translator and editor of *The Golden Treasury of Modern Lyrics* (1925). Binyon died Mar. 10, 1943, at Reading, England.

BIOCHEMISTRY, the science that describes, in the language of chemistry, the structure and functioning of living organisms. The concepts formulated by biochemists are of importance in medicine; the food, agriculture, fermentation, and pharmaceutical industries; and those industries that use agricultural wastes and by-products. Even more important than these applications is the insight that biochemistry has afforded into the nature of life itself.

History. The fermentation process has been intensively studied since Biblical times. Modern studies of the nature of this process have provided understanding of the mechanism of fermentation of sugar by yeast and also of how the energy of foodstuffs is made available to living cells for the performance of work. *(See also* RESPIRATION.)

The earliest important biochemical investigations in the modern era were those of Antoine Laurent Lavoisier (1743-1794) and Pierre Simon Laplace (I749-1827), who showed that the law of conservation of matter applies to living as well as to nonliving systems, and that the heat liberated by the oxidation of foodstuffs in an animal is equivalent to the heat liberated when the same materials are oxidized outside of living cells by chemical means.

During the 19th century biochemists began to identify the materials found in living cells. The German chemist Baron Justus von Liebig (1803-1873) recognized the presence of nitrogen in complex compounds that were later termed proteins by a Dutch chemist, Gerard Jan Mulder (1802-1880). The presence of carbohydrates in plants and animals was understood and knowledge of the chemical structure of carbohydrates was developed by the German chemist Emil Fischer (1852-1919). Meanwhile the various fatty materials of animals and plants were fractionated into their main subclassifications, while many of the individual amino acids, sugars, fatty acids, and many other cell components were purified and their structures established.

Not long after the Swedish chemist Baron Jons Jakob Berzelius (1779-1848) had formulated the concept of catalysis (in which certain substances promote chemical change without themselves changing; *see also* CATALYSIS), it was recognized that living cells also contained biological catalysts, or enzymes. It is now clear that a specific enzyme is required to catalyze each of the thousands of chemical reactions that occur in living cells. Toward the end of the 19th century, the German brothers Hans Buchner (1850-1892), bacteriologist, and Eduard Buchner (1860-1917), chemist, isolated from yeast a cell-free extract that catalyzes alcoholic fermentation, that is, that converts the sugar, glucose, to ethyl alcohol and carbon dioxide. Since then, many scientists studied the details of the individual events that occur during fermentation. These studies served as a model for studying the chemical changes that occur in living organisms.

Fields of Research. Advances in biochemistry and the activities of biochemists can he divided as follows.

Kinds and Structure of Organic Compounds. Of fundamental importance has been the compilation of a list of the organic compounds to he found in living organisms and the elucidation of the structures of each. These compounds range from the simpler amino acids, sugars, and fatty acids, to the pigments that give flowers their color, the vitamins and coenzymes, (the nonprotein portions of enzymes), and the giant molecules of proteins and nucleic acids.

Metabolism and Biosynthesis. The activity that has, perhaps, been most spectacularly successful has been the elucidation of the metabolic pathways for the biosynthesis of naturally occurring compounds from their precursors, that is, from foodstuffs in the case of animals or from carbon dioxide and minerals (through photosynthesis) in the case of plants. Biochemists have succeeded in establishing much of the detail of the major metabolic pathways for the synthesis and degradation of naturally occurring organic compounds in animals, plants, and microorganisms such as bacteria.

Structure and Biological Function of Macromolecules. A third area of interest correlates macromolecular structure and biological function. Thus, biochemists seek to learn how specific proteins serve as catalysts for specific chemical reactions; how the complex polysaccharides of cell walls and membranes serve the cells in which they are found; and how the complex lipids of the nervous system participate in the functions carried out by nerve cells, or neurons.

Cell Function. Yet another aspect of biochemistry is the search for an understanding of how the specialized cells of an animal or plant conduct their unique functions, such as how muscle cells contract, how certain cells make bone, how red blood cells transport oxygen and carbon dioxide in the body, and how flowers make their pigments.

