Science and the Enlightenment Study Guide

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Plot Summary

Science and the Enlightenment is an intellectual and scientific history of the great flowering of scientific and philosophic thought during the 18th century in Europe, the period known as the Enlightenment. The Enlightenment was both an important and radical break with tradition and the foundation of modern science and thought. This book documents that development.

At the outset of the Enlightenment, thinkers were beginning to rebel and move beyond the stifling dogma of Aristotelian thought that had been enforced by the Catholic church since the 11th century. It is no surprise that Enlightenment thought grew out of the work of two Englishmen, who lived in a land that had divorced itself from the Catholic Church. It was Newton and Bacon who developed many of the ideas that led to the Enlightenment both advocating the adoption of the inductive method of observation and theorizing and making a radical break from any reliance on religious revelation or on Catholic philosophy. These initial developments in England led to ripples on the continent of Europe, especially in France and Germany.

It wasn't long after Newton's discoveries that other mathematicians in Europe attempted to continue and expand Newton's discoveries. Descartes developed analytic geometry and Leibniz developed new methods for understanding calculus. These and other developments in mathematics led to further developments in Astronomy and, ultimately, in mechanics.

Until the development of more sophisticated mathematical tools, pure math would have to wait until the 19th century for more advancement. The Enlightenment did see a development in experimental physics, however. Newton contributed to this field greatly as did other scientists. Although many of their theories were ultimately incorrect, the work in this field did lead to many practical developments in the field of electricity and heat research.

It was chemistry, however, that was affected the most by new developments during the Enlightenment. Previously chemistry was the province of Alchemists and doctors, but the Enlightenment saw the development of chemistry as an independent and important field of science. Geniuses like Boyle and Lavoisier developed theories that helped to demolish the old Aristotelian theory of elements and to establish the molecular theory of gases and liquids.

Natural history, or what we might call Biology, and physiology were also created as independent field in this era. While mechanists and vitalists battled it out in the theoretical realm, scientists such as Linnaeus quietly put together the foundations of modern biology and physiology.

Great as these developments were, it was the development in the moral or what we might call the social sciences which were the most influential. Philosophers like David Hume, Rousseau, and Montesquieu developed theories of human nature and law that are still with us today. The Physiocrat in France developed a natural theory of economics that Adam Smith used as the basis of his own theory of economics. Men like Condorcet used the new mathematical techniques to found a quantitative social science and ethical theorists attempted to discover the natural root of our ethical theories and sentiments. In all these ways, this book shows the development of these fields and the birth of modern science out of the ashes of Scholasticism and ignorance.

Chapter 1, The Character of the Enlightenment

Chapter 1, The Character of the Enlightenment Summary and Analysis

Chapter one discusses some of the general themes of the enlightenment thinking and how these ideas influenced scientific thinking. The 16th and 17th centuries were times of great scientific advances, especially in mathematics. This period was known as the "Scientific Revolution" and many of the scientists saw the 18th century as a culmination and continuation of that revolution. At the time natural science was considered a branch of philosophy known as natural philosophy.

Some of the key advances made in the late 17th and early 18th century were in mathematics, specifically the development of calculus and analytic geometry. Progress in mathematics helped foster optimism about the powers of pure reason in general. It is this belief in the power and efficacy of reason and progress that comes to characterize the enlightenment.

Nature also plays a key role in enlightenment thinking. Many enlightenment thinkers believed that it was possible to understand truths about the natural world and even about God without resorting to direct revelation but rather by using reason. The great hero of the enlightenment in France and in England was Isaac Newton, whose work helped to justify the idea that knowledge of the world can be gained through direct investigation and reason. Newton had been so successful in his investigations that many later natural philosophers saw the project of science as being the completion of the Newtonian project. "Newtonianism" became a kind of ideology or philosophy of the enlightenment, though it took on widely different meanings depending on who was using the term. Some who claimed to be followers of Newton, such as Malebranche espoused an extreme form of rationalism while others tended towards empiricism. Newton's name became a rallying cry for enlightenment thinkers because of his brilliance and the success of his work, though not all later thinkers directly followed his method.

At the beginning of the enlightenment the current division of the science into disciplines such as physics, chemistry, biology, botany, etc did not really exist. All natural scientist considered themselves natural philosophers and their research would often overlap into several scientific areas. Many scientific problems were also considered philosophical problems. Questions of physical mechanics were connected to questions about free-will and god's influence in the natural world. Part of the achievement of the enlightenment scientist was the creation of specific scientific disciplines with their own unique questions and methods.

Enlightenment scientific thought arose in part as a rebellion against and a rejection of Aristotelianism in science. The Aristotelian view, endorsed by the Catholic Church, was dominant in the western world from around the 13th century until well into the Scientific Revolution that led to the enlightenment. This system of thought was dogmatic and didn't allow for the freedom of investigation that characterized enlightenment science. The key development of people like Newton and Copernicus was to reject the formal constraints of the "teleological" science of Aristotle. Furthermore, enlightenment thinkers such as D'Alembert appropriated some Aristotelian concepts such as "natural law" for the new enlightenment philosophy. On this view, "natural law" was coextensive with Reason as it was understood at the time. Rather than using "natural law" to direct inquiry, the conclusions of inquiry were thought to constitute "natural law." This was a huge shift in scientific thinking which this guide will explore in more detail in later sections.

Chapter 2, Mathematics and the Exact Sciences

Chapter 2, Mathematics and the Exact Sciences Summary and Analysis

At the beginning of the enlightenment there was debate among many scientists whether it would be profitable to pursue pure mathematics. Diderot was one of the most vocal opponents of pure mathematics as a research program during this period. Diderot believed that pure mathematics had reached the limit of its development and scientists should instead turn their attention to the study of descriptive sciences such as chemistry, experimental physics, and natural history. Contemporaries of Diderot, notably, D'Alembert and Condorcet argued that Diderot was wrong and that scientist should continue to develop methods in pure mathematics.

