EDITOR'S INTRODUCTION: SCIENCE AND MEDICINE

This volume presents the science and medicine articles from the five-volume reference set *Applied Science*, for the benefit of students considering careers in science or medicine, their teachers, and their counselors. Other volumes cover technology, and engineering and mathematics.

Something should be said at the outset about the relationship between science and technology. Terence Kealey states in his book *The Economic Laws of Scientific Research* (1996) that technology is the activity of manipulating nature, while science is the activity of learning about nature. For much of history, the two realms were relatively separate, technologies being developed by artisans, craftsmen, and farmers and the sciences by natural philosophers. Leonard Mlodinow, in *Feynman's Rainbow* (2003) makes a distinction between the Greek way of approaching science and the Babylonian way. The Greeks, the great mathematicians of the ancient world greatly admired pure thought. The Babylonians, technologists at heart, didn't care much about fine theoretical points but made important practical discoveries. The two realms began coming together at the time of the Industrial Revolution. In England the process was tied to the emergence of the Royal Institution, founded in 1799, which made it possible for the general public to learn about technical matters in their spare time and without the training in classical languages and the social standing expected at the universities of Oxford and Cambridge. At about the same time, these august institutions were joined by the "red brick" institutions, which emphasized the training of students for industrial leadership. In the United States, the venerable Ivy League schools, including Harvard, Yale, and Princeton, were joined by the newly established state universities. Some of these were designated as land-grant colleges under the Morrill Act (1862) and were set up to advance agriculture and the mechanical arts. The Morrill Act provided that each state in the Union designate a parcel of land, income from the sale of which would be used to support public colleges and provide for agricultural experimental stations where new ideas in agriculture could be tested.

Educational practice is sometimes slow to recognize changing patterns in society. Colleges in the United States still award bachelor's, master's, and doctoral degrees that have their roots in the Middle Ages. In fact the Bachelor of Arts, Master of Arts, and Doctor of Philosophy degrees are still awarded by the majority of American universities, although the coursework required and the major subjects offered differ greatly from those of a century ago. The bachelor's degree is still awarded to individuals who have completed a four-year course of study, though the emphasis may be on computer science or psycholinguistics instead of the liberal arts. Many schools now award the Bachelor of Science degree to graduates with majors in the sciences (although some, particularly in the Ivy League, award the traditional B.A. degree to all graduates). Additional study is required for the master's degree, and a period of intensive research and the publication of a dissertation is required for the Doctor of Philosophy degree.

Despite the antiquity of the bachelor's, master's, and doctoral designations, what the degrees actually meant was, for a time, quite flexible in early-twentieth-century America. Eventually a measure of quality control was achieved, with colleges being chartered by state governments and subject to review by regional accrediting agencies and, in some fields, by additional specialized agencies.

In the sciences the Doctor of Philosophy degree (Ph.D.) became the standard expected of individuals seeking academic positions or leadership roles in government or industrial laboratories. Prior to World War II, many scientists had to complete their doctoral studies at a European university. Now, as a result of the growth of higher education, doctoral programs can be found on many university campuses. Doctoral education in the United States began at Johns Hopkins University and typically follows the German model, in which the student works under the close supervision of his or her dissertation adviser on a single research question. Doctoral programs generally include some form of comprehensive examinations testing broad knowledge of one's field of interest and often reading knowledge of a foreign language. A Ph.D. in science can lead to many career options. The late Dr. Sally Ride, for instance, the first American woman to go into space, received her Ph.D. in physics from Stanford University.

Students with a strong interest in one of the sciences can also find many satisfactory job placements below the Ph.D. level. Careers in science teaching are open to students with a bachelor's or master's degree. There is currently a critical need for science teachers with majors in the sciences. Students with bachelor's or master's degrees can work as technicians in industrial or governmental laboratories. There are also positions in the armed forces, both civilian and in uniform, and with defense contractors. Students with science degrees often move rapidly into management positions.

Regarding medical fields, the Flexner report of 1910, done with the support of the Carnegie Foundation, did a great deal to standardize medical education. Prior to the work of Abraham Flexner and his colleagues, fly–by-night medical schools existed side by side with reputable institutions, and the patient in need of a doctor could not be sure that the impressive-looking documents on the wall of a medical office guaranteed competence. The Flexner report fixed the Doctor of Medicine degree, awarded after four years at an accredited medical college, generally requiring an accredited bachelor's degree for admission. Remarkably, after the report became public, about half of the medical schools in the United States shut down. Similar standards were imposed for dentists, pharmacists, and veterinarians. Each profession has its own organization, the American Medical Association being the most prominent.

Students interested in the healing professions might also consider becoming a registered nurse, nurse practitioner or physician's assistant. The course of study for these occupations generally takes fewer years than the M.D. degree and emphasizes practical skills a bit more than theory.

To the Student

Your decision to enter a science based or medical field is one that, with persistence, will lead to a comfortable income and, more importantly, a variety of interesting challenges in your career. While in junior high and high school, be sure to practice writing and organizing presentations. If possible do not interrupt your study of mathematics, as mathematics courses build on each other. Resist the temptation to take an easy semester. Start or join a science or health careers club at your school. Talk with the physicians and dentists you visit and any professional scientists who might be in local industry or at nearby colleges. Visit nearby sites that employ scientists.

You are likely to be affected by two recent trends. One is the recent growth in on-line education. Although the widespread availability of computers and the Internet make it possible for students almost anywhere to study almost anything, there is still much to be said for the pre-professional socialization that goes on in college. For science majors, needing to keep to a schedule of assignments, work collaboratively with other students, develop presentation skills, and find information by research are all established aspects of college life. The second trend is the need for continuing professional education. Once you have your professional degree, you will need to attend appropriate professional society meetings. In the health-related professions, this is often a formal continuing-education requirement to retain licensure.

A Brief Survey of the Sciences and Medicine

A clear distinction between science and technology is not possible. Nor is it really possible to separate the sciences and medicine. The International Museum of Surgical Science in Chicago, for example, has a hall devoted to statues of individuals who have had the greatest impact on medical practice today. Three of the six—Louis Pasteur, Marie Curie, and Konrad Roentgen—were academic scientists without medical degrees. Today every large hospital has a Department of Nuclear Medicine; most offer magnetic resonance imaging and positron emission tomography, technologies that have moved from the nuclear physics lab into medical practice in about 20 years' time.