Relation to Genetics. Since the 1940's, studies of fungi and bacteria, and later of higher organisms, including man, have shown that genetic mutations often result in the loss of ability to carry out some specific biochemical reaction. These observations led to the concept of a gene as the unit of information in a chromosome that directs the biosynthesis of a specific protein. When that protein is an enzyme and the gene has been altered, as in a mutation, the cell loses the ability to conduct the reaction for which the enzyme is normally responsible.

The genes are specific portions of molecules of deoxyribonucleic acid (DNA) that can replicate themselves and direct the synthesis of specific proteins within the cell. Much research in biochemistry involves the study of the details of nucleic acid and protein synthesis and is closely related to genetics. Indeed, the two sciences together are often referred to as molecular biology.

Human Disease. No biochemical research is more important than the continuing effort to understand human disease. Every year, increasing numbers of disorders are understood in terms of aberrations from normal pathways of metabolism. Biochemists and physicians have combined to unravel the nature of the fundamental disturbance in such diseases as diabetes and sickle cell disease. More than 8oo such metabolic disturbances have been traced to hereditary gene defects, and alleviations for some of these conditions have been found.

Studies of nongenetic conditions have also been important. Investigation of the salt and acid-base composition of blood plasma in health and disease have made possible the practice of major surgery without danger of shock or dehydration, as well as the successful therapy of pernicious vomiting, infantile diarrhea, and many other disorders. *See also* BIOPHYSICS; CELL; ENZYME; GENETIC COUNSELING; GENETIC ENGINEERING; METABOLISM; NUCLEIC ACIDS; PHOTOSYNTHE- SIS; PROTEINS.

PHILIP HANDLER

BIOELECTRICITY, the study of the natural electrical phenomena in living organisms and their relationship to biological characteristics or behavior. Bioelectricity also includes the study of the molecular, cellular, physiological, or behavioral effects caused, partly or wholly, by the application of electricity to living organisms.

Classical Bioelectricity. In 1791 Luigi Galvani showed that dissected frog muscles contracted when touched by metallic objects. He interpreted this phenomenon as evidence for the existence of electricity in the tissues. Alessandro Volta analyzed Galvani's experiments and concluded (1792) that the electricity was created when the metal touched the tissue. This work led to Volta's invention of the battery, which was used to apply electricity to human subjects, particularly in the treatment of muscle and nerve disorders. Bioelectrical therapy was in common use by physicians throughout the 19th century. Following the rise of biochemistry, and the increased use of drugs, bioelectricity declined as a form of therapy.

In other experiments Galvani showed that frog muscles contracted even when not touched by a metal. This observation led to the discovery that the nervous system is electrical in nature, and that muscle contraction results from the passage of an electrical signal through nerve to muscle. The signal may be triggered voluntarily, as when an individual moves an arm or a leg, or involuntarily, as when a battery is connected to a nerve, thereby eliciting the neural signal that initiates the muscle action. (*See also* BATTERY; ELECTROCHEMISTRY.)

When stronger currents are applied (by means of wires or by using noncontact methods), heat is produced: this is how the microwave oven works. Electrical generation of heat in tissues (diathermy) is occasionally used for treating pain, cancer, and other diseases. (See *also* PHYSICAL THERAPY.)

Electrical signals regulate the activity of the heart. Applied electricity can disrupt this process, resulting in death, an effect known as electrocution.

Electrical signals can be measured between any two points on the surface of a living organism. In man, there are three classes of electrical signals. The electroencephalogram is a relatively weak, rapidly changing signal that originates in the brain. It is useful for diagnosing some diseases, but its significance in normal individuals is unknown. The electrocardiogram, about 100 times stronger, is produced by the rhythmic contractions of the heart; it is used to diagnose various forms of heart pathology. The third type of signal, the surface electrical potential, is comparable in strength to the electrocardiogram but changes more slowly with time. The origin and importance of this signal are unknown.

Up to about 1940 the term "bioelectricity" usually referred to neuroelectrophysiological studies, measurements of the body's electrical signals, or (mostly in a historical context) to the use of electricity for therapeutic purposes.

