AN INTRODUCTORY TREATISE ON BIOPHYSICS

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Contents

Summary

The main objectives of this introductory biophysics treatise are two goals; to provide the university students and researchers with a clear and logic presentation of the basic concepts of biophysics, and to strengthen an understanding of fundamentals thought a brand range of interesting applications. The material covered in the present course of biophysics is concerned with biological concepts necessary to stimulate communication of student with life science (sections 1 to 5). This part directs the reader's attention to the chemistry of living systems, biological energy, and illustrates some physical treatments appropriate to molecular transport within cells and across biological membranes. This will help the student to understand the biological functions at the molecular level, which will make him a ware of living systems mystery. This encourages researchers to make their contributions to the understanding of biophysics. Section (6) treats a number of techniques that are fundamental to biophysical experimental studies. These techniques deal with X-Ray diffraction, nuclear magnetic resonance, and patch clamping technique. This section is an attempt to acquaint the student with some of the more recently used tools of experimental biophysics. Basic principles governing energy exchanges in simple enzymatic reactions are presented in section (7). These principles are then applied to ATP-ADP system as the carrier of chemical energy in the cell. The enzymatic reactions which yield phosphate bond energy, such as photosynthesis, fermentation, and respiration are also discussed. The electricity generated inside the body serves for the control and operation of nerves, muscles and organs are discussed in section (8). In carrying out the special functions of the body, many electrical signals are generated. These signals are the result of the electrochemical action of certain types of cells. By selectively measuring the desired signals one can obtain useful clinical information about particular body functions. In this section (8), I discussed some of these electrical signals. The electrical potentials of nerve transmission and the electrical signals shown in the Electromyogram (EMG) of the muscle, the electrocardiogram (ECG) of the heart, and the electroencephalogram (EEG) of the brain are the most famous signals. Sections (9) and (10), radiation & environmental biophysics are essentials for readers who have not adequate training in electromagnetic radiation and its characteristics, interaction of emr with matter and its biological effects. Exposure to natural background radiation, medical applications, consumer products, are clearly discussed in section (10). Section (11) is concerned with the use of laser in medicine, showing laser generation, tissue interaction, properties of individual lasers, clinical applications, and laser safety. Perhaps two of the most exciting laser therapies are use of laser in cancer treatment, and in vascular surgery to reopen blocked blood vessels and much more recent applications. Section (12) deals with the forms of some basic electronic elements used in medical applications. The specialized techniques which are employed and characterized the signals are described, and special emphasis is attached to issues of patient safety. Molecular genetics

introduces the roles played by DNA and RNA in the flow of genetic information in section (13), genetic code is also discussed. Section (14) is an introduction to modeling of biological system. Almost all of the models are directly compared to quantitative data to provide at least a partial demonstration that some biological models can accurately predict. This section gives the basic steps that take a student from a biological question to a quantitative specification of the system. Animals communicate with each other and why they do it is presented in section (15).

Animals communicate by smells, sound, movement, and electric signals. This section describes the diversity of animal signals. Development of tools and techniques for characterizing and building nano-structures have near reaching applicability across all sciences, bio-nanotechnology—the focus of section (16) could serve as an introduction to bio-nanotechnology. Section (17) deals with molecular structure & intermolecular forces between dipole structure of molecules.

This section illustrates structure & function of some molecules. As trials are going on by proteomics researchers to find out where different proteins are located in human cells and tissues, are discussed in section (18). The last section (19) explains the homeostasis mechanisms i.e. maintenance of constant conditions in the internal environment of the human body. Essentially all the organs and tissues of the body perform functions that help to maintain these constant conditions.

1. Introduction

1.1 Definition of Biophysics

Biophysics is the application of the techniques, approaches, and knowledge of the physical sciences to the problems of the life sciences.

In a sense, it is not new. Many contributions to life science have come from physicists and chemists over a century ago. In another sense it is particularly new. The science of biology, the study of structure and function of animals and plants, has emerged in recent years into the realm of a molecular science. The problems now confronting biologists require the techniques of many disciplines-physics, engineering, chemistry, psychology, and mathematics. Biophysics is but one name for an effort to consolidate all our scientific and technological forces to attack the numerous new problems that have arisen in the study of living things.