This crisis of faith in the power of mathematics during the eighteenth century was strange given the great advances in mathematics that had recently occurred. Part of what caused this pessimism about the future of mathematics was the great success of mathematical analysis in the 18th century. The pessimism was specifically pessimism about the future prospects of mathematical analysis. Analysis is the method of turning mathematical problems into equations. This was the field pioneered by Descartes with his analytic geometry, as well as Leibniz and Newton with their developments of infinitesimal and differential calculus. For Newton, analysis was combined with synthesis in his methodology. Scientist would use analysis to break down problems and concepts into their constituent parts and then use synthesis to recombine them. In practice, though, analysis tended to be overemphasized. One methodologically-minded philosopher, Etienne de Condillac, took this tendency to the extreme when he claimed that all scientific discoveries must proceed by analysis and that synthesis is merely used to check the validity of scientific propositions. Voltaire and other enlightenment thinkers agreed with this emphasis on analysis.

Part of the mania for analysis is related to the rejection of Aristotelianism. According to Voltaire and others the great error of the ancients was their focus on synthesis and for that reason it should be rejected. The paragon of pure analysis is found in the enlightenment focus on "rational mechanics," that is, the investigation of idealized properties that can be quantified. This is contrasted with the investigation of actual objects. The method during this period tended towards extreme abstraction and idealization of mechanical problems, such as motion along a curve. Once solutions were discovered to the abstract problem, the scientists would attempt to make the problem closer and closer to the real objects in question.

This method seems easier and more straightforward than it actually is. Oftentimes, disputes would arise about the kind of idealization involved or about the conception of the properties to be measured. A good example of this kind of controversy is found in the controversy surrounding the proper way to model movement along a curve. A massive body traveling along a curve will continue to travel along the tangent line of the curve after it is released. Because of the limitations of the available mathematical techniques, however, this motion was modeled along a "polygon curve" rather than a true curve. The problem was eventually solved when calculus was developed to focus more on the derivative rather than the differential, that is, once it became easier to account for infinitesimals in calculus.

This problem became more profound in the debate over hard bodies. Newton had claimed that the particles that compose matter are absolutely hard; whereas, others claimed that the particles were elastic. If bodies are composed of hard particles the bodies will immediately change course after impact with another body, while elastic bodies will be slightly deformed before they change direction. The polygon curve simulated the impact of hard bodies and the true curve simulated the impact of elastic bodies. This debate later transformed into a debate about the nature of the forces that act upon bodies.

Leibniz denied the existence of perfectly hard bodies and also, more radically, denied the existence of matter. He claimed that matter was really only a manifestation of force. Leibniz also argued in favor of Vis viva, a living force that was conserved in the universe, ensuring that the universe would never run out of force. The debate over the Vis Viva became one of the central debates in pure mechanics at this time. Vis viva is a metaphysical idea that derives from a belief in a certain kind of God and theological beliefs about what reason requires of that God. Religious and metaphysical debates within science were not uncommon in the enlightenment, but the idea of the Vis viva struck many enlightenment scientists as a step backward into the science of the Middle Ages.

Newton believed that forces could only exist between two bodies. The Vis viva theory claims that force is scalar and absolute, in opposition with Newton's theory. Unlike Leibniz, who believed that a Vis viva was needed to keep the universe from "running down," Newton believed that the universe required active and constant intervention by God to keep from "running down." The followers of Descartes joined Newton in opposing the Leibnizian camp. An experiment in Italy, though, led one of the chief proponents of the "action" view of force, Newton's view, change sides and endorse the Vis viva. Over time, more and more scientist came to believe in something like a Vis viva view of force. Eventually, with its theological commitments removed, Vis viva, now called "energy" became a central concept in modern physics.

One interesting case of the overlap of theoretical and applied math during the enlightenment involved the testing of Newton's theory of gravitation. His theory was tested three times during this period in the controversy over the shape of the earth, the motion of the moon, and the return of Halley's comet. Newton's theory predicted that the earth would be shaped something like an onion, that is, a little wider near the equator and flatter at the poles. Descartes, however, argued that the earth should be shaped more like a lemon, that is, slightly elongated at the poles. Newton argues that his theory could be confirmed if a pendulum at the equator swung more slowly than a pendulum at the pole. Two expeditions, one to the pole and one to the equator, left to test the theory with the pendulums, the evidence they gathered conclusively proved the Newtonian theory. The motion of the moon provided a difficult problem because it involved three attracting and moving bodies: the earth, the moon, and the sun. Calculating the motion of the moon required multivariable calculus, which was not available at the time. Several scientists, though, worked out an approximation of the problem that seemed to prove the Newtonian theory wrong. Clairaut later showed, though, that these men had gotten their calculations wrong and Newton was vindicated. The final test involved predicting the return of Halley's comet. Clairaut claimed that he had predicted the return of the comet by using Newtonian theory. His prediction turned out to be correct and the Newtonian theory of gravity had been rigorously tested by evidence from astronomy.

Towards the end of the 18th century William Herschel with his newly-developed telescope made other real advances in Astronomy. Aside from these advances, development of pure mechanics and refinement of mathematical analysis did not lead to the invention of many new machines or any novel experimental improvements. Because of this, Diderot's prediction of the decline of mechanical philosophy and pure mechanics did seem warranted. It was not the mechanical philosophers and pure mathematicians, however that made the most advances. The principles of pure mechanics were picked up and refined by theoretical physics in the 19th century as well as by chemists and engineers. With the development of more advanced methods, even analysis advanced. Pure mathematics is still a vibrant field in today's university.

Chapter 3, Experimental Physics

Chapter 3, Experimental Physics Summary and Analysis

Since the time of Aristotle, the term "physics" referred to a variety of subject matter, many explicitly philosophical. It wasn't until the Renaissance that experimentation became a common method of investigation, though at the time this type of experimental physics was called "natural magic" and had more in common with Alchemy than with modern physics. Until the 18th century, physics was taught in Latin as a branch of speculative philosophy; whereas, mathematics, useful in the military arts, was taught in the vernacular. This began to change during the enlightenment, however, as it became clear from the work of Newton and others that experimental and quantitative measures needed to be used to help develop and test theories. At the beginning of the enlightenment, experimental physics was the domain of hobbyists and amateurs like Benjamin Franklin. Their success, though, led to a systematic study of experimental physics by natural scientists and, ultimately, to the modern discipline of physics.

It was Dutch scientists in the early 18th century that first began to carve out the more modern domain of physics by excluding natural history, anatomy, and chemistry from the discipline. The Dutch physicists believed that the most promising area of investigation for research was in heat, light, electricity, and magnetism. The Dutch physicists were avid inventors and experimenters and devised ingenious devices to create these forces. The Germans on the other hand, still under the philosophical sway of Leibniz and his follower Christian Wolff, focused on developing a complete, rationalistic science of physics that could account for all physical phenomena.

