philosophy a problem that would take a long time to solve, but that contained dividends rich beyond anyone's imagination in the 17th century.
2. The problem Descartes uncovered was: If all the individual actions in the world always add up to the same total, how are we to think about these individual actions?

B. How did Descartes measure what he called the "quantity of motion" of a given piece of matter?

1. He reasoned that it depended on two factors: how big the matter was and how fast it was moving.
2. In a collision, whatever velocity was given *up* by one piece of matter was given *to* the other one; thus, the total sum of the masses times their velocities remained the same.

C. Adjustments to this view soon cropped up.

1. What happens if two equal blobs of clay move directly toward each other at equal velocities?
2. When they collide, they do not rebound at the same velocity but stick together, and the motion, as well as the motive force, is lost. It would appear that the total sum of motion and motive force has been diminished because the velocities, being opposite in sign, cancel each other.
3. The German Gottfried Leibniz published a critique of Descartes's view in 1686.

D. Although Leibniz did not convince everyone right away, his *vis viva* shifted the focus of the issue.

1. Leibniz was thinking of a different kind of measure of motive force. The focus was on the *effect* the moving object produced, not just the force, the push or pull, it exerted.
2. Natural philosophers continued to argue about the precise nature of the motion and motive force that God would not permit to erode away.

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

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

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

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

D. Light became the subject of renewed interest around this time, as well.

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

E. These many connections among forces raised the question about how they might all be interrelated.

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

Essential Reading:

Hankins, *Science and the Enlightenment*, chapter 2, pp. 28–37.

Supplementary Reading:

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

Questions to Consider:

1. If, for 17th-century natural philosophers, God's immutability was the ultimate guarantee that mechanical force was conserved, what guarantees later laws of conservation?
2. What is the relationship, historical and conceptual, between the search for unity among nature's forces at the beginning of the 19th century and that present in the contemporary dream of unifying nature's four fundamental forces?

Lecture Twenty-Six

Electromagnetism Changes Everything

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

Outline

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

II. In fact, this question was not confined to those who saw themselves as investigators of nature. It was also a major concern among the nature philosophers we met in Lecture Fourteen.

- **A.** There, we met Friedrich Schelling, who rejected the notion that nature was a machine in favor of viewing it as an organism.
    1. An implication of this viewpoint was that all of nature was an organized interdependent unity, held together by a world soul, just as the human organism is a coherent whole unified by a human soul.
    2. This meant that all of nature's forces were interrelated, as well, because they were all parts of the larger organized whole.
    3. Where electricity and magnetism were concerned, Schelling taught specifically that, philosophically speaking, they were one and the same dynamic activity.
    4. Schelling's basic approach inspired those who were influenced by his thought to be ready to find interconnections among nature's forces.
- **B.** One important figure who was influenced by German philosophy was the Danish natural philosopher Hans Christian Oersted.
    1. Soon after earning a doctoral degree in philosophy in 1799, Oersted made an extended trip to Germany and France, where he met Schelling.

    2. Oersted appreciated Schelling's insistence that all of nature must be regarded as an organized whole that was able to be grasped by our reason.
- **C.** Oersted became interested in pursuing the link between electricity and magnetism.
    1. Oersted persisted in this endeavor after he returned to Denmark and became a professor of chemistry in 1806 in Copenhagen.
    2. Oersted showed that if current flowed through a wire, then a *circular* magnetic force existed around the wire. That was not like Newton's forces, which acted in straight lines.
    3. Oersted's discovery caused a great stir and stimulated other experimenters to investigate this strange circular force.
    4. Oersted's appeal to nature philosophy to explain what he'd discovered was not persuasive to most of his contemporaries.

III. Two different approaches to understanding how electromagnetism was produced emerged soon after Orested's announcement.

- **A.** One was presented by André Marie Ampère, who prior to 1820, had established a modest reputation in French scientific circles through work in chemistry and mathematics.
    1. Ampère assumed that any force, magnetic or otherwise, could not really act along a circular path, as Oersted's description of the magnetic force around the current-carrying wire seemed to indicate.
    2. Rather, like all the forces known up to that time, Oersted's apparent circular magnetic force had to be the resultant sum of central forces.
    3. Ampère wound a current-carrying wire around a bar of iron and found that he could *create* a magnet in the iron bar.
    4. Ampère came to the conclusion that magnetism was electricity in motion.
    5. Ampère suggested that even in the case of a permanent bar magnet, there was electricity in motion. He postulated that there was a circular flow of electricity *around each molecule of the iron.*
    6. Ampère wrote the complicated mathematical equations that described the forces that moving electricity exerted. He assumed the forces acted in straight lines perpendicular to the direction of the current's flow.
    7. His achievement marks the beginning of *electrodynamics*—the forces produced by electricity in motion.
- **B.** A completely different approach to the phenomena of electromagnetism was taken by Michael Faraday in England.
    1. Where electromagnetism was concerned, Faraday simply accepted the notion that some forces in nature may act along curved rather than straight lines.

2. Faraday produced lines of magnetic force using one wire, then used them to try to produce an electrical current in a second wire.
3. He found that electrical current was produced when the magnetic lines of force were interrupted, which he learned to do by physically moving a bar magnet that had been wrapped with a wire.

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

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

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

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

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

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

Essential Reading:

Purrington, *Physics in the Nineteenth Century*, chapter 3, pp. 32–55.

Wilson, "Introduction," in Jelved, *Selected Scientific Works*, pp. xv–xl.

Supplementary Reading:

Oersted, "Experiments on the Effect of the Electric Conflict on the Magnetic Needle," in Jelved, *Selected Scientific Works*, pp. 413–416.

Williams, *Origins of Field Theory*, chapters 1–2.

Questions to Consider:

1. Faraday's and Ampère's approaches to electromagnetism were vastly different, yet from each came productive continuing research programs. What complementary aspects of natural science were they addressing?
2. Do you think it merely coincidental that both Faraday and Ampère were extremely religious men in their private lives?

Lecture Twenty-Seven

French Insights About Heat

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

Outline

I. The inventions made possible by electromagnetism contained an interesting question about the interrelationships among forces.