The interdisciplinary nature of the current problems of the biological sciences places additional demands on the individual scientist, engineer, and student. The classic compartmentalization of education no longer seems adequate. Every area of formal training has developed its own techniques, formalisms, and its own jargon. To every student falls the burden of learning entire new languages and this is crucial. The physical scientist or engineer neither comprehends the problems of life science nor contributes to their solution until he can communicate effectively with the life scientists. It seems then that the first task of biophysical training should be that of establishing communication-learning the language and viewpoint of the life sciences.

1.1.1 Classification of Biophysics

1.1.1.1 Physical Biophysics ("True" Biophysics)

- Classical: Mechanics, hydrostatics and hydrodynamics, optics and sound in man

- Modern: Radiological physics, both electromagnetic and matter waves, absorption, scatter; radioactive tracers

1.1.1.2 Physico-Chemical Biophysics (Biophysical Chemistry)

- Structure of large molecules, colloids, and gels
- Energetics or thermodynamics: Energy balance and energy transfer, temperature, food values, electrochemical control of and by redox systems
- Kinetics and mechanisms of physical biological processes, Osmotic flow and water balance, incompressible flow in circulatory systems, membrane differentiation

1.1.1.3 Physiological Biophysics (Physical Physiology)

- Classical: Bioelectricity; brain and heart measurements; volume conduction; membrane potentials
- Modern: Effects of high energy radiations; effect of physical and thermal shocks (radiation therapy, modern space medicine), system control, bioenergetics

1.1.1.4 Mathematical Biophysics

Biostatistics, computers, cybernetics, growth rates and the system concept

The International Union of Pure & Applied Biophysics (IUPAB) In Vienna 1966, 2nd International biophysics Congress

Classified Biophysics according to five special commissions;

1. Biophysics of communication and control processes.
2. Cell and membrane Biophysics.
3. Education and Development in Biophysics.
4. Radiation and Environmental Biophysics.
5. Sub-cellular and Macromolecular Biophysics.

At the 48th council Meeting of IUPAB May, 2002, Buenos Aires, Argentina, biophysics was reclassified according to four task forces:

1. Task force on bioinformatics
2. Task force on Capacity Building and Education in Biophysics
3. Task force on NMR in Biological science, and

4. Task force on biomedical spectroscopy

1.2 Characteristics of Life

It is disconcerting that the first word .encountered in biology should be so difficult to define. "Life" is an abstract word and has to be defined in abstract terms-primarily through concrete examples. It is usually accepted that one can distinguish living from nonliving matter. Biologists have established a set of characteristics whose presence or absence determines the distinction. These characteristics-reproduction, growth, metabolism, and responsiveness are technical terms with specific meanings to the biologist.

1.2.1 Reproduction

That a living system can reproduce itself is an absolute requirement for its continued existence, since the thesis of biogenesis (that all things living today come only from living things) is universally accepted today. This is consistent with present knowledge, in that living organisms have not yet been produced in the laboratory. Sexual reproduction is accomplished when an ovum, or egg cell, is fertilized by a spermatozoon, the male reproductive cell. The resulting fertilized cell is called a zygote. Asexual reproduction occurs in lower life forms when the union of gametes (either ova or spermatozoa) is not involved. This form of reproduction is accomplished by processes like fission (the splitting of a mature cell into two or more parts) by budding (in which the new individual arises from an outgrowth or bud from the parent). Figure 1 illustrates budding in one of the lower forms of life.

1.2.2 Growth

However produced, a daughter organism grows and develops into a mature individual with forms and functions similar to those of its parents. Biological growth differs from that of a crystal or a sand castle. Crystal growth or sand castle growth occurs by accretion, in which ready-made material outside the structure is assimilated into it. Biological growth, on the other hand, occurs from within the system. Growth of living organisms is based on synthesis, the formation of complex materials from simpler materials. Each living system, plant or animal, synthesizes those materials that are unique for its specific species (a group of individuals that resemble each other structurally and physiologically and that, in nature, interbreed, producing fertile offspring).