At the beginning of the enlightenment the Dutch and other experimenters were not primarily interested in measuring their phenomena, but rather in creating it; it wasn't until the end of the enlightenment that measurement of, for example, electricity became an important goal. One reason for this lack of emphasis on measurement was due to the dominant "subtle fluids" theory. Thinkers at the time believed that physical phenomena such as heat and electricity were subtle fluids that carried physical properties but did not posses any mass. Electricity can travel from one object to another, creating physical changes in each object, but the increase in electricity doesn't seem to increase the weight of the electrified object.

To explain these phenomena, scientists postulated that electricity and heat were subtle fluids. This original hypothesis still influences our imagery and language when we speak of electricity as "flowing." The key theoretical problem with electricity and heat, as with gravity and other forces, is how to explain action at a distance that doesn't involve the transfer of any kind of massive substance. Thermometers were measuring something and a subtle fluids theory helped explain what exactly they were measuring. Newton introduced a similar theory to help explain the action of gravity over distances by arguing that the force acted through ether.

Electricity was an extremely popular avenue of research during the enlightenment. Although electricity was first just thought of as a natural oddity, over time, mostly due to increased rigor and ingenuity in experimentation, electricity moved from a natural novelty to a central concern of scientific research. Scientists developed several ways of producing electricity during this period, though most devices used some form of static electricity. One scientist, Dufay, discovered that different types of materials, some vitreous and some resinous, would produce different kinds of electricity that would repel electricity produced from the same kind of material.

Because of this phenomenon, scientists speculated that two kinds of fluids were involved in electricity, vitreous and resinous. One dissenter to this "two fluids" model was Benjamin Franklin. Franklin, heavily influenced by Newton proposed an One-Fluid theory that claimed that electricity was an "atmosphere" that was attracted and repulsed by variations in atmospheric pressure. Franklin's theory was an example of the Newtonian method of reducing phenomenon to a rule that was useful in predicting phenomenon, but not in explaining it. Franklin freely admitted that he was just speculating in his One-Fluid theory but believed his speculation would be more fruitful than a Two-Fluid theory. Franklin claimed that his experiments with electricity showed hat the One-Fluid theory could explain more than Dufay's theory. Eventually the "atmosphere" theory would be thrown into doubt, but the move to operational rather than explanatory theories would continue.

Volta's experiments with the Leyden jar and his stacks of cakes showed that the atmosphere and fluids theories must be mistaken. Volta created a crude battery out of materials lying around his laboratory to generate an electric charge that was not depleted. This result showed that electricity could not be either an atmosphere of two fluids because either one of these things would be depleted eventually; whereas, Volta's charge was not depleted. A related experiment by Galvani involving frog legs hinted at something further. He found that a dissected frog leg would kick in the presence of electricity. This device, the frog leg, was the most sensitive detector of electricity available at the time and allowed for more minute measurements. Volta, experimenting further, created a constant electrical current out of his crude battery. After these experiments, electricity was metaphorically still thought of as a fluid, though the actual mechanical "subtle fluids" theory was dropped.

Heat, like electricity, was also the subject of investigation and theorizing during the enlightenment. According to Aristotle, heat was a quality like color rather than a quantity like height. Galileo's thermometer, crude as it may have been, disproved Aristotle, however. If heat could be measured, it must be a quantity of some sort. In the mid 18th century, Anders Celsius created a scale and a mercury thermometer to measure heat more effectively. Thermometers only measure temperature, not heat, though. As some scientists at the time pointed out, a five-gallon container heated to 95 degrees will have five times as much heat as a one-gallon container heated to 95 degrees, though they both have the same temperature. This led some to believe that heat was a fluid and that the thermometer measured the density of the heat fluid.

This theory was rejected, though, when it was found that volume and mass had nothing to do with the temperature of an object. Instead, Black and Wilcke noticed that far more energy was required to heat a block of ice than was required to heat water to the same temperature. These experiments led to a theory of specific and latent heat. Later once experimental devices were improved, the fluid theory was rejected completely and instead a theory of heat as a mode of motion rather than as a fluid became popular. Still, the fluid theory helped account for the conservation of heat and other heat properties so scientists continued to use the fluid theory even though they claimed to actually believe the mechanical motion theory was correct. In the case of both electricity and heat an erroneous theory, that of "subtle fluids, though ultimately proved false was extremely useful in the development of modern theories of physics.

Chapter 4, Chemistry

Chapter 4, Chemistry Summary and Analysis

As mentioned in the last chapter, before 1750, Chemistry didn't really exist as an avenue of scientific inquiry. Alchemy was the province of magicians and mystics, not a rational, scientific discipline. While alchemy was effectively disproved by the chemical revolution of the 18th century, at the beginning of the century Chemistry was still the province of doctors and alchemists. Although there were significant theoretical changes in chemistry towards the end of the enlightenment, at the beginning it was practical developments in industry and medicine that led to developments in the science. Newton and others hoped that by explaining chemical processes in terms of the mechanics of atoms, they could reduce chemistry to physics. Chemistry was never reduced to mechanical physics, though both sciences share some similarities. The developments in Chemistry were more practical than theoretical, with old distinctions and categories being clarified and rationalized by the new Chemical science, rather than being completely eliminated.

Early debates attempted to understand chemical properties in terms of the Aristotelian categories of Earth, Wind, Fire, Water. The revolutionary development that led to theoretical changes in chemistry started with the discovery that air was not an element but rather a state that other materials could be in depending on the other properties of the matter. The discovery of air or gas as a state of matter began with the discovery of evaporation. Originally it was thought that only water evaporated, but in experiments with alcohol on thermometers, a group of French scientists discovered that alcohol would also evaporate. It was believed that the alcohol was dissolving in the air, but, contrary to the predictions, the evaporation increased in a vacuum where there is no air. Turgot, the French scientists and economist, speculated that the evaporation was the result of heat removing the attractive force of the matter allowing it to expand into the vacuum. Turgot was only partly correct and his theory of "vaporization" could only explain some phenomenon; however, his answer to this problem did push many practical chemist to discover the "oxygen theory of combustion." The key idea that started to come out was that physical states were common to all elements and varieties of matter, not specific to any specific type of matter.