A. In a generator, by turning a coil of wire mechanically, one can obtain electrical current.
1. Is mechanical force here merely *made use of* to produce the electrical force of a current?
2. Or is mechanical force converted to, does it *become*, electrical force?

B. In an electric motor, one starts with electrical current and ends up with the rotating mechanical motion of the armature.
1. Here, is the electrical force of the current merely made use of in obtaining the mechanical rotation?
2. Or does the electrical force become mechanical force?

II. The use of heat to obtain motive force was centered on the invention of the steam engine.

A. The steam engine was a major symbol of the shift from animal power to inanimate power that accompanied industrialization.

B. The invention of the steam engine is an example of technology leading science.

III. Among the first to consider heat from a theoretical, as opposed to a practical, point of view was the French mathematician Joseph Fourier.

A. Born into humble social status in 1768, Fourier exhibited natural sympathies for the Revolution when it came.

1. He survived the Revolution and became a teacher at the newly established École Polytechnique, where he soon acquired an important position in mathematics.
2. He was a technical adviser to Napoleon for the famous expedition to Egypt that Napoleon undertook in the summer of 1798 and was later Napoleon's appointed prefect of Grenoble.

B. During the first decade of the 19th century, Fourier devoted himself to the study of heat; in particular, he investigated how heat flowed through solid bodies.
1. The brilliance of the mathematical techniques he developed to express his results was not recognized until later.
2. Like Oersted, Fourier introduced a non-Newtonian element into physics. In his case, the laws he formulated for the conduction of heat implied that heat flow was not reversible.

IV. Another Frenchman around this time had also become fascinated by the theoretical study of heat—this time, in the steam engine.

A. Sadi Carnot received the benefit of an excellent education from his father.
1. His father, Lazare Carnot, had been a member of the Directory and active in various representative bodies during the French Revolution.
2. Sadi completed his studies in engineering and entered the military.

B. Carnot wanted to know answers to some important practical questions about heat engines:
1. Was there was a maximal amount of motive force that could be obtained using a certain amount of heat?
2. Were some substances better than others in producing a given amount of motive force?

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

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

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

A. Carnot thought of the production of motive force from heat as nature's response to a disturbance in a normally balanced state.
1. Carnot viewed the steam engine as another way of disturbing a normal state, then presenting nature with an opportunity to restore the original state.

2. The heat engine he imagined was an ideal engine; that is, he did not consider heat lost by conduction or by friction of the moving parts, which were viewed as weightless.
3. Carnot did not commit himself in his book to a particular view of what heat was, but his readers took him to mean that heat was a weightless fluid called *caloric*, which was present in or attached to all matter.

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

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

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

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

Essential Reading:

Purrington, *Physics in the Nineteenth Century*, chapter 4, pp. 75–88.

Supplementary Reading:

Marks, *Science and the Making of the Modern World*, chapter 4.7.

Carnot, *Reflections on the Motive Power of Fire*.

Questions to Consider:

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

Lecture Twenty-Eight

New Institutions of Natural Science

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

Outline

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

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

1. There were those, such as Georges Cuvier, who insisted on gathering empirical information, from which generalizations about nature could be formed, as the primary responsibility of the investigator of nature.
2. In the German states, nature philosophers urged that the mere accumulation of information about nature was seeing nature only from the outside, when one also needed to include the special knowledge humans possessed because they were a part of nature.
3. In France, Jean-Baptiste Lamarck complained that the mere gathering of facts ignored the need to bring ideas *to* the interrogation of nature.

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

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

2. With the final defeat of Napoleon in 1815, Europe tried to put itself back together.
3. To complicate the situation, the continuing Industrial Revolution provided its own disruption of the social order and contributed to the working class's increasing awareness of its own unfavorable circumstances.
4. Accompanying all this was the emergence of what has been called a *public sphere* in the middle class, a defining feature of which was the acknowledgment that argument, not status, should determine authentic social authority.
5. It is in this fluid situation that a new idea of a scientific community began to take shape.

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

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

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

1. Although the focus of the articles was natural science, political issues began to appear, as well, forcing the authorities to intervene.
2. Oken was given a choice: Cease publication of *Isis* or lose his professorship at Jena University.

III. The founding of a society for natural science greatly accelerated the congealing of a scientific community.

A. Up to this point, gatherings of those interested in the study of nature were local groups, often with a narrow focus within the natural sciences.

1. Exceptions, of course, were the Royal Society in England and the Academie des Sciences in France.
2. But these were exclusive societies, not open to anyone interested in natural science.

B. Again, Lorenz Oken took the lead in creating a new society for German science.

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

C. The idea of a national society with an annual conference open to all was a tremendous success.

1. The 1828 meeting was held in Berlin, where the king of Prussia attended an evening social occasion of some 1,200 people.
2. Although not yet professionalized, those who pursued research in natural science had acquired a greater social visibility than they had ever had before.

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

A. During the 1820s in Britain, there was concern that Britain was falling behind in natural science.

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

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

C. As in Germany, the new society focused attention on an emerging social identity.

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

Essential Reading:

Purrington, *Physics in the Nineteenth Century*, chapter 2, pp. 9–19.

Supplementary Reading:

Thackray and Morrell, *Gentlemen of Science*, chapter 2.

Questions to Consider:

1. How were the new institutions of natural science discussed here different from older associations, such as the British Royal Society and the French Academie des Sciences?
2. How would you characterize what the new name *scientist* connoted that was not captured by the older term *natural philosopher*?

Lecture Twenty-Nine
The Conservation of What?

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

Outline

I. The new institutions of natural science and the emerging identity of the natural scientist we encountered in the last lecture occurred on the eve of a period of major scientific achievement.

A. One key episode in the natural science of this period was the development of ideas about what would eventually be called *energy*.

B. This story illustrates one of history's ironies.

1. One of the historians who has written about this subject is Thomas Kuhn, whose central concern revolved around the idea that energy conservation was discovered by several people at the same time.
2. It is much more likely that, had we been alive in these years, we would not have observed simultaneous discovery of this concept.
3. Many historians of science today depict this episode as a protracted struggle to understand nature that only gradually produced a consensus.

C. In this lecture, we will choose three from among the contributors, all under 30, to the construction of this consensus.