Modern Bioelectricity. Life manifests itself in a complex series of chemical reactions which themselves are a result of electrical forces. Sometimes it is possible to study the biochemistry of life without explicitly considering the electrical forces. This approach has been successful in research into gene regulation and the immune response. It has been less fruitful, however, in areas such as memory, learning, and growth control following injury. The difficulty in explaining (at least some) biological phenomena — including life itself on a biochemical basis — led to consideration of bioelectrical factors. The problem was first brought into focus in 1941 by the Hungarian biochemist Albert Szent-Gyorgyi. He concluded that life could not be adequately explained by the presence or absence of any particular chemical substance, but rather must exist in the electrical state of the substances constituting the organism. In this view, a live animal and a dead animal differ in their bioelectrical, not their biochemical, status. These ideas led to a resurgence of interest in bioelectricity.

Among the first results of the new research was the discovery that bone is a piezoelectric material; that is, a material in which electrical forces are generated when mechanical forces (as during standing or walking) are applied to it. Since mechanical forces are needed for bone to remain healthy (a bone that is not routinely used begins to waste away), it appeared that piezoelectricity might be the link between the external factor (the mechanical force) and the internal response (bone cells producing new bone). Experiments generally supported this idea, and in 1979 the first electrical technique for treating bone diseases came into general use. Other pathological systems and diseases, including pain, infection, addiction, and cancer, may also be amenable to bioelectrical therapy. *(See also* BIOMEDICAL ENGINEERING; SOUND AND ACOUSTICS: PIEZOELECTRIC.)

Another aspect of modern bioelectricity developed following public hearings in New York City, in the period 1974 to 1978, involving high-voltage power lines. Power lines, and other structures such as television, radio, and radar antennas, produce an electromagnetic field in their vicinity. Persons living or working near these structures are chronically exposed to the electromagnetic field. The question was whether the exposure might be a danger to health. At first, concern was based on reports of alterations in growth and development, and in the endocrine and neurological systems, of persons and animals exposed to electromagnetic fields in laboratory studies. The validity of the reports is generally accepted, but there is no consensus regarding the inferred risk to humans. Reports linking prolonged exposure to electromagnetic fields with cancer, suicide, and other diseases, began to appear from about 1980. Despite this, a clear outline of the public-health problem associated with bioelectrical phenomena has not emerged.

Naturally occurring electrical factors are an important part of the life cycle of various organisms. Life forms including bacteria, insects, birds, and perhaps whales, can detect the earth's magnetic field. This capability is used for orientation and navigation purposes, during migration, and in the quest for food.

In the case of the five senses (sight, hearing, touch, smell, and taste), both the cells that detect the external stimuli, and the nerves that carry the information to the brain, are known. In most instances of bioelectrical effects, however, the cells that detect the presence of the electrical energy and the neural pathways are not known. Two theories employ novel concepts to explain the detection of electrical energy by cells. One theory postulates a cooperative interaction between nerve cells, the other holds that detection occurs only in association with specific electrical conditions. Another theory deals with the link between exposure to electrical energy and disease. According to this theory, electrical energy causes stress, and long-term exposure to this stress taxes the body's adaptive capacity by weakening the immune system, thereby leading to disease. *See ALSO* BIOCHEMISTRY; BIOLOGY; BIOPHYSICS; BIOSPHERE; and NEUROTRANSMITTER.

Further Reading on Bioelectricity. A number of books are available for the general reader and the specialist. The following three titles assume some acquaintance with the elements of chemistry, biology, and physics: *The Electrical Activity of the Nervous System* by Mary A. Brazier (4th ed., Krieger, 1977); *Electromagnetism & Life* by Robert 0. Becker and Andrew A. Marino (SUNY. i982); and *Applied Body Electronics: A Preview into the Field of Electrobiology* by Arden B. Andersen (Andersen, 1987). A comprehensive account of all aspects of bioelectricity will be found in *Modern Bioelectricity*, edited by Andrew A. Marino (Dekker. 1988).

ANDREW A. MARINO