At the close of World War II, there was considerable debate as to the proper relationship between science and government in peacetime. Some conservatives wanted to impose strong military control over scientific research. In 1945 Vannevar Bush, who had been director of the wartime Office of Scientific Research and Development, published the report *Science: The Endless Frontier,* which painted a very rosy picture of the gains to be derived by public investment in basic scientific research. Among other things, Bush emphasized the role that government could play in supporting research in universities, research to fill in the middle ground between purely academic research and research directed toward immediate objectives. Further, universities had a natural role to play in training the next generation of scientists, engineers, and physicians. Bush's arguments led to establishment of the National Science Foundation and to expanded research funding within and by the National Institutes of Health in the United States. This trend was accelerated by the Soviet Union's launch of Sputnik 1, the first Earth satellite, in 1957, an event that shook the American public's faith in the inevitable superiority of American technology. In the twenty-first century, science and technology are supported by many sources, public and private, and the pace of development is perhaps even greater than at any time in the past.

The Preliterate World

According to archaeologists and anthropologists, the development of written language occurred relatively recently in human history, perhaps about 3000 B.C.E. Many of the basic components of technology date to those preliterate times, when humans struggled to secure the basic necessities—food, clothing, and shelter—against a background of growing population and changing climate. When food collection was limited to hunting and gathering, knowledge of the seasons and animal behavior was important for survival. The development of primitive stone tools and weapons greatly facilitated both hunting and obtaining meat from animal carcasses, as well as the preservation of the hides for clothing and shelter. Sometime in the middle Stone Age, humans obtained control over fire, making it possible to soften food by cooking and to separate some metals from their ores. Control over fire also made it possible to harden earthenware pottery and keep predatory animals away at night.

Even without language a primitive human had to be something of a naturalist and anatomist. It is certain that the medicinal properties of certain plants were discovered, and in the process of extracting meat from killed animals, a basic knowledge of anatomy was gained. There is also evidence that primitive humans performed trepanations, opening a hole in a person's skull in order to cure headaches. Such drastic procedures were not necessarily fatal. Skulls with healed trepanations have been found in ancient burial sites.

With gradually improved living conditions, human fertility and longevity both increased, as did competition for necessities of life. Spoken language, music, magical thinking, and myth developed as a means of coordinating activity. Warfare, along with more peaceful approaches, was adopted as a means of settling disputes, while society was reorganized to ensure access to the necessities of life, including protection from military attack.

The Ancient World

With the invention of written language, it became possible to enlarge and coordinate human activity on an unprecedented scale. Several new areas of technology and engineering arose. Cities were established so that skilled workers could be freed from direct involvement in food production. Logistics and management became functions of the scribal class, the members of which could read and write. Libraries were built and manuscripts collected. The beginnings of mathematics may be seen in building, surveying, and wealth tabulation. Engineers built roads so that a ruler could oversee his enlarged domain and troops could move rapidly to where they were needed. Taxes were imposed on the public to support the central government, and accounting methods were introduced. Aqueducts were needed to bring fresh water to the cities.

By 500 BCE a number of cultures were advanced enough to have a body of medical knowledge and recognize the need for physicians. The first of these conditions occurred in ancient Egypt, where medical manuscripts can be dated to 3000 BCE and surgery was practiced by 2750 BCE. The Egyptians' anatomical knowledge undoubtedly grew as a result of belief in an afterlife for which the deceased had to be prepared by mummification. The ancient Babylonians also left extensive medical texts, as did the ancient Hindus and the Chinese.

Hippocrates of Cos (450–370) BCE is often considered to be the "father" of modern Western medicine. Hippocrates is known as the author of a code of medical practice and was widely considered to be the author of the so-called "Oath of Hippocrates," versions of which are still administered by many medical schools. Hippocrates was also among the first to establish a theoretical basis for health. Building on the four-element theory of Empedocles (air, earth, fire, and water), he considered health to be a balance of four "humors": blood, phlegm, black bile, and yellow bile. Illness arose when one of the humors was present in excess. This belief led to the practice of bloodletting, one that continued until the 1850s.

The Greek physician Galen (169–217 CE) was a major influence on modern surgery. By the time of Galen, strictures had arisen against the dissection of the human body, so Galen's writings are based on his dissection of Barbary apes. In medieval universities Galen, like Aristotle, would become one of the ancients not to be questioned. By the Renaissance, however, the attitude toward dissecting humans had changed, and medical schools again allowed dissections. The pendulum may have swung a bit too far. In Renaissance Florence public dissections were conducted at Carnival time (the period leading up to penetential Ash Wednesday), with the public attending in costume, as if at a modern Halloween party.

The Scientific Revolution

The Renaissance and the Protestant Reformation marked something of a rebirth of scientific thinking. This "scientific revolution" would not have been possible without Gutenberg's printing press and the technology of printing with movable type. With wealthy patrons, natural philosophers felt secure in challenging the authority of Aristotle and Galen. Galileo published arguments in favor of the Copernican solar system. In the *Novum Organum* (1620; "New Instrument"), Sir Francis Bacon formalized the inductive method, by which generalizations could be made from observations, which then could be tested by further observation or experiment. In England in 1660, with the nominal support of the British Crown, the Royal Society was formed to serve as a forum for the exchange of scientific ideas and the support and publication of research results. The need for larger-scale studies brought craftsmen into the sciences, culminating in the recognition of the professional scientist. Earlier Bacon had proposed that the government undertake the support of scientific investigation for the common good. Bacon himself tried his hand at frozen-food technology. While on a coach trip, he conceived the idea that low temperatures could preserve meat. He stopped the coach, purchased a chicken from a farmer's wife, and stuffed it with snow. Unfortunately he contracted pneumonia while doing this experiment and died forthwith.

The Industrial Revolution followed on the heels of the Scientific Revolution in England. Key to the Industrial Revolution was the technology of the steam engine, the first portable source of motive power that was not dependent on human or animal muscle. The modern form of the steam engine owes much to James Watt, a self-taught technologist. The steam engine powered factories, ships, and, later, locomotives. In the case of the steam engine, technological advance preceded the development of the pertinent science—thermodynamics and the present-day understanding of heat as a random molecular form of energy.

It is not possible, of course, to do justice to the full scale of applied science and technology in this short space. In the remainder of this introduction, consideration will be given to only a few representative fields, highlighting the evolution of each area and its interconnectedness with fundamental and applied science as a whole.

Atomic Theory and the Nucleus

If a single idea permeates modern science, it is the atomic theory, the idea that all matter is composed of atoms. While we may owe this idea to the ancient Greek philosopher Democritus, it did not make much headway until the French savant Antoine Lavoisier published his *Elementary Treatise on Chemistry* in 1789 and the English schoolteacher John Dalton suggested, in the mid-nineteenth century, that pure chemical substances were composed of atoms in a fixed ratio. From this realization it was just a short time until the great Russian chemist Dmitri Mendeleev had arranged the atoms in the now-familiar periodic table.