II. We first need to review what heat was thought to be.

A. The caloric theory of heat, which assumed that heat was an inherently light substance that permeates gross material bodies, originated with Aristotle's identification of fire as one of the four basic elements.

1. In this conception, temperature could be associated with the amount of caloric that occupied a given volume.
2. The observed evening-out over time of the temperature of two bodies originally at different temperatures could be visualized easily as the flow of caloric from the hotter to the colder body until the density of caloric in each is the same.

B. An alternative explanation was that heat was the motion of the ultimate particles making up a specific mass.

1. This view was entertained at least as early as the 17th century to account for the *creation* of heat through friction.
2. At the turn of the 19th century, Benjamin Thompson (Count Rumford) undertook a series of experiments in Germany that involved boring canons.
3. Rumford's conclusion was that the only way his results made sense was if heat was the result of the motion of the particles in the metal.

C. Each theory of what heat was also had severe weaknesses.

1. How could the caloric theory account for the inexhaustible heat produced in the boring of canons if the heat were due to a set amount of caloric in the metal canons that was somehow set free during the boring process?
2. How could Rumford explain the transfer of the Sun's heat to the Earth on the assumption that it was a mode of motion of the corpuscles of gross matter?
3. As the decade of the 1840s dawned, both ideas about heat were still appealed to, depending on the context.

III. One of the routes to conservation came by way of physiology. It was undertaken by a young German physician named Julius Robert Mayer.

A. Mayer signed on as the ship doctor for a Dutch expedition to the East Indies in early 1840, where he observed something unexpected.

1. He records being surprised by the "uncommon redness" of the venous blood he drew—it looked like that from an artery.
2. He explained this by invoking Lavoisier's theory of animal heat, according to which animal heat results from oxidation going on in the blood.

B. Mayer next made another inference about the heat produced by the body.

1. He believed that mechanical motion could not be generated out of nothing.
2. He argued that the heat produced by the oxidation in the blood, while in part supplying the heat the body needs to keep warm, must also be related to the mechanical motions the body makes.
3. In asserting that heat became mechanical motion, Mayer was arguing that there was a mechanical equivalent of heat.

C. Mayer's publications on his return to Germany were unusual in several ways.

1. An 1842 paper cast his assertions in a philosophical mode that many did not appreciate.
2. Further, Mayer was a religious man who was vehemently opposed to godless materialism; thus, he refused to regard forces as properties of matter.
3. By arguing that force was cause, he eventually came to the notion of the conservation of force.

IV. A more concrete argument about force conversion occurred in the experimental work of James Joule from Manchester in England.

A. Joule had no knowledge of Mayer's work but had become convinced on his own that when mechanical motion produced heat, there is a constant ratio of the work done by the motion to the heat produced.

B. Joule attempted to establish this conclusion through a series of experiments, which he reported at the British Association meetings beginning in 1843.

C. His most well known experiment involved a paddlewheel that was turned in an insulated bucket of water by a slowly falling weight.

D. He was able to measure the rise in temperature of the water and correlate it with the amount of work done by the descending weight, thus obtaining a precise measure of how much heat equated to how much mechanical work.

V. One of the earliest announcements of the general result implied by Mayer's and Joule's work, the conservation of force, was given in Germany in July of 1847 by another young medical doctor, Hermann Helmholtz.

A. Helmholtz began his medical studies in Berlin, working with a group of students who were wrestling with the problem of vital force, which they thought could be reduced to mechanical forces acting on matter.

B. In 1847, Helmholtz wrote a paper entitled "On the Preservation of Force," which many regard as the first general statement of energy conservation.

1. He imagined a system of bodies, each body in a specific position relative to the others and all the bodies subject to various forces acting among them.
2. If, after a time, the bodies moved to different positions because of the forces acting on them and if they were subsequently moved back to their original positions, Helmholtz argued that any work gained by the first motions would be exactly lost by the movements back to the original position.

C. Helmholtz's analysis was general. It was not limited to a single cause of motion, as in the example just given, but could include many acting simultaneously.

D. There are two kinds of force in Helmholtz's analysis, and each can be converted into the other.
   1. One he calls the "tensive force," because it is exerted without motion resulting.
   2. The other is the "living force," *vis viva*, or the force the weight exerts by virtue of its being in motion.
   3. At any time, then, one has all tensive force and no living force, all living force and no tensive force, or some combination of part tensive and part living.
   4. What stays the same here is the total of the two forces, the sum of the tensive and the living force.

VI. Although we have arrived at a general result, there was not yet clarity about what was conserved.

A. The word Helmholtz used was *force*, not *energy*.

B. It is easy to see why we should avoid characterizing these developments as simultaneous discoveries of the conservation of energy.

Essential Reading:

Smith, *Science of Energy*, chapters 3–5.

Purrington, *Physics in the Nineteenth Century*, chapter 4, pp. 88–101.

Supplementary Reading:

Caneva, *Robert Mayer and the Conservation of Energy*

Questions to Consider:

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

Lecture Thirty

Culture Wars and Thermodynamics

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

Outline

I. In Lecture Twenty-Nine, we followed the stories of three individuals, Robert Mayer, James Joule, and Hermann Helmholtz, as they struggled with the question of how heat was converted into mechanical motion.

A. Mayer, Joule, and Helmholtz all agreed that Carnot had erred in assuming that heat was merely made use of, but not used up, when steam engines produced motive force.

B. In this lecture, we want to explore how scientists came to the conclusion that these interconversions back and forth could not just go on forever.

II. For those who were trying to understand heat in the 1840s, the choice appeared to be between Carnot and Joule.

A. If Carnot was right, then heat was made use of in steam engines (as water is used in the example of a mill wheel in Lecture Twenty-Seven), but it was not converted into force.

B. If Joule was right, then heat became mechanical motion; it disappeared as mechanical motion appeared. Here, heat was converted into mechanical force.

C. In Germany, a young physicist named Rudolf Clausius challenged this way of seeing things in 1850. Clausius suggested that there were important aspects of both physicists' works that should be retained.
   1. He regarded Carnot's assertion that the fall in temperature was proportional to mechanical work as valid.

2. He also thought Joule was correct that heat was converted into mechanical motion.
3. His solution was to suggest that when heat was used to obtain mechanical work, only *some* of the heat was turned into mechanical work, while some was merely transferred from a warm body to a colder one.

