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 O. Becker and Andrew A. Marino (SUNY, 1982); 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