That atoms were made of component parts was well established by 1900. The existence of the atomic nucleus, however, was not suspected for another decade. Once it was known that most of the mass of the atom is concentrated in the tiny atomic nucleus, held together by forces many hundreds of times stronger than that between protons, nuclear physics came into its own. While nuclear physics made possible the atomic bomb that destroyed two Japanese cities in 1945, ending World War II in the Pacific, the ability to create isotopes in the laboratory was quickly applied to the treatment of cancer, and later medical imaging, saving a great many lives.

The Beginnings of Chemotherapy

In 1792 the Scottish inventor William Murdock discovered a way to produce illuminating gas by the destructive distillation of coal, producing a cleaner and more dependable source of light than previously was available and bringing about the gaslight era. The production of illuminating gas, however, left behind a nasty residue called coal tar. A search was launched to find an application for this major industrial waste. An early use, the waterproofing of cloth, was discovered by the Scottish chemist Charles Macintosh, resulting in the raincoat that now carries his name. In 1856 English chemist William Henry Perkin discovered the first of the coal-tar dyes, mauve. The color mauve, a deep lavender-lilac purple, had previously been obtained from plant sources and had become something of a fashion fad in Paris by 1857. The demand for mauve outstripped the supply of vegetable sources. The discovery of several other dyes followed.

The possibility of dyeing living tissue was rapidly seized on and applied to the tissues of the human body and the microorganisms that afflict it. German bacteriologist Paul Ehrlich proposed that the selective adsorption of dyes could serve as the basis for a chemically based therapy to kill infectious disease-bearing organisms. Although Ehrlich's chemical theory is laughable today, it led to the first effective chemotherapy: the use of Salvarsan, an arsenic-based synthetic drug developed by Ehrlich and his team, as a treatment for syphilis.

Optical Technology, the Microscope, and Microbiology

The use of lenses as an aid to vision may date to China in 500 B.C.E. Marco Polo, in his journeys more than 1,700 years later, reported seeing many Chinese wearing eyeglasses. In 1665 English physicist (and curator of experiments for the Royal Society) Robert Hooke published his book *Micrographia* ("Tiny Handwriting"), which included many illustrations of living tissue. Antonie van Leeuwenhoek was influenced by Hooke, and he reported many observations of microbial life to the Royal Society. The simple microscopes of Hooke and van Leeuwenhoek suffered from many forms of aberration or distortion. Subsequent investigators introduced combinations of lenses to reduce the aberrations, and good compound microscopes became available for the study of microscopic life around 1830.

While van Leeuwenhoek had reported the existence of microorganisms, the notion that they might be responsible for disease or agricultural problems met considerable resistance. Louis Pasteur, an accomplished physical chemist, became best known as the father of microbiology. Pasteur was drawn into applied research by problems arising in the fermentation industry. In 1857 he announced that fermentation was the result of microbial action. He also showed that the souring of milk resulted from microorganisms, leading to the development of "pasteurization"—heating to a certain temperature for a specific amount of time—as a technique for preserving milk. As a sequel to his work on fermentation, Pasteur brought into question the commonly held idea that living organisms could generate spontaneously. Through carefully designed experiments, he demonstrated that broth could be maintained sterile indefinitely, even when exposed to the air, provided that bacteria-carrying dust was excluded.

Pasteur's further research included investigating the diseases that plagued the French silk industry. He also developed a means of vaccinating sheep against infection by *Bacillus anthracis* and a vaccine to protect chickens against cholera. Pasteur's most impressive achievement may have been the development of a treatment effective against the rabies virus for people bitten by rabid dogs or wolves.

Pasteur's scientific achievements illustrate the close interplay of fundamental and applied advances that occurs in many scientific fields. Political scientist Donald Stokes has termed this arena of application-driven scientific research "Pasteur's Quadrant," to distinguish it from purely curiosity-driven research (as in modern particle physics); advance by trial and error (for example, Edison's early work on the electric light); and the simple cataloging of properties and behaviors (as in classical botany and zoology). The study of applied science is a detailed examination of Pasteur's Quadrant.

Electromagnetic Technology

The history of electromagnetic devices provides an excellent example of the complex interplay of fundamental and applied science. The phenomena of static electricity and natural magnetism were described by Thales of Miletus in ancient times, but they remained curiosities through much of history. The magnetic compass was developed by Chinese explorers in about 1100 B.C.E., and the nature of Earth's magnetic field was explored by William Gilbert (physician to Queen Elizabeth I) around 1600. By the late eighteenth century, a number of devices for producing and storing static electricity were being used in popular demonstrations, and the lightning rod, invented by Benjamin Franklin, greatly reduced the damage due to lightning strikes on tall buildings. In 1800 Italian physicist Alessandro Volta developed the first electrical battery. Equipped with a source of continuous electric current, scientists made electrical and electromagnetic discoveries, practical and fundamental, at a breakneck pace.

The voltaic pile, or battery, was employed by British scientist Sir Humphry Davy to isolate a number of chemical elements for the first time. In 1820 Danish physicist Hans Christian Ørsted discovered that any current-carrying wire is surrounded by an electric field. In 1831 English physicist Michael Faraday discovered that a changing magnetic field would induce an electric current in a loop of wire, thus paving the way for the electric generator and the transformer. In Albany, New York, schoolteacher Joseph Henry set his students the challenge of building the strongest possible electromagnet. Henry would move on to become professor of natural philosophy at Princeton University, where he invented a primitive telegraph.

The basic laws of electromagnetism were summarized in 1865 by Scottish physicist James Clerk Maxwell in a set of four differential equations that yielded a number of practical results almost immediately. These equations described the behavior of electric and magnetic fields in different media, including in empty space. In a vacuum it was possible to find wavelike solutions that appeared to move in time at the speed of light, which was immediately realized to be a form of electromagnetic radiation. Further, it turned out that visible light covered only a small frequency range. Applied scientists soon discovered how to transmit messages by radio waves, electromagnetic waves of much lower frequency. Higher frequency waves included Roentgen's X-rays and the gamma rays now used in radiation therapy.

Heredity, Evolution, DNA, and the Genetic Code

The theory of evolution by natural selection was put forth by Charles Darwin and Alfred Russell Wallace in 1859. Although initially unpopular with religious leaders, because it seemed to require millions of years of Earth history instead of the few thousands posited in the Bible, it gained in acceptance over time. The theory, in a nutshell, proposes that populations of organisms produced offspring with some variation in their ability to survive in their environment, and, over time, only the organisms fittest for their environment survive. The theory did not explain how the variations occur or how they are transmitted from parent to offspring. Unbeknownst to Darwin and Wallace, the transmission of traits from one generation to the next was being studied in pea plants by an Austrian monk, Gregor Mendel. Mendel defined dominant and recessive genes and derived the classical laws of inheritance by observation, over generations, of his plants.