Later, Joseph Black preformed several experiments on magnesia alba, dissolving it in a variety of compounds to prove that there was more than one variety of "air" trapped in the substance. He discovered, what he called, "fixed air" (CO_2) that had many different properties from ordinary air. Another scientist, Cavendish, discovered what he called "inflammable air" or Hydrogen gas. In a series of systematic experiments, Joseph Priestly discovered several other types of "air" including nitrous oxide, hydrogen chloride, and ammonia, as well as pure oxygen. These two discoveries, the discovery of gaseous states and the discovery of various "airs" combined with the next discovery, the discovery of the nature of combustion, to form the basis of modern chemistry.

The man to make the discovery of the nature of combustion was the founder of modern chemistry, Lavoisier. Boyle had discovered that air was necessary for combustion and that flames would die in a vacuum. After a series of experiments, Boyle, Hooke, and Mayow developed a theory that "air" was necessary for matter to dissolve into during combustion. German experimenters developed another theory based on the notion of the "phlogiston." The theory held that some kinds of matter contained "oily earth," that is, Phlogiston, which is released in combustion. Different kinds of air absorb phlogiston; however, Boyle had shown that because of the changes in weight through combustion, Phlogiston must weigh nothing. This result was very problematic for the theorists, but they adopted the phlogiston theory as a working hypothesis and used it to help suggest new research programs. By the time Lavoisier began his experiments, the phlogiston theory had been popular for about 20 years in Europe.

The genius of Lavoisier and what set him apart from other researchers at the time was his single-minded dedication, ambition really, and his exacting, meticulous experimentation. Lavoisier eventually postulated that phlogiston was not in the matter that burned, but rather in the air that is needed for combustion. He found that heated matter weighted the same after heating as before, but that when heated in sealed container, air would rush into the container after heating and add weight to matter. He believed this proved his theory that phlogiston was in the air not matter. He knew, though, that "fixed air" or CO2 would put out fire so he speculated that air was made up of several different gasses. He found that "eminently respirable air," which he named oxygen was necessary for combustion. Lavoiseir, in experiments with "flammable air" (hydrogen) and oxygen, was able to create and separate water into its chemical parts. In so doing, Lavoisier further developed the oxygen theory and showed that air and water, as well as fire, three of the Aristotelian elements were really compounds.

Lavoisier's discovery led not only to theoretical developments but also to changes in chemical terminology; many substances were described by how much oxygen they contained, most notably acids. This terminology is still used by chemists. With the oxygen theory and the reform of chemical terminology, the last vestiges of alchemy and Aristotelianism were banished from chemistry.

A later development was the introduction of atomic theory to chemistry. John Dalton, a meteorologist noticed that different gases reacted to gravity differently and speculated that gases were composed of atomic structures. Through experimentation and further rationalization the atomic theory advanced into modern chemistry. Heat and fire were not completely understood until the 19th century, but the basis of thermodynamics was already in place.

Chapter 5, Natural History and Physiology

Chapter 5, Natural History and Physiology Summary and Analysis

The term "biology" didn't begin to be used until the end of the 18th century. Before that time and during the enlightenment, "natural history" and "physiology" covered the subject matter we now think of as biology as well as several other subject areas. In the pre-enlightenment world, still under the sway of Aristotelian distinctions, "nature" referred to anything that was not created by humans. There was much dispute about the similarities and differences between different areas of nature, as well as how humans, especially human physiology fit into the general natural scheme. Natural history and natural science started out during the enlightenment as a purely descriptive science, classifying and organizing the natural world.

In the beginning, scientists avoided looking for causes in nature and were unable to make sense of how the natural world worked. Over time, the descriptive enterprise led to speculation and theorizing about causes, though without more advanced techniques and material, enlightenment scientists were unable to take the next theoretical steps to understand natural causes. At the outset of the enlightenment, medical doctors and pharmacists dominated the study of natural history and physiology, though as advances were made in Chemistry and Physics, some experimental philosophers or natural scientists begin to take a more active role in natural science.

The dominant view at the beginning of the enlightenment was still the mechanical philosophy of Descartes. He argued that every object in nature aside from the human soul operated in a mechanical fashion and that all action was controlled by inert particles of matter. He believed that the human soul was different in kind from inert matter and possessed different properties. He went so far as to argue that animals were a type of automata, like a robot, that didn't posses a motive force aside from the mechanical forces that people like Newton described. This was obviously a mistake, but the idea was simply a confusion between description and cause. The mechanical physics of Descartes and Newton could describe the motion of animals, but just because their motion could be modeled by the dynamics of Newton, it didn't follow that there was nothing else going on in animals or plants. The desire to describe nature would lead to more and more refinements of the Cartesian view, ultimately leading to its rejection as untenable.

The mechanical model didn't provide any explanation of the underlying physiology of animals. Because of this, scientists moved to an increasingly phenomenological approach to the science. They would catalog and link the phenomena of life, but they would avoid trying to explain the underlying root of the phenomena. This practice is an experimental approach that was popular among many of the more practical-minded scientists of the time. There was another advantage to the phenomenological approach, namely that it avoided any religious questions that might arise from investigating causes.

The mechanical philosophy, though materialistic in some sense, postulated that God had created the harmony of order and complexity in the universe. So long as the mechanical explanation held, natural history could be understood as an extension of natural theology. Science would need not conflict with religion. It was only in the 19th century with Darwin that this view was eventually defeated. Using the mechanical philosophy as an underlying assumption also allowed scientists to dispense with any account of "souls" or animating forces. If all of nature, aside from humans, possess locomotion and action in virtue of their mechanical properties, a full description of nature will be a phenomenological one. This was the project that animated many of the early investigators, though their views would inevitably change over time.

Experimental physiology began as a move away from the mechanistic view that the body is composed of pumps, pulleys, etc. to a science that studied physical processes such as regeneration, growth, and nutrition. From Galvani's early experiments with frogs, scientists knew electricity could cause movement in limbs of animals, living and dead. Scientists at the time didn't understand exactly how electricity affected animal limbs, but it gave them a starting point for investigation. A series of experiments also showed that different kinds of "airs" affected plants in different ways, discoveries that would have an affect on the understanding of digestion later in the enlightenment.

At the time, scientists were divided on the causes of movement in animals. Some believe there was a vital force inherent in all matter that caused motion; Leibniz held this view; others believed that nature was fundamentally mechanical and that only humans possessed a vital force, a soul. Although most practicing scientists avoided this debate altogether, the argument between mechanists and vitalists raged in the background. A series of experiments regarding digestion seemed to provide evidence against the vitalist view when it was found that chemicals in the stomach caused digestion by breaking down food matter into constituent parts.