III. Similar conclusions were made the following year by the young Scotsman William Thomson .

A. Like Clausius, who he acknowledged, had stated it first, Thomson believed that both Carnot and Joule were right.

1. Like Clausius, Thomson concluded that when heat is used to produce motive force, some of it becomes motive force and some is moved from a higher temperature to a lower one by conduction.
2. Carnot had not considered heat flow by conduction, because his heat engine was an ideal heat engine.
3. But in the real world, there would always be heat conducted though the sides of the boiler of any heat engine.

B. Thomson drew an interesting conclusion from this analysis.

1. He was impressed that the part of the heat during this process that was conducted could not be converted into mechanical work.
2. He reasoned that some of the heat during this process became unavailable to do work. It was, in Thomson's word, "dissipated."
3. Thomson now appropriated the word *energy* instead of *force* to focus on the motion of matter, as opposed to the mere push of the steam on the piston.
4. The word *energy*, referring to the work done, only slowly replaced *force* in these treatments of thermodynamics.

C. In 1854, Hermann Helmholtz made clear the cosmic implications of Thomson's dissipated energy.

1. He pointed out that the store of dissipated heat in the cosmos must be constantly increasing, because it could not be reconverted.
2. He concluded that the store of dissipated heat would grow until, eventually, all force had been converted into it: "Then all possibility of a further change will be at an end, and the complete cessation of all natural processes must set in."

IV. The new vision of the future of the physical world had an impact on religious assumptions.

A. This would not be the case for the irreligious scientific materialists we will meet in the next lecture.

B. A heat death would, however, clash with the old Laplacian cosmos we encountered in Lecture Two.

C. The new view based on the dissipation of energy had a particular impact on those who held more traditional religious positions.

1. One such individual was William Thomson, who had been raised in the Presbyterian Church of Scotland.
2. Thomson seemed to be caught in the middle between the biblical literalists of the Free Kirk and the liberal compromisers with deistic naturalism.

D. Thomson crafted his own religious position in conjunction with his new understanding of energy.

1. The irreversibility of all physical processes suggested an end to the world, which opposed Laplacian naturalism and was consistent with his Presbyterian faith.
2. Thomson, therefore, opposed such writers as Lyell, who suggested that the Earth's past was a steady state, with no progression at all.
3. Thomson declared that "everything in nature is progressive," by which he meant that nature developed irreversibly.
4. On the other hand, Thomson did not think that the end times were close at hand, as more traditional Presbyterians did.

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

Essential Reading:

Smith, *Science of Energy*, chapters 6–7, 9.

Supplementary Reading:

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

Questions to Consider:

1. For you, is the idea of a heat death of the universe compatible with religious faith (as it was for Thomson), or does it undermine a religious view of the future?
2. How does the running down of the universe jibe with current ideas of the universe's expansion?

Lecture Thirty-One

Scientific Materialism at Mid-Century

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

Outline

I. In the last two lectures, we have followed physicians and physicists as they have tried to sort out ideas about energy.

- **A.** We observed what a challenge it was to sort out the meaning of conversions of force from one kind to another, especially where the force of heat was concerned.
- **B.** The controversy over scientific materialism, which arose around the same time, caught the attention of the educated public.

II. The 1840s was an active time in Europe, intellectually, economically, socially, and politically.

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

III. The use of natural science to promote materialism became very visible around mid-century.

- **A.** Among the first proponents of scientific materialism was a fiery young professor of zoology from Giessen in Germany.
  1. Karl Vogt completed a medical degree in 1839, then spent five years studying fossils and geology under the direction of the noted Swiss naturalist Louis Agassiz.
  2. He then spent three years in Paris in the middle of the tumultuous 1840s before accepting a position in zoology at Giessen University in Germany.
  3. His *Physiological Letters* contain his most famous statement, made to support his materialistic view of mental activity, that "thoughts stand in the same relation to the brain as gall does to the liver or urine to the kidneys."
  4. After revolution broke out in Germany, Vogt was elected a representative to the Frankfurt Parliament, where he continued to take radical stances.
  5. He defended revolution as something sanctioned by nature and depicted scientists as necessary revolutionaries.
  6. He also attacked religion and its institutions, declaring unrestrained war against church and religion.
- **B.** Vogt's sounding the materialistic alarm found an echo in the work of a young Dutch physiologist, Jakob Moleschott.
  1. Moleschott was educated in Germany in physiology, where he met Ludwig Feuerbach and impressed him with a study of the physiological chemistry of food.

2. He proclaimed that because life was merely an exchange of matter, differences in diet determined differences in thought and character.
3. The book was reviewed by Feuerbach, who endorsed Moleschott's materialistic explanation of human character in a phrase that has been famous ever since: "You are what you eat."
4. In 1852, Moleschott's book *The Cycle of Life* declared again that life was not the result of a special force; rather, it was the result of the forces of matter: heat, light, electricity, and mechanical motion.
5. His radical ideas caused such a stir that he soon lost his position and left Germany for Switzerland.

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

1. Büchner came from a family of gifted children. His brother Georg had penned two plays that have stood the test of time, and his sister Luise became a leader in Germany's nascent women's movement.
2. He was inspired by the 30^{th} anniversary meeting of the German Society of Natural Scientists and Physicians in 1853.
3. His famous book, *Force and Matter*, appeared for the first time in 1855. Eventually, it would reach 21 editions and be translated into 17 foreign languages.
4. Büchner's slogan, "No force without matter, no matter without force," aggressively proclaimed that there was no such thing as immaterial spirit.
5. He set out on a campaign to eliminate every kind of supernaturalism and idealism from the explanation of natural events.
6. His strong conviction that the empirical method of natural science was the only route to knowledge led to the conclusion that philosophy must adopt its approach.
7. Büchner celebrated the conservation of force, which he interpreted as the "immortality" of force in 1857, as a confirmation of his materialistic vision.
8. Büchner's summary statement of scientific materialism became the symbol of the movement.

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

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

1. The conviction that natural science supported materialistic metaphysics was held with an emotional commitment rivaling that of religious individuals.
2. Büchner's rejection of the inevitability of universal heat death betrays an optimistic vision of the future not warranted by his materialistic beliefs.

