SPECIAL ISSUE:

PHYSICS AND BIOLOGY

This issue of PHYSICS TODAY is devoted to the interface between physics and biology, commonly termed biological physics or biophysics. Physicists tend to consider biological physics as physics inspired by biology and biophysics as biology revealed by physical methods—or to put it colloquially, what biology can do for physics and what physics can do for biology. Biologists take a broader view. Cells and organisms must know some physics as well as biology because they have evolved in the face of daunting physical constraints. So biophysics includes the physics mastered by living things. Some of this physics is understood by physicists, and some is not. In the former case, one is awed by how much physics organisms know. In the latter case, one is intrigued by how much physics they might yet reveal. The topics addressed in this issue of PHYSICS TODAY deal with these two domains.

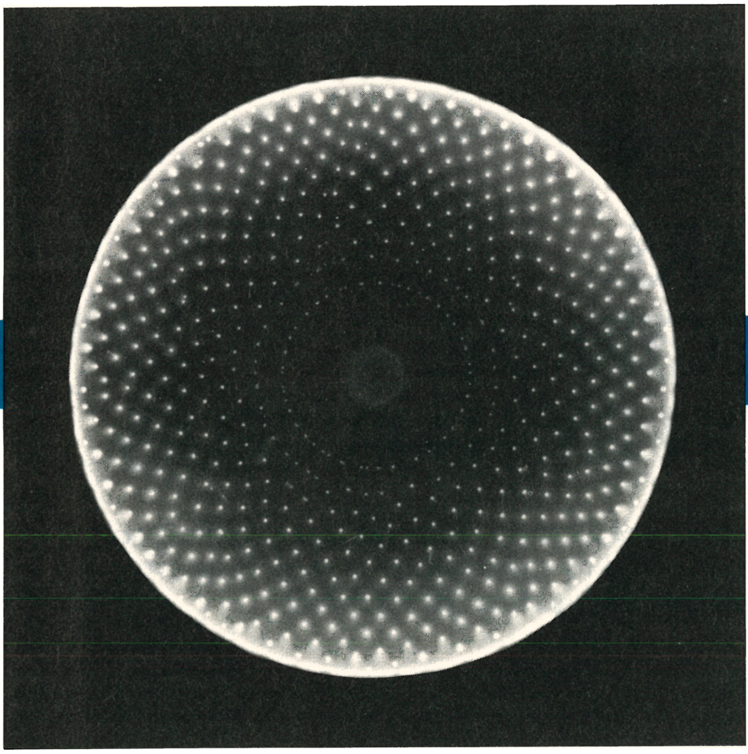
This is not to denigrate the application of physical methods to biological problems. The impact of such methods on modern biology is profound; the most conspicuous triumph is probably structure determination by x-ray diffraction.[1] Other physical methods used in biology are now so widespread that we take them for granted: light and electron microscopy, centrifugation and electrophoresis. One marvels more at the techniques that are recent and thus exotic: structure determination by nuclear magnetic resonance and magnetic resonance imaging, positron emission tomography, magnetoencephalography, laser optical trapping, scanning tunneling microscopy, atomic force microscopy and characterization of ion channels by patch clamping. In the background, but essential to a number of these efforts, is high-speed digital computing.

Physical methods also include physical modes of thought. The change in emphasis from the study of the biochemical makeup of cells to the ways in which cells store and process information was fundamental to the revolution in molecular biology, as described, for example, in the autobiography of Francis Crick.[2]

It also is true that many advances in modern biology are based on chemical methods that are remarkably simple. These include the cutting and splicing of DNA, the labeling of DNA by fluorescent or radioactive probes, the amplification of DNA in cells by cloning or in test tubes by the polymerase chain reaction, and, most remarkable of all, DNA sequencing. More often than not, all one has to do to apply such techniques is buy a kit and follow the instructions on the box.