The problem during this period is that neither view really accounted for the experimental evidence. This fact became increasingly clear in the experiments about regeneration. Researchers discovered that a certain kind of aphid was able to reproduce itself asexually. Another set of experiments on polyps found that the polyp could regenerate itself from any part that was cut off. Both of these results were problematic. In the case of the polyps, if any part of the polyp could regenerate another whole organism, this seemed to suggest that the soul must be distributed, if it existed at all.

The mechanical theory followed Aristotle in assuming that every substance must have the potentiality of its final form. This led some scientists to believe that miniature animals actually existed in eggs that were released when connected with sperm. Further investigation with humans and plants, however, showed that both the mother and father contributed to the traits of the offspring, hence the egg could not really contain a miniature, somewhat fully-formed animal in any form.

During this period there were also advances in taxonomy and geology. The changes in geology may not have seemed like much at the time, but the theories that they would lead to in the 19th century, specifically the theory of plate tectonics, would set the stage for the development of evolutionary theory. Furthermore, Linnaues and his work in botany and taxonomy would create the framework that is still used in the natural sciences for the categorization of plants and animals. All these developments led to the foundations of the modern sciences of biology and ultimately to the theory of evolution.

Like developments in chemistry and physics, though, it was not until the 19th century that these sciences would emerge into full maturity.

Chapter 6, The Moral Sciences

Chapter 6, The Moral Sciences Summary and Analysis

The scientific and rational mindset of the enlightenment wasn't limited to the natural sciences. Enlightenment thinkers believed that mankind and society were also the proper subject of study and sought to develop a new "social science" that would put ethics and politics on the type of firm foundation they had developed for subjects like chemistry or physics. One of the leaders in this movement was the one of the same scientists that had been instrumental in the development of chemistry, Turgot. Turgot was made finance minister and controller general of France under Louis XVI during a time of increasing turmoil and financial instability. Turgot believed that if he rationalized policy to be more in line with what he saw as man's nature, he would be able to create an objective science of politics and stabilize the French system.

Since men and women are the same all over the world and because reason is universal, it should be possible (as Turgot and other enlightenment thinkers believed) to develop a science derived from the laws that govern human reason and use those laws to develop a science of politics and society. Different groups of enlightenment thinkers developed different approaches to developing social science. Scottish philosophers, chief among them Adam Smith and David Hume, used the uniformity of human emotions and moral sentiments as the basis of their science of man. Rationalists, typically in France, founded their social science on a mathematical derivation of human rights and duties from precepts of pure reason. In both cases, the success of each approach in the natural sciences encouraged those who sought to extend the investigation to social science. They also sought to ground any future science of human action and politics on a firm foundation of nature and natural facts, rather than on revelation from religious sources.

A key development along these lines was Montesquieu's Spirit of the Laws. Montesquieu argued that legal and political systems should suit human nature. He also argued that while human nature was in some important senses universal and fixed, men's temperaments are affected by external conditions, most notably, by climate and geography. Paradoxically, showing differences in human behavior in different climates could support the arguments in favor of a universal human nature if the variation was stable and the result of external conditions. Confident of his evidence for the existence of a universal and general human nature, Montesquieu investigated history to determine the similarities in forms of law to try to find the "spirit" underlying all proper law that accord with human nature. His book, outside of France and inside France, was one of the most popular and respected books on politics during the enlightenment.

The other great work in the moral sciences during this period was also French and endeavored to become the greatest collection of knowledge in the world, the Encyclopedia. Francis Bacon had originally encouraged an encyclopedia to collect and organize the sum of human knowledge. A French publisher eventually arranged the funds and hired Diderot and D'Alembert as editors. Diderot was heavily influenced by Bacon and divided the work into the categories of knowledge that Bacon laid out in his great works. Diderot and D'Alembert claimed that they attempted to find the best authors in the world to write the articles on a subject, but many argued that the work was a piece of materialistic and atheistic propaganda. Diderot and D'Alembert both began as rationalists in the French tradition, though over time, probably due to his work on the Encyclopedia, Diderot's interest turned more and more to Chemistry and natural history, while D'Alembert's interest was still firmly rooted in mathematics. These differences alienated the editors from each other and others, but despite their differences, both men worked on the Encyclopedia, which became a center for enlightenment science during the period.

A figure that figures heavily into the history of Enlightenment thought, though is to a great extent a critic of the enlightenment, is Rousseau. In some ways, Rousseau was reaching back to an earlier view of man and politics in his discussion of political virtue, though his understanding of reason was firmly based in enlightenment thought. Rousseau believed men had corrupted themselves in society and that society needed to be reformed to reflect the truth in men's heart for them to be truly free and virtuous. Still, Rousseau is not so different from thinkers such as Montesquieu, at least in the abstract. Both were very concerned to show that the proper basis of social institutions and morality was in the facts of nature, specifically human nature. They disagreed on the substance of those facts, but nature, despite its content was still the basis of social intuitions.

Another group of men that sought to put social institutions on form foundation of nature were the Physiocrats. These men believed society needed to be in accord with nature to be healthy and attempted to transfer economic and political intuitions to meet this end. In opposition to the Mercantilist orthodoxy of the times, the Physiocrats believed that agriculture, not manufacturing was the key to a nation's economic health. They also held that the only taxation that was justified was taxation of agricultural land. Although the Physiocrats have been largely exonerated over the course of the last several centuries, their land tax proved disastrous for France. Turgot, a noted Physiocrat, became finance minister to the king and instituted his tax plan, which enraged the countryside and increased the internal turmoil in France, eventually helping lead to the Revolution.

It was the British though, specifically David Hume, who created an interest in probability by showing how deterministic theories of human action could not explain what they claimed. Probability had been important in commerce and in law in the past, but it wasn't until the enlightenment that the science developed into a separate field of inquiry. In the enlightenment, some, most notably Condorcet, applied these new developments in mathematics to political theory. Condorcet developed a method, based on probability to determine the accuracy of jury results based on how many people sat on the jury known as the Condorcet Jury Theorem. He also developed a method of elections known as the Condorcet method to correct for the indeterminacy that occurs in most electoral situations. This theory of elections was also, potentially an attack on Rousseau's notion of the general will. A deep skepticism about democracy coupled with a commitment to liberal principles colored his work. It was Condorcet's commitment to using mathematics so as to develop a scientific approach to politics that ended up being his primary legacy; he is now considered one of the important founders of modern social science.