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

1. The new spirit of Realism was evident elsewhere in the culture, as well as in the materialistic controversy that flowed from natural science.
2. It was visible in the *Realpolitik* pursued by Otto von Bismarck, who used it to successfully unite the German states into a new Reich by 1870.
3. It was evident in the school of Realism in art and in the literature of the period that attempted to "tell it like it is," rather than to focus on edifying the reader.
4. After mid-century, Karl Marx abandoned the exhortation of his *Communist Manifesto* and sat down in the British Museum to examine economic data.

Essential Reading:

Sperber, *Revolutionary Europe*, chapters 5–6.

Supplementary Reading:

Gregory, *Scientific Materialism in Nineteenth Century Germany*, part 2.

Questions to Consider:

1. Why is it that natural science frequently carries a public image of being materialistic?
2. Why was it so hard to mount an effective public reply to the popular materialism of mid-century?

Lecture Thirty-Two

The Mechanics of Molecules

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

Outline

I. One of the assumptions of the scientific materialists was that molecules in motion determined the nature of reality.

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

II. Already in the early 19th century, there were hints that the laws of matter might be different from those Newton had found for the heavens.

- **A.** In the 18th century, much of chemistry was dominated by what historians have called the *Newtonian dream*.
  1. The idea was to proceed in chemistry the same way Newton had described the laws of planetary motion—to find mathematical expressions of the forces involved.
  2. In spite of various attempts to quantify short-range chemical forces, no one had been successful in realizing the Newtonian dream in chemistry as the century came to a close.

- **B.** The appearance of a basic question, about how chemical substances combined, led chemists in France and England to pursue a different course in chemistry at the turn of the 19th century.
  1. The question was: When chemical substances combine to form a composite, do they always combine in the same proportions, or can the proportions vary?
  2. In France, a debate arose on the issue, with Joseph Proust asserting that the proportions were fixed, while Claude Berthollet argued that they could combine in an infinite variety of proportions to produce composites with different properties.
- **C.** A few years later in England, John Dalton was fascinated with the different gases that made up the atmosphere: Why did they remain mixed instead of separating out in layers?
  1. He assumed that the gases were composed of particles that, because they repelled themselves selectively, without repelling the atoms of other gases, resulted in a general mixture.
  2. He determined to establish the number and weight of the elementary chemical substances that entered into combination.
  3. Studying instances in which different compounds resulted from the same elementary substances, Dalton came to the conclusion that the proportions in which they combined were not only fixed, but in many cases, were simple multiples of one another.
  4. He formulated what has become known as the *law of definite proportions*: When atoms combine to form a compound, the number of combining atoms of the different elements form simple, definite ratios.
  5. Dalton was now able to determine the relative weights of the atoms that combined.

III. Additional insights strengthened atomic theory over the course of the century.

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

5. Avagadro nevertheless concluded that equal volumes of gases under the same conditions possess equal numbers of molecules, a law that still bears his name.

B. Chemists also sought regularities among the growing list of elementary substances.

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

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

A. Rudolph Clausius, whom we met in Lecture Thirty, is a key figure in the development of kinetic theory.

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

B. In 1860, James Maxwell contributed to the further development of kinetic theory.

1. He applied the emerging mathematical study of statistical variation to kinetic theory.

2. Although Maxwell's proposal became part of kinetic theory, it was not until the 20th century that experimental proof was obtained.

C. The success of kinetic theory contributed to the introduction of a new style of thinking about nature.

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

Essential Reading:

Purrington, *Physics in the Nineteenth Century*, chapters 6–7.

Supplementary Reading:

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

Questions to Consider:

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

Lecture Thirty-Three

Astronomical Achievement

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

Outline

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

   A. While Berthollet and Proust were arguing over whether proportions of chemical reagents were fixed or infinitely variable, the nebular hypothesis of Pierre Simon Laplace began to exert influence.

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

   B. Laplace's *Celestial Mechanics* came into English in a translation of 1831 by a remarkable woman, Mary Somerville.

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

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

   A. Two popular authors championed the nebular hypothesis in Britain.

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

   B. The nebular hypothesis was not without its detractors.

      1. Many regarded it as proof of atheism, because it replaced God as creator with natural law.
      2. Some argued that the supposed primal fluid that made up nebulae was not really a fluid at all.
      3. One of the nebulae that had attracted attention was the Great Nebula in the constellation Orion.
      4. The issue became focused when the Earl of Rosse completed construction of the world's largest telescope, a gigantic reflector nicknamed the "Leviathan of Parsonstown," and turned it on Orion in 1845.
      5. Lord Rosse's telescope resolved the grand nebulae into stars. He also was able to show, for the first time, that some nebulae had spiral arms, which he conjectured to be rotating masses of stars.

   C. Lord Rosse's resolution of the Orion nebula did not destroy the nebular hypothesis.

      1. Some, including the author of the famous *Confessions of an Opium Eater*, Thomas De Quincey, regarded Lord Rosse's resolution of the nebula as the death knell of the nebular hypothesis.
      2. Defenders of that hypothesis, such as John Nichol and Robert Chambers, simply argued that nebulae came in two varieties: those that could be resolved and those that were genuinely nebular fluid.
      3. As a result, the hypothesis continued to be debated throughout the century.