This DNA revolution has had relatively little impact on physics. Paul Berg and Maxine Singer, eminent molecular geneticists, wrote a book called *Dealing with Genes*[3] that is designed to educate the layman. In the preface the authors note that physics is largely inaccessible to biologists because biologists are not trained to deal with abstract mathematical concepts, while biology is largely inaccessible to physicists because physicists have not acquired the specialized vocabulary associated with the complexity and novelty of biological mechanisms. Berg and Singer completed part of their book at the Institute for Advanced Study in Princeton, New Jersey. "Curiously," they write, "our ability to work uninterrupted at Princeton was assured by the almost universal lack of interest on the part of the Institute's physicists and mathematicians in talking to biologists." Stark evidence for a cross-field barrier!

Another revolution is under way in behavioral biology. This includes the study of sensory transduction: how cells, organelles and organisms receive, interpret and act upon signals originating in the external environment. Even the simplest bacteria that live in your gut are exquisitely sensitive to changes in their chemical environment and can move about in a purposeful manner.[4] An example of bacteria exhibiting such motion as well as biological self-organization is shown in the figure on the next page.[5] Higher organisms respond to a wider range of stimuli—chemical, thermal, mechanical, optical, electrical and magnetic—using devices that work close to the limits of sensitivity imposed by physics. To understand these devices, one is forced to understand elements of both physics and biology, and so the language barrier is less severe. Two examples are given in this issue: A. J. Hudspeth and Vladislav Markin, in their article beginning on page 22, describe detection of mechanical strain by hair cells in the inner ear, and Joseph Bastian (page 30) surveys electrosensation by weakly electric fish (shown on the cover of this issue). The first of these two articles focuses on sensory transduction at the cellular level, while the second deals more broadly with system design. For the latter, one could consider an acoustic



Biological self-organization is exhibited by *Escherichia coli* growing in a thin layer of soft agar. The pattern, formed by motile cells of the bacterium and revealed by scattered light, is about 7 centimenters in diameter. Dense aggregates form in the wake of a circular band that moves slowly outward from the point of inoculation. The cells aggregate in response to gradients of chemical attractants that they excrete.[5]

system such as echolocation in bats, but weakly electric fish are less well known, and there has been considerable attention of late concerning the possible effects that electromagnetic fields may have on living systems. These creatures are specialists at generating, receiving and decoding electrical signals.

The most complex object in all of biology is the human brain. John Hopfield broaches the question, How does it compute? in his article starting on page 40. A large brain acquires an intelligence that's absent from simple nervous systems by means of networks with high connectivities. Can one find simple physical models of the dynamics of neural networks that lead to the heart of this issue, or will particular details of neurobiology prove paramount?

The remaining articles in this issue deal with proteins: the functions of some specific proteins and the complexity of proteins in general. Graham Fleming and Rienk van Grondelle (page 48) describe the proteins used by plants to convert solar energy into chemical energy, beginning with the harvesting of light by antenna pigments and ending with the separation of charge and transport of protons across the thylakoid membrane. How is energy passed from the light-harvesting pigments to reaction centers, and how do these centers orchestrate electron transfer?

Hans Frauenfelder and Peter Wolynes (page 58) consider proteins more generally as models for the physics of complexity. Glasses and spin glasses are probably the two "simplest" systems that are truly complex. Many problems regarding glasses remain unsolved despite the long time that glasses have been studied by physicists, chemists and materials scientists. Biological systems, in particular biomolecules, may provide answers to some of these questions. Proteins may be ideal systems with which to study concepts of complexity: They exist at the border between classical and quantum physics; the structures of many proteins are known; they can be modified at the molecular level through genetic engineering; and they contain many spectroscopic probes. Proteins display an enormous diversity of conformational states. How can these states be characterized and how do their occupancies evolve with time?

The five articles in this issue cover only a small fraction of biophysics and biological physics. More can be learned from recent conferences and books.[6–9] This is a cross-field endeavor to which physicists can make major contributions. But to do so, they need to learn enough biology to be able to talk with biologists and to distinguish problems that are central from those more peripheral. Since much of biology is descriptive, the physicist has a strong advantage: It is much easier for a physicist to learn biology than for a biologist to learn physics. Perhaps one of these articles will strike the necessary spark.

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