The Revolution in France was devastating to the enlightenment pursuit of science in that country. Many of the leading experimenters and scientists were killed in the terror including the great Lavoisier and Condorcet. The genie had been let out of the bottle and despite the disruptions of the wars of liberation, science continued upon the path that had been set during the enlightenment.

Characters

Isaac Newton

Newton was one of the chief forces that led to the development of science in the Enlightenment. Although most of his work was done prior to the Enlightenment, the force of his work, especially his developments in Physics and Mathematics, inspired others and gave them the tools necessary for more advanced scientific study. His development of calculus and laws of motion as well as his theory of gravity were revolutionary. The calculus allowed more advanced modeling of motion and the development of a scientific approach to physics. His laws of motion and theory of gravitation showed the type of conclusions that careful analysis of nature could lead to and inspired scientific inquiry all over Europe.

Despite the enormity of his scientific contributions, second to none in the history of science, Newton may have actually been more important during the Enlightenment for his method. His method became the ideological and philosophical fountainhead of all Enlightenment thought. He believed that nature was ordered by laws that could be understood by human reason and hence, men should use reason to discover potentially all the laws of nature. This was notable because Newton is claiming first that laws, which must, in some sense, not change, govern nature. He is also claiming that men can know these natural laws through reason, rather than through revelation. This was radical because in effect if not intention, his approach undermined the Scholastic and Aristotelian orthodoxy. According to Scholastics, who also held to a natural law view, knowledge of ends was necessary for knowledge of properties of things. Newton rejects this view and argues that direct investigation of events will lead to knowledge of laws.

Francis Bacon

Bacon was a 16th Century English philosopher, scientist, and statesman. During the reign of Elizabeth the first of England, Bacon became Attorney General for the Queen. Bacon was an outspoken and influential advocate for a new method in science and philosophy. England, since the reign of Henry VIII, was a protestant country outside the rule of the Catholic church. This fact allowed Bacon to challenge the intellectual orthodoxy of the Catholic church, especially the dominant Aristotelian scholasticism and to pose his alternatives. Instead of a focus on deductive reasoning from first principles or ends, Bacon proposed a method that relied on induction and observation to generate regularities that could then be tested. This Baconian method became known over time as the scientific method.

Bacon's views were radical, and he challenged his contemporaries and his followers to use his method to wrest the secrets of nature from the jealous guarding of nature herself through uncompromising investigation. Bacon was an influence for Newton who developed Bacon's method in a different way and is generally considered to be one of the great antecedents of the Enlightenment and of modern science. Bacon's work, the Novum Organum, was a direct challenge to Aristotle and proposed a new way to understand logic. Bacon also wrote Utopian texts, and though the idea is controversial, some believe that Francis Bacon is the true author of Shakespeare's plays. Whether or not he wrote the plays attributed to Shakespeare, he is certainly one of the greatest thinkers in the history of the world and was a hero and inspiration to many Enlightenment thinkers.

Immanuel Kant

German philosopher in the 18th century who argued in his paper "What is Enlightenment" that true enlightenment is being guided by the power of reason and bound by rules that one makes for themselves in accord with reason. He is also the author of one of the greatest works of speculative metaphysics and Epistemology, the Critique of Pure Reason and influential works of ethics and politics. He attempted to combine the two dominant philosophical strands of the time, empiricism and rationalism, though his work, especially in ethics and politics, has a heavy strand of rationalism. Extremely religious, Kant sought to show that religion was compatible with the Enlightenment view, though the success of these attempts is not clear.

Rene Descartes

Great French mathematician and philosopher who developed the first systematic alternative to Scholasticism, a kind of rationalism. He was also responsible for the development of analytic geometry, a very important contribution to pure mathematics and physics. His views were also influential in the debate over generation and motion. He held a mechanical view, in line with his philosophical dualism, that body and mind are wholly separate and hence, all bodies without minds (animals, rocks) are nothing more than automata like a robot.

D'Alembert

He was a French mathematician and editor of the Encyclopedia. Unlike his friend Diderot, D'Alembert confined his studies to mathematics and physics and is still known for one of his contribution to mechanics. An atheists and rationalist, D'Alembert was a central figure in the Enlightenment because of his position as a popularizer and a propagandist of Enlightenment theory.

Voltaire

He was a French writer, most known for his novel Candide, and popularizer of Enlightenment views. Voltaire had an effect in every area of the enlightenment and was influential in connecting other thinkers as much as for his own ideas. A religious dissenter, though not an atheist, and proponent of social reform, Voltaire was a great champion of the ideas that later led to the American and French Revolutions.

Malebranche

He was the chief follower of Descartes; Malebranche sought to extend Descartes philosophy. A proponent of the mechanical view, Malebranche believed God needed to play a role in the everyday occurrences of motion; in this way he differed from Leibniz and other believers in the Vis Viva view.

Lavoisier

He was a French nobleman responsible for the development of modern chemistry. He developed and popularized the Oxygen theory of combustion and effectively destroyed the Phlogiston theory. He was responsible for naming Oxygen and Hydrogen and was the first to discover water was composed of hydrogen and oxygen. Known for exacting Scientific methods, he was eventually killed by the Jacobins in the French Revolution reign of terror.

Condorcet

Great French mathematician and father of modern quantitative social sciences. He sought to base investigation into human nature and social institutions on a firm mathematical foundation. A proponent of democracy and social change, Condorcet developed several ideas which are still considered important today. Eventually killed by the Jacobins during their reign of terror.

Rousseau

French philosopher known for his arguments that society corrupts the natural goodness of mankind and that social institutions should be reorganized to be instruments of the general will. A great influence on Kant, Rousseau is an important Enlightenment figure though many of his views seem alien to some of the generally held views during the enlightenment.

Diderot

French scientist and co-editor of the Encyclopedia with D'Alembert. Diderot wrote the famous and influential introduction to the Encyclopedia that codified many important Enlightenment ideals. He was attracted, more than D'Alembert, to natural science and was probably closer to empiricism than many of his countrymen.

Leibniz

German enlightenment philosopher and mathematician who developed calculus at about the same time that Newton did, though Newton was given most of the credit. Devoutly religious, Leibniz held that a life force the Vis Viva, was present in all things and was ultimately the cause of motion. In this, he disagreed with Newton and Descartes. His views, though sometimes strange, have been vindicated in many ways by modern science.