III. Another major discovery in astronomy around the same time involved a new planet.

- **A.** The only addition to the planets since ancient times had come in the late 18th century, when William Herschel discovered Uranus, whose motion provided the occasion for yet another new planet.
  1. In 1781, William Herschel noticed an object he first took to be a comet. The object had been cataloged before, but its motion had not been detected.
  2. Eventually, Herschel recognized it as a new planet circling the Sun. After several years, astronomers were reasonably sure that they had established the orbit of the new planet, named Uranus for the Greek god of the heavens.
  3. As interest in Uranus waned, it was observed sparingly in the early 19th century.
  4. In 1820, more ancient observations of Uranus were uncovered, and they raised a problem, because they were at variance with the orbit that had been established.
  5. Various hypotheses were offered in the 1830s to account for the difference.
  6. Astronomers settled on the idea that an unknown planet, beyond the orbit of Uranus, was causing it to deviate from the established orbit.
- **B.** Discovery of the new planet was a story of frustration.
  1. Both a Frenchman and an Englishman took up the problem in the 1840s.
  2. The problem was to identify the mass and position of a planet that would exert the gravitational pull on Uranus to pull it out of its orbit as observed.
  3. Solutions to the problem were offered, but astronomers failed to actually look for the new planet.
  4. The Frenchman Urbain Leverrier wrote to a German astronomer in Berlin, instructing him where to look for the new planet, Neptune.
- **C.** The discovery of Neptune illustrates several interesting things about natural science at the time.
  1. It confirmed once again the power of science, because Leverrier had deduced the existence of a new planet by making calculations on paper and instructed observers where to look.
  2. The implication was that natural science can unearth nature's secrets, if one has the ability and patience to employ the methods of science.
  3. It made clear that natural science was not immune to the effect of distinct national rivalries. Leverrier's discovery was heralded as an example of the prestige of French science.

  4. In an attempt to win credit for English science, John Herschel observed that Adams had had the solution earlier than Leverrier; the French were outraged.

Essential Reading:

Neeley, *Mary Somerville*.

Smith, "Abyss of Heavenly Wilderness," http://www-personal.umd.umich.edu/~jonsmith/orion.html.

Supplementary Reading:

Grosser, *Discovery of Neptune*.

Questions to Consider:

1. Did the nebular hypothesis promote ideas of organic evolution, or did evolution stimulate interest in the nebular hypothesis?
2. Why might the French and English be particularly sensitive about the respective glories of their scientists in the 1830s and 1840s?

Lecture Thirty-Four
The Extra-Terrestrial Life Fiasco

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

Outline

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

II. The issue of other worlds and extra-terrestrial life has roots deep in the Western past.

- **A.** The issue was made particularly significant when the theologian Thomas Aquinas was reprimanded for heretical teachings in the condemnations of 1277.
  1. Aquinas had explored Aristotle's views, among which was his conclusion that the Earth, being the center of the cosmos, was the only place where life existed.
  2. In 1277, the Catholic Church officially permitted the idea that life might exist elsewhere, a position that Christian theologians before that time had rejected as pagan.
  3. Within 150 years, the question arose whether creatures who lived elsewhere were covered by the redemptive sacrifice of Christ or whether Christ would have to go to other worlds and die again.
- **B.** Between the medieval period and the end of the 18th century, a consensus emerged among theologians and natural philosophers that extra-terrestrial life was likely.
  1. Reformers and later natural philosophers of the 17th century saw no problem with extra-terrestrial beings.
  2. In the 18th century, the growing field of natural theology embraced other worlds as a testimony to God's greatness.

  3. Numerous others also regarded extra-terrestrial life as possible, some even as a testimony to God.
- **C.** Into this comfortable consensus fell the bombshell of Thomas Paine's *Age of Reason* of 1793.
  1. Paine mocked what he regarded as a conceit of Christianity to believe in extra-terrestrial life and, at the same time, to insist on the universality of Christ's redemptive sacrifice.
  2. Paine threw down the gauntlet to Christians: Either give up belief in Christ's redemptive role, or give up belief in extra-terrestrial life.
- **D.** The reaction to Paine was quick in coming and lasted for years.
  1. Most reactions were to reassert belief in both Christ's redemption and the existence of other worlds.
  2. New works on extra-terrestrial life continued to appear over the first half of the century.

III. At mid-century, a new bombshell exploded on the scene.

- **A.** An anonymous publication, *Dialogue on the Plurality of Worlds*, appeared in England in 1853.
  1. The author asked what to make of the other worlds science shows to us as far as redemption is concerned.
  2. The author was, in effect, agreeing with Thomas Paine: Either give up universal redemption or give up extra-terrestrial life.
  3. This author chose to give up extra-terrestrial life.
- **B.** The denial of the existence of extra-terrestrial life was regarded as scandalous by many.
  1. When the author of the book was found to be William Whewell, the master of Trinity College, Cambridge, and known defender of natural science, astonishment was everywhere.
  2. How could such a progressive figure take such a backward-looking position?

IV. The ensuing debate exposed a variety of opinions on the question.

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

V. As the century wound down, a new debate over extra-terrestrial life emerged.

A. The Italian astronomer Giovanni Schiaparelli tested a new telescope's capacity to observe a planetary surface.

1. He observed dark lines that he dubbed "channels" (*canali*), opening a debate on Martian canals that would last into the 20th century.
2. Schiaparelli favored the view that the channels were natural waterways but did not oppose the idea that they could have been intentionally constructed.
3. By this time, a growing number of celestial bodies had been eliminated as fit sites of possible life. The new technique of spectral analysis permitted scientists to determine the elements that made up many heavenly bodies.
4. Although some doubted that the lines on Mars represented anything real, new observations near the end of the century confirmed that the lines were undeniable.
5. Camille Flammarion in France and Percival Lowell in the United States popularized the notion that Mars could well be inhabited, to the delight of the general public.

B. Eventually, scientists concluded that the atmosphere of Mars was unable to support life, with the possible exception of microbes or primitive plants.

C. Nevertheless, belief in the possibility of extra-terrestrial life has continued unabated to the present day and is now as strong as ever.

Essential Reading:

Crowe, *Extraterrestrial Life Debate*, chapters 5–7, 10.

Supplementary Reading:

Whewell, *Of the Plurality of Worlds*.

Questions to Consider:

1. Why has the history of concerns with extra-terrestrial life been intimately associated with the history of religion?
2. Given that consideration of extra-terrestrial life has never depended on an actual encounter with other life forms, it is really a reflection about ourselves. What does this story from the 19th century tell us about ourselves as human beings?

