Chapter 1
Nature and Subject of Biophysics

The subjects of Biophysics are the physical principles underlying all processes of living systems. This also includes environmental biophysics, which represents physical influences on physiological functions.

Biophysics is an interdisciplinary science somewhere between biology and physics – as may be concluded from its name – and it is furthermore connected to other disciplines, such as mathematics, physical chemistry, and biochemistry. The term "biophysics" was first used in 1892 by Karl Pearson in his book "The Grammar of Science."

Does biophysics belong to biology, or is it a part of physics? Biology, by definition, claims to be a comprehensive science relating to all functions of living systems. Hence, biophysics, like genetics, biochemistry, physiology etc., should be considered as a special part of biology. This view has not remained undisputed by physicists, since physics is not confined to subjects of inanimate matter. Biophysics can be considered, with equal justification, as a part of physics. Especially today, when the boundaries between classical disciplines are no longer fixed, it would be futile to try to balance those aspects against each other. Biophysics appears to be one of the best examples of an interdisciplinary science.

The delimitation of biophysics from clearly unrelated areas appears to be much easier than its definition. Biophysics, for example, is by no means some sort of conglomeration of various physical methods that can be applied to solving biological problems. The use of a magnifying glass, the most primitive optico-physical instrument, for example, has just as little to do with biophysics as the use of the most up-to-date optical or electronic measuring instruments. Biophysical research, of course, requires modern methods, just as other fields of science do. The nature of biophysics, however, is actually defined by the scientific problems and approaches rather than by the applied methods.

Biophysical chemistry and bioelectrochemistry can be considered as specialized subareas of biophysics. Medical physics, conversely, is an interdisciplinary area which has its roots in biophysics but has ramifications of far-reaching dimensions, even with medical engineering.

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Biophysical thought can be traced back to early phases of philosophical speculation on nature, i.e., to antiquity. This applies to the earliest mechanistic theories of processes of life and insights into their dynamics, for example of Heraclitus in fifth century B.C. The promotion of scientific research in the Renaissance also includes biophysical considerations. Leonardo da Vinci (1452–1519), for example, investigated mechanical principles of bird flight, using them as models for engineering design. A remarkably comprehensive biomechanical description of functions, such as the mobility of limbs, bird flight, the movement involved in swimming, etc., was given in the book of Alfonso Borelli (1608–1679) "De motu animalium" published in Rome, as early as 1680. The same Borelli founded a school in Pisa of *iatro-mathematics* and *iatro-physics* in which the human body was perceived as a mechanical machine, and where attempts were made to draw medical conclusions from that perception (ίατρός – Greek term for physician). Iatro-physics has often been considered a mechanistic forerunner of medical biophysics.

Throughout the history of Biophysics there have been attempts to apply the actual state of physics to understand the processes of life. Even though early considerations were based on mechanical models, later other models including electrical, thermodynamic, and quantum mechanical were used. In fact, there is a mutual interaction of physics and biology. Reference can be made, in this context, to the frog experiments undertaken by Luigi Galvani (1737–1798). The physics of electricity was thus studied in direct relationship with phenomena of electrophysiology. Worth mentioning is the famous controversy between Luigi Galvani and Alessandro Volta (1745–1827) about the so-called "elettricità animale," which had serious personal consequences for both.

As soon as electromagnetic fields were discovered and technically generated, the French physicist Jacques Arsène d'Arsonval applied them for therapeutic purposes, and in 1891 he published the paper "Action physiologique de courants alternatives." Similar investigations were performed by Nikola Tesla in the USA. In 1906, the German physicist Karl Franz Nagelschmidt coined the term *diathermy* for this effect.

It is well known that medical observations played a role in the discovery of the first law of thermodynamics by J. R. Mayer (1814–1878). Calorimetric studies of heat generation of mammals were conducted in Paris by A. L. Lavoisier (1743–1794) and P. S. de Laplace (1749–1827) as early as about 1780. Reference should also be made, in this context to the investigations of Thomas Young (1773–1829), and later Hermann von Helmholtz (1821–1894) on the optical aspects of the human eye and on the theory of hearing. These activities added momentum to the development of physiology which thus became the first biological platform for biophysics.

The development of physical chemistry at the beginning of the twentieth century was accompanied by application of these discoveries and knowledge to understanding the various functions of living cells, including osmoses, membrane potential etc. There have also been many instances in which biologically induced problems had stimulating effects upon progress in physics and physical chemistry. Brown's movement, discovered in pollen grains and subsequently theoretically explained by A. Einstein, is an example. Research on osmotic processes, as well, was largely stimulated by the botanist W. Pfeffer. The temperature dependence of rate constants of chemical reactions was initially formulated in terms of phenomenology by S. Arrhenius (1859–1927), and has, ever since, been applied for a great number of functions of life, including phenomena as sophisticated as processes of growth. Studies of physico-chemical foundations of cellular processes have continued to be important in biophysical research, especially, after the introduction of the principles of nonequilibrium thermodynamics. In particular, biological membranes, as highly organized anisotropic structures, are always attractive subjects for biophysical investigations.

A decisive impetus has been given to biophysical research through the discovery of X-rays and their application to medicine. It was attributable to close cooperation between physicists, biologists, and medical scientists which paved the way for the emergence of radiation biophysics, which not only opened up possible new approaches to medical diagnosis and therapy but also made substantive contributions to the growth of modern molecular biology.

A cornerstone in the development of biophysics was the lecture of Erwin Schrödinger in 1943, and his subsequently published book "What is Life?" This opened up the discussion of thermodynamics of living systems leading to the expansion of classical thermodynamics to cover nonequilibrium systems with nonlinear behavior. The books of A. Katchalsky, I. Progogine, H. Haken and many others, introduced elements of thermodynamics and nonlinear systems analysis into biophysics. This led to the development of theoretical biophysics and furthermore to systems theory. As a pioneer Ludwig von Bertalanffy must be mentioned, considering the living organism as an open system and coining the German term *Fließgleichgewicht* (steady state) for this state. The first edition of his book "General System Theory" appeared in 1968. In 1948, Norbert Wiener's book "Cybernetics: or Control and Communication in the Animal and the Machine" led to the birth of *biocybernetics*, which today is merged with *computational neuroscience*.

This brief review of the history and development of biophysics allows us to draw the following conclusions about its nature and relevance: Biophysics seems to be quite a new branch of interdisciplinary science, but in fact, biophysical questions have always been asked as long as science has speculated about the processes involved in living systems. Biophysics relates to all levels of biological organization, from molecular processes to ecological phenomena. Hence, all the other biological subareas are penetrated by biophysics, including biochemistry, physiology, cytology, morphology, genetics, systematics, and ecology. Many aspects of biophysics are the basis of health protection measures.

Biological processes are among the most intricate phenomena with which scientists find themselves confronted. It is, therefore, not surprising that biologists and other scientists have repeatedly warned against schematism and simplifications. Such warning is justified and is a permanent reminder to the biophysicist of the need for caution. Yet, conversely, there is no reason to conclude that biological phenomena are too sophisticated for physical calculations. Despite the fact that at present we are not able to explain all biological reactions, no evidence has ever been produced that physical laws are no longer valid when it comes to biological systems.