Objects/Places

Enlightenment

The Enlightenment is the period of European history, primarily in France, Germany, and Great Britain during which there was an explosion of scientific discovery and an emphasis on the power of human reason. The enlightenment is a diverse phenomenon, but several ideas dominate the thinking of this period: the universality of Reason, the importance of natural over supernatural explanations, and the importance of new science as a tool for human betterment and advancement.

Encyclopedia

A project undertaken in the mid 18th century in France to collect and organize existing knowledge about science and philosophy. Diderot and D'Alembert edited the encyclopedia and Diderot wrote the introduction, which is taken to be the clearest embodiment of, at least French, enlightenment thought.

Natural Philosophy

In the 18th century, at least at the beginning, there was no clear distinction between philosophy and science as all scientific study originally started as philosophical inquiry. Natural philosophy referred to any area of investigation dealing with natural facts, also called experimental philosophy.

Aristotelianism

The dominant philosophical tradition in Europe from the 13th to the 18th century. The philosophy is especially concerned with finding the "ends" or functions of things in nature and determining their properties from an analysis of their ends. This philosophy was rejected by scientific empiricism in the enlightenment, which rejects the notion of proper ends and instead looks to investigate the properties of things directly without reference to ends.

Ancien Regime

Name for the French state before the revolution, often used to refer to any non-democratic, non-enlightened regime in the 18th century.

Phlogiston

A theory of combustion that argued that combustion occurred because of the presence of a property of heat or Phlogiston in matter. The theory was decisively overturned by the advent of the Oxygen theory of combustion and the work of Lavoisier.

Subtle Fluids

An early attempt to explain the properties of heat by reference to invisible fluids.

Leyden Jar

Early invention used to store electricity, basically a capacitor, for experimental purposes.

Vis Viva

A theory proposed by Leibniz to explain motion and generation that claims that force is conserved because the energy in question is contained in all things and is transmitted during motion.

Condorcet Jury Theorem

Probability theory developed to predict the accuracy of a group of people coming to the correct decision based on the number of people deciding. An important development in the enlightenment that is still used in the social sciences.

Scholasticism

Dominant educational and philosophical school in Europe from the 11th to the 18th century. It is a combination of Catholic theology and Aristotelian exemplified in the work of Thomas Aquinas. The enlightenment is largely a move away from and an attack on Scholasticism.

Rationalism

The philosophical tradition that sees unaided reason as the key tool for discovering truth about nature and man. Rationalists tend to be interested in mathematics and see the mathematical method as the preferred method for science in general. Rationalism is especially prevalent in France during and after the enlightenment.

Empiricism

In many ways, empiricism is the opposite and chief competitor to Rationalism as a method in science and philosophy. Investigates particular phenomena to determine general properties of things and uses natural science, especially biology as its model. Empiricism is especially prevalent in the English speaking world during and after the Enlightenment.

Themes

Mechanical vs. Vital Explanations

One of the key disputes during the enlightenment was between mechanical and vital explanations of natural phenomena, especially motion. The proponents of the mechanical view included Descartes and Newton, while the vitalists were led by Leibniz. Mechanists held that the physical world was purely a world of matter and that God's direct intervention was necessary for motion to occur. That is, force was explained in some sense by the intervention of God. Descartes, a famous proponent of the mechanical view held that mind and body or soul and matter were two, completely distinct types of things and that only the human soul had the motive force that is characteristic of mind or soul; whereas, the rest of the universe was composed of matter without the animating force of soul. To explain the motion of inanimate matter, Descartes and others argued that an animating force from God was required. This led to the odd result that the primary rationalists were also the main proponents of the direct intervention of God in daily life.

Vitalists on the other hand held that soul and body were actually untied and that all matter included a life force or a Vis Viva that created the possibility of motion. Another implication of this view is that all matter is potentially conscious, the view known as panpsychism. Despite the strangeness of both of these views, they represent an attempt to come to terms with an explanation of phenomena that is explicable by reason. It also shows the connection between philosophy and science in the Enlightenment. During this period, scientists attempted to explain everything based on an overarching theory; later scientists moved to leave some constructs like "force" somewhat unexplained. Although the enlightenment thinkers sought to explain natural phenomenon without recourse to revelation, there were still genuine mysteries about how to explain certain phenomena and God without recourse to revelation.

The Power of Reason

Immanuel Kant in his seminal, "What is Enlightenment?" argues that the primary characteristic of the enlightenment is the primacy of reason in all human affairs. Enlightenment, Kant argues, is a type of spiritual and philosophical maturity where we realize that only reason can be our masters and we see that we must subjugate our passions and our religion to the force of reason. Kant also argues, however, that while all things should be subject to rational inquiry, pure reason has limited power in some domains. Kant takes this view, at least partially, from the work of David Hume who argued that pure reason had an even more limited domain. So, though all Enlightenment thinkers believe, as Kant does, that reason should rule our behavior, many disagree about what constitutes reason and what the limits of reason are.

The two main approaches to philosophy that start to emerge in this period, empiricism and rationalism, differ primarily in what they believe to be the proper use and scope of reason. Empiricists, following Bacon and Locke, believe that reason's power is to develop generalizations of phenomena and to test these generalizations. All knowledge, though, ultimately comes from observation. Rationalists on the other hand often seem to hold that the power of pure reason without observation is able to generate most if not all of the important scientific and philosophical truths. Despite their differences, though, it is important to see that both of these views make the use of human reason primarily over any other way of attaining knowledge. This is in opposition to the view that religious revelation and authority are necessary for knowledge about the universe. The reliance on reason is common today, but in the Enlightenment it was considered revolutionary.

Naturalism

Naturalism was an important component and development of the Enlightenment, though their naturalism was considerably different form modern naturalism. Naturalism in the Enlightenment meant an interest in the functioning of the natural world, primarily an interest in the functioning of specific phenomena. This may seem odd, after all, what else would they be studying if not the natural world?

Before the development of Bacon's scientific method and Newton's calculus and theory of mechanics, though, much of the knowledge and theories of nature were explicitly philosophical. Aristotelian categories of Earth, Air, Fire, and Water were still used throughout the period leading up to and during the Enlightenment. It was thought, by Aristotelians that through understanding the necessary interactions between elements and the natural ends of things, it was possible to deduce the characteristics and properties of nature. Despite the fact this method had shown no progress during the several centuries leading up to the Enlightenment, it was still embraced until it was chipped away by Enlightenment thinkers.