Lecture Thirty-Five

Catching Up With Light

Scope: At the beginning of the 19th century, Thomas Young in England and Augustin Fresnel in France successfully employed a wave conception of light to describe aspects of its behavior. Later in the century, the Scotch physicist James Clerk Maxwell envisioned electrical and magnetic effects as the result of rotations in an imponderable medium of great elasticity and subtlety believed to permeate the whole of planetary and stellar space. His mathematical description of the distortions took the form of wave equations that not only provided a new level of clarity about electricity and magnetism but also led to the discovery of startling results about light and the development of an entire spectrum of electromagnetic radiation. Measurements of light's speed occurred in the 1880s when Albert Michelson improved a technique of Jean-Bertrand-Léon Foucault. This he repeated later, with Edward Morley, in an attempt to explore the role of Maxwell's ether in transmitting light. The surprising results sharpened the question about the status of hypothetical models, because the ether possessed properties that defied the imagination. Did the ether really exist?

Outline

I. We ended our investigation of the question of extra-terrestrial life with sensational claims about life on Mars.

A. By the end of the 19th century, telescopes had improved to the point at which distinct features on Mars could be detected.

1. The meaning of these features was, of course, subject to a great diversity of opinion.
2. But telescopes could focus light from distant objects better than ever before.

B. The question of what light itself was and how it moved had been the subject of inquiry since the Middle Ages.

1. In the 17th century, a Danish astronomer, Olaus Roemer, demonstrated that the speed of light was not infinite, as some had assumed.
2. In the same century, René Descartes explained light as pulses, or waves in a medium that existed between the object and the eye, that were propagated by mechanical means.
3. Newton believed, however, that this pulse theory of light could not account for a newly discovered property—polarization.
4. By the beginning of the 19th century, no consensus had emerged about the best explanation of what light was.

C. In this lecture, we will see that this changed with the establishment of a new wave theory.

II. In the early years of the 19th century, the wave theory of light received new backing.

A. The English physician Thomas Young was a remarkable man, whose interests and abilities carried him well beyond the medicine he practiced for a living.

1. He was broadly educated in languages, including some ancient languages of the Near East, and played a key role in deciphering the ancient Egyptian writing known as *hieroglyphics*.
2. As a physician, he was curious about the connection between the body and sensation.
3. In 1801, he set out to conduct his own experiments in the investigation of what light was.

B. Young did an experiment from which he concluded that light was made of waves, but not the kind of waves Descartes had envisioned.

1. He passed a beam of light through two holes and examined how the emerging light fell on a screen.
2. What he saw was a pattern of bright and dark regions, something that did not make sense if light consisted of a ray of particles, as Newton imagined.
3. Young imagined that light moved through an ethereal medium that existed between an object and the eye, somewhat like waves moving through water.
4. He then explained the bright regions of the pattern he observed as the places where the crests of the waves emerging from the two slits coincided and the dark regions as the places where the crest of one wave coincided with the trough of another, thus canceling each other.
5. Young figured out a way to explain polarization using his waves, as well.

C. Young's wave theory was developed and confirmed in France during the second decade of the century.

1. Augustin Fresnel provided a mathematical description of how waves could be used to explain the way light bends around obstacles.
2. Fresnel's mathematical wave theory implied that a small disk placed in the path of a beam of light would cause the light to bend around the edges and converge toward the center to produce a bright spot in the middle of the shadowed region, an implication that was confirmed in 1818.
3. Light would be regarded as waves in the ether for the remainder of the century.

III. In the middle of the century, James Maxwell discovered something new about light while trying to decipher why electricity and magnetism were related, as Oersted, Ampère, and Faraday had found them to be.

A. We saw the basics of electromagnetism back in Lecture Twenty-Six.

1. The work of Oersted, Ampère, and Faraday uncovered various aspects about the intimate relationship between electrical and magnetic force.
2. But no one felt that they understood *why* this relationship existed.

B. In 1860, Maxwell made a mechanical model that related electrical and magnetic force.

1. He visualized the relationship between electrical and magnetic force in a current-carrying wire as a mechanical interaction between parts of an ethereal substance.
2. He postulated that there were rotating vortices or eddies in this ether that penetrated the wire and that they were separated by tiny spheres rotating in the opposite direction to act as ball bearings between the vortices.
3. The circular-acting magnetic forces were represented by the rotating vortices, while the electrical charges were represented by the little ball bearings.
4. Because the system was interlocked, rotating motion in one produced motion in the other.
5. Maxwell generalized his result by suggesting that the ether, which was present in but not confined to the wire, had vortices and ball bearings everywhere, not just when it penetrated the wire.
6. This implied that, just as rotating magnetic vortices produced electrical force in the ball bearings of the ether in the wire, they could also do the same in regions of space where no wire was present.
7. In space, these changes produced electromagnetic waves traveling through space and appeared as a real current if a wire or conducting substance was encountered.
8. Maxwell proceeded to depict his mechanical model in a series of mathematical equations.

C. Maxwell's model and the equations that arose from it held several revealing implications.

1. The equations depicting the model were equations that described waves.
2. His theory predicted that these waves shared properties of light waves—they could be reflected and refracted by appropriate substances.
3. Startlingly, Maxwell's theory predicted that the electromagnetic waves would travel at about 3×10^8 m/sec, the speed that a French physicist had recently calculated light to travel!

4. Maxwell concluded that light consisted in the transverse waves of the same medium that was the cause of electric and magnetic phenomena.

D. Developments after Maxwell confirmed that his theory represented a fundamental insight, although it took some time for confirmation to come.

IV. Maxwell's theory, although successful, also introduced problems.

A. This occurred when Albert Michelson and E. W. Morley attempted to confirm the relative velocity of the Earth through the ether in 1887.

1. Assuming that the Earth created a "wind" as it traveled through the ether, they sent two beams of light from one point in the direction of the wind and perpendicular to that direction.
2. Both beams were reflected back to the point, where they were expected to arrive at slightly different times because of the differing effects of the ether wind on their journeys.
3. The interference pattern produced was expected to change as the perpendicular beams of light were placed in different orientations, but no difference in the interference pattern was detected.
4. Some assumed that the ether was dragged along with the Earth, an idea that was discredited by experiments.
5. Scientists were left with a conundrum: The ether was neither stable nor moving with respect to the Earth!

B. The other problem was that properties of the ether were hard to grasp.

1. Light could be blocked by matter. Yet, as electricity and magnetism showed, the ether penetrated wires and other conducting matter.
2. It turned out that the elasticity of the ether had to be greater than that of steel.
3. The overarching question for those immersed in an age of Realism was: Is there *really* an ether with vortices and wheel bearings as Maxwell originally envisioned?
4. If it was only a heuristic model, why did it work so well in explaining electricity and magnetism and in uncovering their relationship to light and other kinds of radiation?
5. It is an old problem: How realistically is the scientist to take the model?