1.2.3 Metabolism

The energy changes and chemical reactions that occur within a living organism are referred to collectively as the metabolism of that organism. These changes provide for the growth, maintenance, and repair of the organism. The constant expenditure of energy is one of the essential attributes of living things. Metabolic processes are either anabolic referring to those processes requiring an expenditure of energy with which complex materials are synthesized from simple ones, or catabolic, in which complex chemical systems are broken down and energy is released.

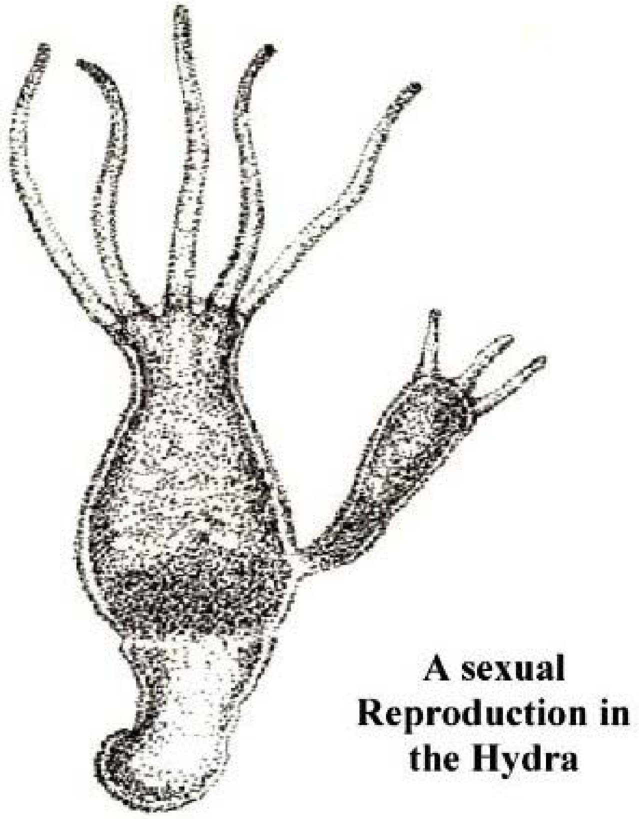

Figure 1: An example of asexual reproduction by budding. The hydra shown here is a rather simple animal which reproduces by growing a small version of itself along its side. The young hydra detaches from its parent and grows as an independent individual.

Plants are in general better chemical synthesizers than animals, since they can manufacture their own organic compounds from inorganic material in the soil and air. Animals must depend on plants for much of their food.

1.2.4 Movement

An important characteristic of living things is their ability to move themselves or cause movement of their surroundings. In most animals, movement is obvious: they run, fly, crawl, or swim using muscles that can contract and relax. Many animals spend their entire life in one place; sponges, oysters, and corals are fixed. Yet they possess organs that move the water and its digestible foods through their bodies. Very small animals often possess microscopic hair like projections called cilia and flagella, whose motion propels them. At an even lower level, the motion of protoplasm, a generic term for the living substance inside cells, causes motion of the organism by a slow oozing process called amoeboid motion. Plants too are often in motion. Some leaves and flowers fold and unfold periodically. At the cellular level, the streaming motion of the protoplasm in the leaves of plants is called cyclosis.

1.2.5 Responsiveness

The characteristic responsiveness of plants and animals to their immediate and longrange environment is incorporated into traits called irritability (the ability to react to stimuli) and adaptation. The response of living things differs from that of a rock, which, when released, falls in response to gravity, or from an electron that accelerates in response to an electric field. The irritability of living organisms is not passive. The response to a stimulus by the simplest animals is the result of trial and error adjustments. Higher forms of animal life respond to stimuli rapidly, using complex organs to adjust, as when a boy catches an object unexpectedly thrown toward him. In contrast, plants respond negatively to gravity by growing upward and positively to light by growing toward light sources.