We have already seen that what enlightenment thinkers mean by "Nature" varies considerably; still they typically understand that inductive methods are necessary to understand nature as it is, rather than as Aristotle may have believed it was or as it should be. This led to the view that nature was the primary fount of knowledge rather than revelation or supposed laws of metaphysical necessity. In many ways then, though there was much metaphysical speculation during this period, metaphysics as an investigation of nature was permanently displaced by science during the enlightenment.

Style

Perspective

The story of the enlightenment is told in a synoptic manner, and the author assumes that the reader has some knowledge of the period. The author is clearly sympathetic with the overall flavor of Enlightenment thinking, though it is not at all clear how deep this sympathy runs. The author is a historian and is concerned with the historical details of the Enlightenment as well as the interrelationships between different Enlightenment thinkers. This book is meant to be an introductory study, though some issues are investigated in depth. It is clear though that the author is not attempting to develop any special theory of the Enlightenment, rather he is merely trying to present a survey for someone who wants to learn more about the Enlightenment, that is, someone who has some knowledge of the period but is by no means an expert.

At the end of the book, there is a bibliographical essay explaining what works the authors used in the research for the book. He cites Foucault, a notable and influential critic of the enlightenment as an influence, suggesting that the author's apparent sympathy towards Enlightenment thinkers should be tempered. It is clear though that whatever his ultimate views regarding the Enlightenment, the author clearly sees the developments in this period to be a huge improvement over Aristotelian thought. Furthermore, the author takes the general structure of the Encyclopedia as his own structure, indicating that he at least considers the Encyclopedia to be of the utmost importance to Enlightenment thought.

Tone

In terms of tone, there is almost nothing noteworthy about the author's tone in this book. As already mentioned, the author clearly has an interest and some sympathy with Enlightenment thinkers, though it is not clear how far that sympathy extends. The author writes in the measured, almost anonymous, style of modern, academic history, and if he intends to ridicule or support one view over the other in the text, this would be hard to determine from the measured, cool tone of the book.

Despite the measured tone, however, there does seem to be a delight in the accomplishments of these thinkers. Indeed, it is easy to feel and share this excitement with the author. In these pages we learn about the quest and often acquisition of knowledge by some of the greatest minds in human history. Despite later attacks on Enlightenment thinkers (critiques, which this author may accept though that is not at all clear from the text here) it is not hard to see how a historian, even one whose sentiments have been molded by the practice of his discipline would marvel at the men chronicled in these pages. It is no surprise that the author ends his work on the moral sciences and his tone becomes a little more enthusiastic when he is discussing these men. All in all, though, partly form the nature of the subject matter and partly, no doubt, to the standards of his discipline, the author adopts and maintains an even, measured tone throughout the book.

Structure

The structure of this book is, for the most part, straightforward. The book is 216 pages and is composed of six chapters. Each of the chapters, except for the first chapter, which functions as a kind of overview of the Enlightenment, is dedicated to one science or several sciences that were developed during the enlightenment. The chapters proceed in a development from the most abstract of the sciences, mathematics, to the least abstract, moral sciences; or, rather, maybe the proper way to distinguish these chapters in not by level of abstraction but by their connection to observation.

Mathematics was seen as fundamental to all other sciences and was the product of pure reason, that is, not the result of observation. Physics on the other hand, is the product of mechanical dynamics—itself a kind of applied mathematics, but at some level requires and uses observation. Chemistry and natural history become more and more observational and experimental and moral sciences like economics, ethics, and politics while involving theories, are the product of observation.

Maybe the author is trying to say that while the Enlightenment begins with pure reason and mathematics, the culmination of Enlightenment thinking is in the human or social sciences. This would, in itself, be an interesting thesis as it sometimes held that the Enlightenment subjugated actual men to the theoretical devices of scientists and turned society into a kind of machine; the author may be suggesting the opposite, that is, while reason is the ostensible end of Enlightenment thinking, it is really people, not abstractions that concern the Enlightenment thinkers.

Quotes

"Objectivity was the opposite of self-interest and ambition; the natural philosopher served mankind rather than himself." (7)

"The ideology of the Enlightenment tended to make natural philosophers into heroes, and in France the greatest hero of all was Newton, partly because he was from England, the source of free thought and liberty in the minds of Frenchmen like Voltaire and Montesquieu, but also because he solved the riddle of the planets, showing that their motions obeyed the same laws as motions on earth." (9)

"Newton had advocated a method of analysis and synthesis in experiment whereby complex phenomena were to be analyzed into simple components...and then recombined by 'synthesis.'" (20)

"Newton believed that the universe would run down if it were not for God's intervention to renew his creation." (33)

"In fact, the Chemical Revolution was more the creation of a new science than a change in an existing one. Before 1750, chemistry could not be regarded as an independent discipline. It had long antecedents, but they were ancillary to other fields. Alchemy was a source for many of the recipes and much of the apparatus of chemistry, but this information was concealed in intentionally ambiguous and allegorical language." (81)

"The recognition of the vaporous state meant that chemists for the first time understood that the ability of a substance to completely fill its container did not mean that it was a single chemical element." (85)

"...absolute dichotomies in the history of science always gets us into trouble, because it ignores the middle ground that and the fact that most scientists are more interested in their experimental results than in global theories such as mechanism and vitalism." (120)

"According to Turgot, the solution was to develop a new objective science of society, founded on the constraints of human nature and the mutual needs of all men and women." (159)

"What Turgot wished to establish was a social science." (159)

"Most particularly they believed that human actions should be regulated by nature and not by precepts taken from the Bible, and they believed natural science gave insights into the workings of human nature." (161)

"In every case Rousseau's message was that man is born in a state of virtue and that society has corrupted him." (174)

"...the Physiocrats ...believed that the improvement of society could be brought about by making economic activity agree more closely with the laws implanted in nature by Providence. History had no value for them." (175)

Topics for Discussion

Explain the dispute between the vitalists and the mechanists.

Why was Newton so important to the Enlightenment?

Explain the difference between the ideology of the Enlightenment and Aristotelian theories of science.

What role did religion play in the Enlightenment?

How are Enlightenment views with us still today? How are our modern views different?

How were the French and English Enlightenment movements different?

What is Enlightenment?