The mechanism of variation was identified in part by Thomas Hunt Morgan, who studied the genetics of fruit flies extensively. Morgan saw under the microscope that the nucleus of each of his fruit-fly cells contained chromosomes (so-called because they took up colored dyes easily), and each chromosome involved a number of colored bands that were duplicated when the cell divided into offspring cells. The chromosomes contained long molecules of deoxyribose nucleic acid (DNA). The molecules were arranged as a double helix, and they differed in composition from species to species and gene to gene. It was then realized that the sequence of base pairs in a particular DNA molecule was actually a set of instructions for assembling amino acids into protein molecules, in which the proteins were characteristic of each species.

The double-helical structure for DNA was proposed by J. D. Watson and F. H. C. Crick in 1955 and published in a four-page paper in the journal *Nature,* to almost universal acclaim. This was followed by the development of techniques for assembling a DNA strand to order, and making millions of copies in a very short time. The discovery of these techniques of microbiology allowed for the introduction of DNA evidence into court and to the determination of which genes were responsible for various genetic diseases. It is impossible to say where this technology will lead over the careers of those now in medical school. In principle one drop of blood, or one cheek cell, can give a complete genetic profile of an individual.

The Computer

One of the most clearly useful modern artifacts the digital electronic computer, as it has come to be known, has a lineage that includes the most abstract of mathematics, the automated loom, the vacuum tubes of the early twentieth century, and the modern sciences of semiconductor physics and photochemistry. Although computing devices such as the abacus and slide rule themselves have long histories, the programmable digital computer has advanced computational power by many orders of magnitude. The basic logic of the computer and the computer program, however, arose from a mathematical logician's attempt to answer a problem arising in the foundations of mathematics.

From the time of the ancient Greeks to the end of the nineteenth century, mathematicians had assumed that their subject was essentially a study of the real world, the part amenable to purely deductive reasoning. This included the structure of space and the basic rules of counting, which lead to the rules of arithmetic and algebra. With the discovery of non-Euclidean geometries and the paradoxes of set theory, mathematicians felt the need for a closer study of the foundations of mathematics, to make sure that the objects that might exist only in their minds could be studied and talked about without risking inconsistency.

David Hilbert, a professor of mathematics at the University of Göttingen, was the recognized leader of German mathematics. At a mathematics conference in 1928, Hilbert identified three questions about the foundations of mathematics that he hoped would be resolved in short order. The third of these was the so-called decidability problem: Was there was a foolproof procedure to determine whether a mathematical statement was true or false? Essentially, if one had the statement in symbolic form, was there a procedure for manipulating the symbols in such a way that one could determine whether the statement was true in a finite number of steps?

British mathematician Alan Turing presented an analysis of the problem by showing that any sort of mathematical symbol manipulation was in essence a computation and thus a manipulation of symbols not unlike the addition or multiplication one learns in elementary school. Any such symbolic manipulation could be emulated by an abstract machine that worked with a finite set of symbols that would store a simple set of instructions and process a one-dimensional array of symbols, replacing it with a second array of symbols. Turing showed that there was no solution in general to Hilbert's decision problem, but in the process he also showed how to construct a machine (now called a Turing machine) that could execute any possible calculation. The machine would operate on a string of symbols recorded on a tape and would output the result of the same calculation on the same tape. Further, Turing showed the existence of machines that could read instructions given in symbolic form and then perform any desired computation on a one-dimensional array of numbers that followed. The universal Turing machine was a programmable digital computer. The instructions could be read from a one-dimensional tape, a magnetically stored memory, or a card punched with holes, as was used for mechanized weaving of fabric.

The earliest electronic computers were developed at the time of World War II and involved numerous vacuum tubes. Since vacuum tubes are based on thermionic emission—the so-called Edison effect—they produced immense amounts of heat and involved the possibility that the heating element in one of the tubes might well burn out during the computation. In fact, it was standard procedure to run a program, one that required proper function of all the vacuum tubes, both before and after the program of interest. If the results of the first and last computations did not vary, one could assume that no tubes had burned out in the meantime.

World War II ended in 1945. In addition to the critical role of computing machines in the design of the first atomic bombs, computational science had played an important role in predicting the behavior of targets. The capabilities of computing machines would grow rapidly following the invention of the transistor by John Bardeen, Walter Brattain, and William Shockley in 1947. In this case fundamental science led to tremendous advances in applied science.

The 1960s saw the production of integrated circuits – many transistors and other circuit elements on a single silicon wafer, or chip. Currently hundreds of thousands of circuit elements are available on a single chip, and anyone who buys a laptop computer will command more computational power than any government could control in 1950. Further, the "lab on a chip" is becoming a reality, able to diagnose and, in time, prepare medicine for most medical conditions.

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Further Reading

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NUTRITION AND DIETETICS

FIELDS OF STUDY

Chemistry; physiology; medical nutrition therapy; management; sociology; economics.

SUMMARY

Nutrition and dietetics, a multidisciplinary field for acquiring and using nutrients from food sources to sustain life and growth, incorporates the science of economically producing and making available foods to a global society. Illnesses may result from inadequate or poor food choices, and certain health conditions require modifying foods in the diet to maintain or restore health.

KEY TERMS AND CONCEPTS

- **Body Mass Index (BMI):** Measure of body fat based on a person's height and weight.
- **Diet:** Food and beverage consumed by a person.
- **Dietary Reference Intake (DRI):** System of recommended nutrients developed by the National Academy of Science's Institute of Medicine for planning and assessing diets.
- **Dietitian:** Person trained in nutrition, food science, and areas related to food consumption.
- **Food Insecurity:** Inability to acquire safe, nutritious food to sustain and nourish life.
- **Hunger:** Lack of sufficient food as a result of food insecurity.
- **Malnutrition:** Condition of inadequate nutrient intake.
- **Metabolism:** Chemical reaction involved in obtaining and expending energy from food.
- **Nutrient:** All substances obtained from food to provide energy, growth, and regulation of cell activity.
- **Obese/Overweight:** Having excessive body fat.

Definition and Basic Principles

Nutrition is the science of providing and processing nutrients from food for survival and growth. It involves assimilating nutrients and turning food consumed into energy. Approximately fifty nutrients are essential for human life and health.