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

Essential Reading:

Smith, *Science of Energy*, chapters 11, 14.

Smith, "Force, Energy, and Thermodynamics," pp. 304–310.

Supplementary Reading:

Holton and Brush, *Physics, the Human Adventure*, chapter 23, pp. 341–350; chapter 25, pp. 374–379.

Questions to Consider:

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

Lecture Thirty-Six

The End of Science?

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

Outline

I. In the last lecture and throughout this series, we have seen a number of occasions when scientists encountered results that appeared to be inconsistent with the mechanical model of nature they had been perfecting.

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

II. Accomplishments over the course of the 19th century formed the basis for a growing confidence about the power of natural science.

- **A.** We've seen reason for this confidence in the biological sciences.
- **B.** The situation was the same in the physical sciences.

III. Some scientists became so confident that they felt they had the tools to finish the work of understanding nature.

- **A.** They reflected their belief, typical of the Realism of the day, that scientific theory was able to depict nature as it really is.
  1. Some were impressed with how far natural science had come when compared to human understanding of nature in the past.
  2. They were confident that science had identified a method, based on careful observation and experimentation, that would lead humankind ever closer to nature's truth.
  3. The cosmos was the clockwork universe ruled by deterministic law.
  4. To these scientists, explaining something scientifically meant to take apart nature's machinery to see how it worked.
  5. Given the success of mechanical models in kinetic theory and electromagnetism, they were confident that persistent problems would someday be resolved.
  6. The unifying power of the concepts of energy and the field convinced many that physical science might be coming to its end.
- **B.** Confidence in mechanistic natural science grew to impressive levels in some circles during the late 19th century.
  1. In 1887, the soon-to-be president of the American Association for the Advancement of Science predicted that no great, original, and far-reaching discoveries or novel and almost revolutionary applications lay ahead.
  2. In 1894, Albert Michelson suggested that physicists basically understood the laws of nature. What was left was to make them more precise.
  3. Some theologians shared this image of science nearing its end.
- **C.** Not everyone shared this naïve confidence in mechanistic science.
  1. Maxwell, although he certainly believed in an ether that possessed mechanical properties, was hesitant to embrace his particular model of the ether as something that actually existed.
  2. Such physicists as Ernst Mach and Pierre Duhem and the mathematician Henri Poincaré began to reevaluate the nature of scientific theory, each moving away from the simple claim that theory represented nature as it really was.
  3. And there always were those warning signs we've identified; these may not have been consciously noticed, but they were, at least, recorded in the sub-consciousness of scientists.
  4. Clearer were inconsistencies about the ether that Michelson and Morley had exposed that could not be easily explained.
  5. Such men as Lord Kelvin referred in 1901 to the "clouds" that hung over physical theory.

IV. As the new century dawned, two major developments, quantum theory and relativity, exposed the overconfidence of these scientists as premature and challenged the foundations of the age of Realism.

A. The work of the physicist Max Planck challenged a fundamental assumption of 19th-century physics, that is, that changes in energy (when it is given off or taken on) occur continuously.

1. Our perception of natural processes that, for example, require energy to occur is of smooth or continuous change.
2. In accounting for the energy radiation that occurs when a body is heated from lower to higher temperatures, it was assumed that the variations of output observed occurred smoothly or continuously.
3. No one, however, was able to give a complete account of the energy pattern from low to high temperatures. The middle-range temperatures were especially problematic.
4. Planck eventually solved the problem, but his solution involved abandoning the assumption that energy had to be radiated continuously.
5. He introduced the idea of *quanta*, or permissible discrete amounts of energy, in his successful description of the overall energy pattern.
6. If nature behaved the way Planck described it in this context, then an object seemed to disappear from its first position and reappear at a second position.
7. When Planck's idea of quantizing energy found applications in other areas of physics, physicists began to take seriously that perhaps nature did indeed behave in such a bizarre fashion.
8. Gone was the intuitive idea that nature was a deterministic machinery whose laws were within our grasp.

B. Albert Einstein's insistence that the laws of electromagnetism were not exceptional led to another major revolution in our view of nature.

1. His real motivation was concern to show that the laws of electromagnetism were not inconsistent with the laws of motion.
2. Einstein imagined what the world would look like if he rode on a beam of light by which we obtain information about the world.
3. If he traveled as fast as light, he would not be able to see anything ahead of him because the light could not get ahead of him to be reflected back from objects.
4. Because that would happen only when he was going the speed of light, he had a test that would tell him absolutely that he was not at rest.
5. But the law of inertia said that motion was relative, that one could *not* tell absolutely if one were moving, only that one was moving with respect to something else.

6. Thus, the laws of electromagnetism and of moving bodies were at variance with each other, something Einstein did not want to be.
7. To ensure the consistency of all the laws of physics, Einstein declared that light's speed was absolute, that it would not show differences from one observer to another.
8. This meant that light's speed did not change to accommodate different frameworks of space and time, but that space and time changed to accommodate the constancy of light's speed.
9. The idea of changing space and time presented the world of 19th-century physics with its second example of a "great, original, and far-reaching discovery" that had been declared impossible in 1887.

C. The erosion of a comfortable Realism in natural science was accompanied by other breakdowns of Realism around the turn of the new century.

1. Realism in art and literature gave way to new forms that did not strive to depict the world as it really is.
2. In the world of politics and diplomacy, things were beginning to go awry, only to collapse with the outbreak of world war.

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

Essential Reading:

Purrington, *Physics in the Nineteenth Century*, chapters 8–9.

Cline, *Men Who Made a New Physics*, chapters 3–5.

Supplementary Reading:

Badash, Lawrence. "The Completeness of Nineteenth-Century Science."

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

Questions to Consider:

1. Just as at the end of the 19th century, the end of the 20th century also saw declarations of "the end of science." Why do these sentiments periodically appear? Is their appearance at the end of centuries significant?
2. Do you think that quantum theory and relativity will ever be abandoned as either incorrect or severely limited approaches?