Adaptation refers to the ability of plants and animals to adjust to the demands of the changing world. Each species may become adapted by seeking out a favorable environment or by changing itself to better fit itself to its present surroundings. Adoption may be an immediate response of an organism that depends on its irritability or a long-term process involving mutation (change) and selection. The geographic distribution of species is dependent on the limitations of adaptation within those species. The factors affecting such distribution are almost endless; they include temperature, water, predators, competitors, food availability, etc.

1.3 A Few Biological Generalizations

The biosciences share with the physical sciences a history of piecing together large bodies of facts into hypotheses, theories, and laws. The hope is that in both cases the resulting accepted body of knowledge has been inferred from careful evaluation of careful observations. Most life scientists today agree that the phenomena associated with life can be explained in terms of the same principles that govern the physical sciences.

In particular, no vital force distinguishes between living and nonliving systems. Living systems are composed of the same atoms as the nonliving ones, and they are subject to the same laws. It should be borne in mind, however, that our understanding of the laws of the physical sciences evolves with time, and the improvement of our understanding of those laws by discoveries in the biosciences is not by any means prohibited.

The cell theory at present includes the assumptions that new cells are formed by division of preexisting cells, that there exist basic similarities in the constituents and metabolic activities of all cells, and that the activity of the organism as a whole is just the sum of the activities and interactions of its individual cells.

A more controversial generalization in modern biology is the theory of organic evolution, whose stormy history was begun centuries before Charles Darwin published “The Origin of Species” in 1859. The theory of organic evolution is the notion that plants and animals existing today were not the product of special creation, but have descended from previously existing, simpler organisms by gradual modifications that have accumulated in successive generations.

Darwin’s book presented massive evidence that organic evolution had occurred. He further suggested the theory of natural selection to explain the means by which evolution might take place.

Darwin's theory is based on the following arguments:

1. Minor variations occur in a group of plants or animals whose members are too numerous or each individual to obtain the necessities of life and survive.
2. Those individuals possessing characteristics that give them an advantage in the struggle for life are more likely to survive.
3. The survivors will transmit the advantageous characteristics to their offspring, ensuring the transmission of that characteristic to future generations.

Inherent in Darwin's theory is the struggle for existence, the cliché "survival of the fittest", and the inheritance of advantageous characteristics by progeny of the surviving individuals. The central role of the theory of organic evolution in present-day biological sciences is indeed impressive. Modern courses in zoology and botany use the theory as the basis of organization, classification, and study. It is usually discussed as though it were an immutable fact, but it might be noted that there are still scientists and layman who seriously contest the theory.

A related generalization arose from observations by embryologists, who study the development of organisms from the fertilized egg. This concept is called either the biogenetic law or the law of recapitulation, which expresses the observation that in the course of embryonic development, organisms tend to repeat some of the corresponding stages of their evolutionary ancestors. Thus, a human embryo, during the various stages of its development, resembles a fish, an amphibian, a reptile, and so on. The implication is that the history of evolution of the species is recorded in the individual's embryonic development. This is occasionally enunciated by biological buffs in their own jargon as "ontogeny recapitulates phylogeny." Other generalizations have become part of the biosciences and have exerted various influences on teaching and research in these areas. Some, like the recent "one gene-one enzyme-one reaction" theory of Beadle and Tatum, are widely accepted and will be discussed subsequently. All are tested repeatedly and are subject to constant revision, as are all concepts in the sciences.

1.3.1 Cellular Organization

A series of discoveries and observations spanning two centuries established the cell as the fundamental unit of living material. There are, however, several levels of organization above and below the cell level. Groups of cells, perhaps of many different varieties, make up a tissue which serves a specialized function. Muscle, skin, or nerve tissues are examples in animals, while plants have bark or water conduction tissues. An even higher level of organization is realized in an organ, a group of tissues that performs a relatively complex function, such as the brain or heart in an animal or the flower or root in a plant. An organism usually refers to an entire individual of a particular species. At a lower level of organization than the cell are the organelles, which are identifiable structures inside a cell that perform a particular function. The organelles and their component parts comprise the ultra structure of cells. Cells are usually described in terms of their morphology, or structure and form, and their physiology, or function.

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