Dietetics is the science and art of procuring, planning, and preparing foods to supply nutrients in a palatable, pleasing, and economical way. It incorporates principles of nutrition and of the interactions among nutrients. In a broader scope, dietetics includes the social, cultural, and psychological aspects of food acquisition and consumption.

Background and History

Antoine-Laurent Lavoisier, the father of nutrition, recognized the relationship between food and respiration in the 1700's. In 1830, Dutch chemist Gerard Johann Mulder classified proteins. W. O. Atwater, the father of American nutrition, published the first table of food values in 1896. Two decades later, American biochemist E. V. McCollum referred to vitamins and minerals as "protective foods."

Most vitamins were discovered in the early 1900's, although their presence in certain foods had been noted. Scientists first recognized vitamin A in 1913. Since the Middle Ages, an unidentified substance in cod liver was known to prevent rickets, and in the 1920's, this substance, vitamin D, was isolated from vitamin A. As early as 1753, English physician James Lind had noted that sailors fed citrus fruits avoided scurvy. It was not until 1928, however, that vitamin C was first isolated. Deficiencies of substances, later named B vitamins, were known to result in beriberi, pellegra, and other diseases. Scientists classified B vitamins by numbers (B1, B2, B3, and so on) as they isolated specific types.

In 1917, Lenna F. Cooper founded the American Dietetic Association (ADA) to help the government conserve food and improve the nation's health and nutrition during World War I.

How It Works

Energy Metabolism. Calories are units of heat measure used for body energy. One pound of body weight equals 3,500 calories. Body metabolism and activity levels determine daily calorie needs. Most adult women need 1,900 to 2,100 calories, while adult men need about 2,100 to 2,400 calories each day. Calorie requirements decrease with age because metabolism naturally slows about 5 percent per decade after age forty. Only the energy nutrients—carbohydrates, fats, and proteins—provide calories to the body.

Carbohydrates, also known as sugars and starches, are primary sources of calories. Each gram of carbohydrate yields about 4 calories. The simple sugar glucose is the major fuel source and the only sugar found in the body. Two other simple sugars are fructose, found mostly in fruits, and galactose, a component of the double sugar lactose. Sucrose, a double sugar known as table sugar, is the most common sugar in the diet. Complex glucose molecules, called starches, come primarily from potatoes and grains.

Lipids or fats yield about 9 calories per gram. Fats act as carriers for fat-soluble vitamins. Dietary fat improves palatability and provides satiety. Two common types of fats significant in health are saturated and unsaturated fatty acids. Saturated fats, primarily from animal sources, are generally solid at room temperature. These fats may cause buildup of fatty plaques in the blood and contribute to blood clots.

Unsaturated fats, found in plants, are better choices for a healthful diet. These fats, usually soft or liquid at room temperature, vary from monounsaturated (the major fatty acid in olive oil) to polyunsaturated fatty acids (found in cottonseed, soybean, corn, and canola oils). Hydrogenation, a process that changes fatty acids from liquid to solid, creates trans fats. Trans fats raise blood cholesterol levels and may contribute to heart disease.

Protein comes from the Greek word meaning "to take first place." Proteins, found in every living cell, are composed of amino acids. Of the twenty-two known amino acids, nine are essential in the diet. Nonessential (dispensable) amino acids are derived from the essential ones or manufactured in the body. Protein, which yields about 4 calories per gram, is inefficient as a source of energy. However, with insufficient carbohydrate, the body converts protein into glucose for energy. Protein builds and repairs body tissue. Amino acids may function as precursors for transport substances such as lipoprotein. Complete proteins, found in meats, eggs, and milk, contain all essential amino acids. Plant sources such as legumes and nuts lack at least one essential amino acid and are incomplete proteins.

Fat-Soluble Vitamins. Vitamins, organic substances needed by the body in minute quantities, are categorized into fat soluble and water soluble. Each vitamin has specific functions. Generally, vitamins regulate cell metabolism in conjunction with enzymes and contribute toward construction of body tissue. The fat-soluble vitamins—A, D, E, and K—can be stored in fatty tissues in the body.

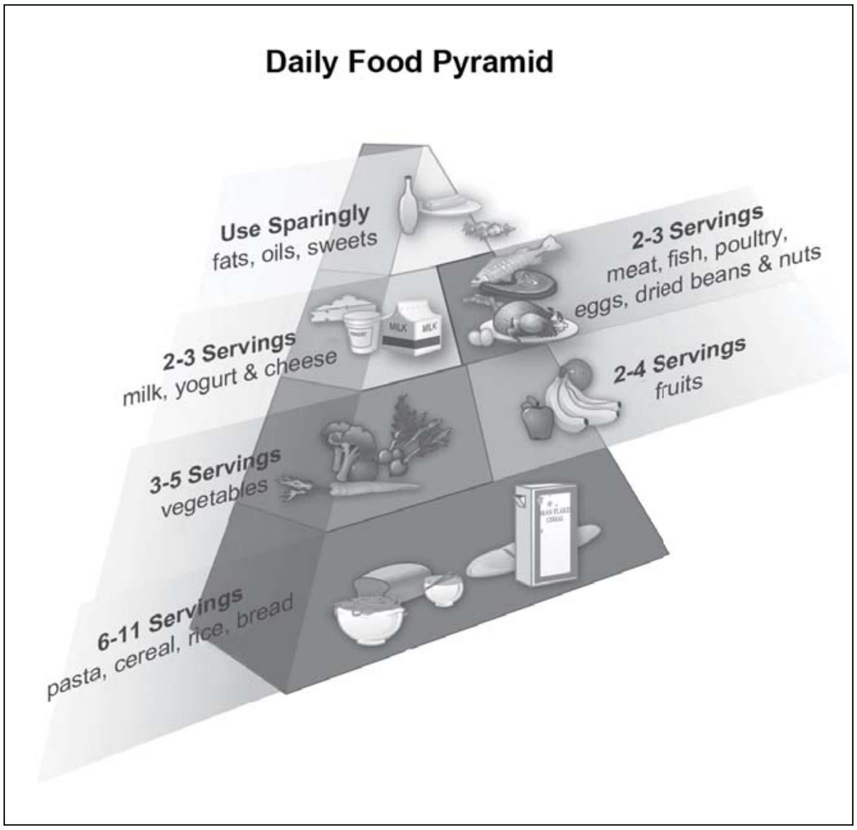
Vitamin A (retinoid), necessary for growth and development of skeletal and soft tissues and maintenance of normal epithelial structures, is called the anti-infective vitamin. Major sources are dark green and deep yellow fruits and vegetables. Few sources other than cod liver oil provide significant amounts of vitamin D. Therefore, most all forms of milk are fortified at a level of 400 international units (IU) per quart. Vitamin D helps form normal bones and teeth and provides other functions. Vitamin E (tocopherol) is an antioxidant important in protecting cells from oxidation. Sources include vegetable oils, margarine, whole-grain products, seeds, and nuts. Vitamin K, important in blood clotting, is found in most green leafy vegetables.

Water-Soluble Vitamins. Vitamin C (ascorbic acid) functions in the formation of collagen, wound healing, metabolic functions, and other roles. Foods high in vitamin C include citrus fruits, strawberries, cantaloupe, and cruciferous vegetables. B vitamins are important in energy metabolism. Thiamin (B1) is called the antineuritic vitamin. Riboflavin (B2), rarely deficient in the diet, is found most abundantly in milk and dairy products. Niacin (B3) is prevalent in meats, poultry, fish, peanut butter, and other foods. Other major B vitamins include folic acid (B9), B6, and B12.

Minerals. Minerals have varied functions in building tissue. The major minerals, found in larger quantities in the body, include calcium, phosphorus, magnesium, and iron. More than 99 percent of calcium and 85 percent of phosphorus in the body is in the bones. Calcium, essential in blood coagulation, is involved in nerve, enzyme, and hormone functions and other activities. Iron is primarily involved in oxygen transport within the blood. Although many trace elements have been identified as essential, the best known are copper, zinc, manganese, cobalt, selenium, chromium, and molybdenum.

Applications and Products

Even with sufficient global food supplies, much of the world fails to acquire appropriate nutrition to sustain good health. Food insecurity (a lack of nutritious food) or excessive weight problems often result



from limited knowledge, skills, or the financial means to procure more healthful foods.

Food Insecurity. Food insecurity affects more than 1.02 billion people worldwide. Almost 15 percent of Americans (nearly 50 million people) are food insecure. Of these people, about 8 percent have very low food security, causing reduced food intake and disruption of normal eating patterns. The remainder use a variety of coping strategies, including participation in various food programs.

Food insecurity is more prevalent in households with incomes near or below the federal poverty line, single parent households, and black and Latino households. In the United States, numerous agencies exist to alleviate food insecurity. The three largest federal food and nutrition assistance programs are the National School Lunch Program, the Supplemental Nutrition Assistance Program (formerly the Food Stamp Program), and the Special Supplemental Nutrition Program for Women, Infants, and Children. Efforts to reduce hunger 50 percent by 2015 depend on forming new partnerships at every level. That involves improved coordination among existing U.S. Department of Agriculture (USDA) programs, expansion of technical assistance, increasing public awareness of causes for food insecurity, and finding solutions.

Hunger and malnutrition affect individuals, nations, and the world community, affecting labor productivity and economic development. Multifaceted factors contributing to hunger include greed, overpopulation, unemployment, political and civil unrest, and limited productive resources. Elimination of worldwide hunger requires efforts from agriculture, development of human capital, and improved infrastructures. Advanced seed varieties increase crop production in developing countries, creating a need for additional workers who then acquire food from their incomes. However, a lack of costly irrigation systems, fertilizers, and pesticides make advanced technologies unsuitable for many poor farmers.

Worldwide hunger is linked to price fluctuations in world markets and changing agricultural policies. Prices of imported items, such as fuel and manufactured goods, rise faster than exported food products, causing international debt to accumulate in developing countries. The economic crisis of 2009 differed from previous food crises. Simultaneous effects on large portions of the world hindered traditional coping strategies. The 2006 to 2008 food and fuel crisis intensified economic difficulties. Although food commodity prices decreased, they remained high by historical standards. The impoverished spent as much as 40 percent of their income on food.

The United Nations considers access to food a basic human right. Ethnic and political conflicts intertwined with cultural, religious, economic, and social systems remain problems in abating hunger.

The Weight Epidemic. Worldwide, 1 billion people are overweight, and 300 million of these people are obese. In the United States, the percentage of obesity remained relatively stable from 1960 to 1980. Since then, however, the prevalence of obesity has more than doubled. Nearly 70 percent of American are considered overweight, and about 33 percent are obese.

For adults, excessive weight ranks second only to smoking as a lifestyle choice affecting health and longevity. Overweight and obesity intensify and increase risks for chronic illnesses, including heart disease, stroke, certain cancers, and type 2 diabetes. Excessive weight has been linked to other health conditions and increased morbidity. Children and teens with weight problems show increased susceptibility to potential forerunners of heart disease. Additionally, excessive weight in children leads to lower self-esteem.

One recognized standard for determining a person's healthy weight is the body mass index (BMI). A BMI score between 19 and 24 suggests a healthy weight. A score under 19 indicates that the person is underweight. Scores between 25 and 29 are classified as overweight and scores over 30 signify obesity. Values above 35 indicate stage-one obesity and scores of 40 or greater, held by nearly 6 percent of the population, reflect stage-three obesity.

Weight management constitutes a balance between calories taken in and calories used. Overweight and obesity occur when more calories are consumed than the body uses. Being sedentary and exercising less can lead to weight gain. The appeal and convenience of high-calorie fast foods have caused them to replace more nutritious fruits and vegetables in people's diets. Oversized portions worsen the problem.

The expense and limited availability of more wholesome foods make the food insecure more vulnerable to becoming overweight or obese. Making nutritious foods and beverages more affordable and readily available in all communities may help prevent obesity. Ways to accomplish this include offering healthier choices in different settings, competitively priced foods in low income areas, and incentives for food purveyors and retailers to service those areas.

Fascinating Facts About Nutrition and Dietetics

- Cholesterol, a fat sterol found only in animal sources, can be high-density lipoprotein (HDL) or low-density lipoprotein (LDL). LDL, the "bad" cholesterol, can clog arteries and lead to heart attacks, but HDL, the "good" cholesterol, can keep it from sticking to artery walls.
- Ultraviolet rays from sunlight can form vitamin D with the aid of cholesterol in the skin.
- The amount of an element in soil determines the mineral content found in plant foods grown in that soil.
- Nutrient-dense foods provide substantial amounts of vitamins and minerals with relatively few calories.
- Stevia, an artificial sweetener derived from a South American plant, was declared safe in December, 2008, by the Food and Drug Administration. By early 2009, more than 110 beverages and health care products sold in the United States contained stevia.
- Among the obese, those who carry their weight in the abdominal area (waist size greater than 35 inches for women and greater than 40 inches for men) are more susceptible to disease than those who carry the excess weight in their butts, hips, and thighs.
- Free radicals, resulting from certain body functions and unhealthy lifestyle choices such as smoking, compromise cell integrity and cause greater susceptibility to cardiovascular disease and some cancers. Antioxidant properties in vitamins E and C and carotenoids (lutein, lycopene, and beta-carotene) neutralize free radicals and protect the cells.

Impact on Industry

The health of Americans affects the overall economy. Government, industry, and business sectors support education and research to combat health care problems related to poor nutritional habits.

Research and Education. Government support of medical research comes primarily through clinical trial or grants from the National Institutes of Health (NIH) of the U.S. Department of Health and Human Services (HHS). Other sponsors include individuals, organizations, or companies related to or interested in nutrition and health.

Coordinated efforts of the USDA and HHS provide several levels of education and initiatives to improve health. The Healthy People 2010 initiative focused on ensuring quality of life and eliminating disparities in health care among individuals of different races, ethnic groups, and economic levels. The initiative suggests including nutrition and weight status as an area of emphasis to assist Americans in making wiser food choices.

Since 1980, the USDA and the HHS have provided dietary guidelines for Americans to promote optimum health and reduce the risk of chronic diseases for those aged two years and older. These agencies use scientific research and findings to update the content of their guidelines every five years. Earlier versions targeted the general public. The 2005 report, which targeted policy makers, nutrition educators, nutritionists, and health care providers, summarized individual nutrients and foods information into a suggested pattern for the general public.

In 2005, My Pyramid replaced the Food Guide Pyramid to allow consumers and educators to adapt guidelines to individual tastes and lifestyles. Different calorie levels recommend specific numbers of servings in six color-coded categories of food: fruits, vegetables, grains, meat and beans, milk, and oils.

The dietary approach to stop hypertension (DASH) diet focuses on consuming more fruits, vegetables, low-fat dairy foods, whole-grain products, fish, poultry, and nuts. It recommends eating less red meat, limiting concentrated sweets to less than five servings per week, and limiting foods high in saturated fat, cholesterol, or total fat.

In 1987, dietary reference intake (DRI) replaced the recommended dietary allowance (RDA) established by the Food and Nutrition Board in 1941 to evaluate nutritional intakes of large populations. RDA data were based on average nutrients needed to prevent deficiencies. The DRI, determined by the Institute of Medicine and government funded, shifted the focus from preventing deficiencies to decreasing risks of chronic illnesses through nutrition. Four criteria for DRI include estimating average requirements of nutrients to meet the needs of 50 percent of the population, assessing nutrient values of foods without an established RDA, considering upper intakes or nutrient levels without causing health risks, and the RDA standard.

Industry and Business. Consumers choose from more than 45,000 items in the average supermarket. The food industry recognizes that consumers desire nutritional food choices and uses the latest health trends to market products, often prominently noting on the packaging that products are low fat, contain no trans fats, or are whole grain. For example, as people began to turn to products containing probiotics, which are believed to help the digestive system, Dannon began to market a yogurt containing probiotics. However, it came under fire for its marketing claims, revised the wording on its products, and settled a false-advertising lawsuit. The food industry's influence on diet and nutrition has come under criticism, especially in regard to its marketing of food products to children.

Under the 1990 Nutrition Labeling and Education Act, most food products were required to include a nutrition facts label listing nutritional information about the product, including serving size and calories, as well as the amount of fat, sodium, cholesterol, protein, carbohydrates, and vitamins and minerals as a percent of daily values. The government has launched campaigns to make consumers more aware of these labels and teach people how to read them. This raised awareness and scrutiny of nutrition labels has resulted in food companies developing low-fat, reduced-carbohydrate, whole-grain, and low-sodium versions of products. To develop these products and create nutrition labels, the food industry has employed many dietitians and nutritionists.

Industries in which dietitians and nutritionists have important roles are hospitals, nursing homes, schools, and weight loss or fitness centers. They design diets and nutrition plans that address the special health needs of people and provide adequate and appropriate nutrition for young people, often within strict budget limits.

Careers and Course Work

Dietetics provides opportunities in multifaceted areas, including working to improve the nutritional state of both healthy and diseased people and dealing with societal issues related to food supply, distribution, and consumption. Career choices continue to expand in education, research, media, health care sites, and industry. Many dietitians work in corporate settings. Others opt to launch independent practices, working with individuals in fitness centers and businesses such as supermarkets and creating and conducting employee wellness programs.

A dietitian must have at least a bachelor's degree from an accredited institution, with approved course work and training from the American Dietetic Association. A registered dietitian (RD) has successfully completed a national examination for credentialing. Many states have their own licensing systems as well.

Social Context and Future Prospects

Cultural attitudes and beliefs, social influences, marketing, media, and other factors affect food choices, but taste preference remains a major influence. Although people tend to eat primarily according to their personal preferences, 60 percent of Americans claim to make an effort to eat a healthful diet to avoid future health problems. Heart disease, high blood pressure, diabetes, obesity, and other diseases and disorders in which diet plays a role remain common in the United States. Dietitians can play a significant role in helping people attain better health and physical well-being. As the roles that diet and nutrition play in human health are better understood, dietitians and nutritionists can make dietary recommendations to improve the health of the general public as well as of people with special dietary needs. In addition, they can advise companies in the food industry so that these companies can prepare processed and packaged foods that are not only healthful but also appealing.

Linda R. Shoaf, B.S., M.S., Ph.D.

Further Reading

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Shiels, Maurice Edward, et al. *Modern Nutrition in Health and Disease.* 10th ed. Philadelphia: Lippincott Williams & Wilkins, 2006. A comprehensive textbook and reference on the science of nutrition. Covers major areas from basic nutritional sciences to prevention and treatment of diseases.

U.S. Department of Health and Human Service. *A Healthier You: Based on the Dietary Guidelines for Americans.* Rockville, Md.: U.S. Department of Health and Human Service, 2005. A guide designed to help the public eat a more healthful diet.

Whitney, Ellie, and Sharon Rady Rolfes. *Understanding Nutrition.* 11th ed. Belmont, Calif.: Thomson Learning, 2008. A comprehensive textbook of general nutrition featuring a glossary for each chapter, nutrition portfolio, summary, and related Web sites. Illustrations, diagrams, and appendixes.

Web Sites

American Dietetic Association
http://www.eatright.org

National Institute of Child Health and Human Development
Diet and Nutrition
http://www.nichd.nih.gov/health/topics/diet_and_nutrition.cfm

U.S. Department of Agriculture
Food and Nutrition Information Center
http://fnic.nal.usda.gov/nal_display/index.php?tax_level=1&info_center=4

See also: Cardiology; Gastroenterology; Geriatrics and Gerontology; Pediatric Medicine and Surgery.

subsequently wrote books on aeronautics and continued experimenting. Joseph is credited with designing a calorimeter and a hydraulic ram, and Jacques-Etienne invented a method for the manufacture of vellum.

Morse, Samuel F. B. (1791-1872): An artist and inventor born in Massachusetts, Morse painted portraits and taught art at the City University of New York before experimenting with electricity. In the mid-1830's, he designed the components of a practical telegraph—a sender, receiver, and a code to translate signals into numbers and words—and in 1844 sent the first message via wire. Within a decade, the telegraph had spread across America and subsequently around the world. The invention would inspire such later advancements in communication as radio, the Teletype, and the fax machine.

Nernst, Walther (1864-1941): A German physical chemist, physicist, and inventor, Nernst discovered the Third Law of Thermodynamics—defining the chemical reactions affecting matter as temperatures drop toward absolute zero—for which he was awarded the 1920 Nobel Prize in Chemistry. He also invented an electric lamp, and developed an electric piano and a device using rare-earth filaments that significantly advanced infrared spectroscopy. He made numerous contributions to the specialized fields of electrochemistry, solid-state chemistry, and photochemistry.

Newton, Sir Isaac (1642-1727): The English physicist, mathematician, astronomer, and philosopher is considered one of the most gifted and scientifically influential individuals of all time. He developed theories of color and light from studying prisms, was instrumental in creating differential and integral calculus, and formulated still-valid laws of celestial motion and gravitation. He was knighted in 1705, the first British scientist so honored. From 1699 until his death he served as master of the Royal Mint and during his tenure devised anticounterfeiting measures and moved England from the silver to the gold standard.

Nobel, Alfred (1833-1896): A Swedish chemist and chemical engineer, Nobel invented dynamite while studying how to manufacture and use nitroglycerin safely. In the course of building a manufacturing empire based on the production of cannons and other armaments, he experimented with combinations of explosive components, also producing gelignite and a form of smokeless powder, which led to the development of rocket propellants. Late in his life, he earmarked the bulk of his vast estate for the establishment of the Nobel Prizes, annual monetary awards given in recognition of outstanding achievements in science, literature, and peace.

Oppenheimer, J. Robert (1904-1967): A brilliant theoretical physicist, researcher, and teacher born to German immigrants in New York City, Oppenheimer was the scientific director of the Manhattan Project, which developed the atomic bombs dropped on Japan during World War II. Following the war, he was primary adviser to the U.S. Atomic Energy Commission and director of the Institute for Advanced Study in Princeton, New Jersey. He contributed widely to the study of electrons and positrons, neutron stars, relativity, gravitation, black holes, quantum mechanics, and cosmic rays.

Owen, Richard (1804-1892): An English biologist, taxonomist, anti-Darwinist, and comparative anatomist, Owen founded and directed the natural history department at the British Museum. He originated the concept of homology, a similarity of structures in different species that have the same function, such as the human hand, the wing of a bat, and the paw of an animal. He also cataloged many living and fossil specimens, contributed numerous discoveries to zoology, and coined the term "dinosaur." Owen advanced the theory that giant flightless birds once inhabited New Zealand long before their remains were found there.

Paré, Ambroise (c. 1510-1590): A French royal surgeon, Paré revolutionized battlefield medicine, developing techniques and instruments for the treatment of gunshot wounds and for performing amputations. He greatly advanced knowledge of human anatomy by studying the effects of violent death on internal organs. He pioneered the lifesaving practices of vascular ligating and herniotomies, designed prosthetics to replace amputated limbs, and was the first to create realistic artificial eyes from such substances as glass, porcelain, silver, and gold.

Pasteur, Louis (1822-1895): A chemist, microbiologist, and teacher born in France, Pasteur focused on researching the causes of diseases and methods for preventing them after three of his children died from typhoid. He proposed a germ theory,

TIMELINE

The Time Line below lists milestones in the history of applied science: major inventions and their approximate dates of emergence, along with key events in the history of science. The developments appear in boldface, followed by the name or names of the person(s) responsible in parentheses. A brief description of the milestone follows.

2,500,000 B.C.E.	**Stone tools:** Stone tools, used by Homo habilis and perhaps other hominids, first appear in the Lower Paleolithic age (Old Stone Age).
400,000 B.C.E.	**Controlled use of fire:** The earliest controlled use of fire by humans may have been about this time.
200,000 B.C.E.	**Stone tools using the prepared-core technique:** Stone tools made by chipping away flakes from the stones from which they were made appear in the Middle Paleolithic age.
100,000-50,000 B.C.E.	**Widespread use of fire by humans:** Fire is used for heat, light, food preparation, and driving off nocturnal predators. It is later used to fire pottery and smelt metals.
100,000-50,000 B.C.E.	**Language:** At some point, language became abstract, enabling the speaker to discuss intangible concepts such as the future.
16,000 B.C.E.	**Earliest pottery:** The earliest pottery was fired by putting it in a bonfire. Later it was placed in a trench kiln. The earliest ceramic is a female figure from about 29,000 to 25,000 B.C.E., fired in a bonfire.
10,000 B.C.E.	**Domesticated dogs:** Dogs seem to have been domesticated first in East Asia.
10,000 B.C.E.	**Agriculture:** Agriculture allows people to produce more food than is needed by their families, freeing humans from the need to lead nomadic lives and giving them free time to develop astronomy, art, philosophy, and other pursuits.
10,000 B.C.E.	**Archery:** Archery allows human hunters to strike a target from a distance while remaining relatively safe.
10,000 B.C.E.	**Domesticated sheep:** Sheep seem to have been domesticated first in Southwest Asia.
9000 B.C.E.	**Domesticated pigs:** Pigs seem to have been domesticated first in the Near East and in China.
8000 B.C.E.	**Domesticated cows:** Cows seem to have been domesticated first in India, the Middle East, and sub-Saharan Africa.
7500 B.C.E.	**Mud bricks:** Mud-brick buildings appear in desert regions, offering durable shelter. The citadel in Bam, Iran, the largest mud-brick building in the world, was built before 500 B.C.E. and was largely destroyed by an earthquake in 2003.
7500 B.C.E.	**Domesticated cats:** Cats seem to have been domesticated first in the Near East.
6000 B.C.E.	**Domesticated chickens:** Chickens seem to have been domesticated first in India and Southeast Asia.
6000 B.C.E.	**Scratch plow:** The earliest plow, a stick held upright by a frame and pulled through the topsoil by oxen, is in use.
6000 B.C.E.	**Electrum:** The substance is a natural blend of gold and silver and is pale yellow in color like amber. The name "electrum" comes from the Greek word for amber.