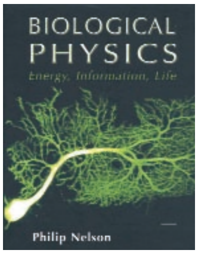


the undergraduate physics curriculum. To some extent, the idea has been forced on them by the revolutionary changes happening in biology. In *Biological Physics: Energy, Information, Life*, Philip Nelson, a professor of physics at the University of Pennsylvania in Philadelphia, wrote in the book's introduction addressed to instructors: "A few years ago my department asked their undergraduate students what they needed but were not getting from us. One of the answers was a course on biological physics. Our students could not help noticing all the exciting articles in *The New York Times*, all the cover articles in *Physics Today*, and so on. They wanted a piece of the action."

Nelson's decision to focus in his book on biological physics as opposed to biophysics reflects a long-felt division between physicists and biologists. In 1949, Max Delbrück stated the following: "Biology is a very interesting field [because of] the vastness of its structure and the extraordinary variety of strange facts, but to the physicist it is also a depressing subject because the analysis seems to have stalled around in a semi-descriptive manner without noticeably progressing towards a radical physical explanation. . . . We are not yet at the point where we are presented with clear paradoxes."

Delbrück's point of view is still shared by quite a few physicists today (see, for instance, commentary by Robert B. Laughlin in PHYSICS TODAY, December 2002, page 10). Nevertheless, the desire of the undergraduate physics students at Nelson's university to have a biological physics class reflects the thoughts of Edward O. Wilson, who saw the significant impact the discovery of the structure of DNA had on our perception of how the world works. "Reaching beyond the transformation of genetics, it injected into all of biology a new faith in reductionism," Wilson wrote in *Naturalist* (Island Press, 1994). "The most complex of processes, the discovery implied, might be simpler than we had thought."

One way in which physicists have sought a compromise with physics and biology is by distinguishing the terms "biological physics" and "biophysics." According to researchers Hans Frauenfelder, Peter Wolynes, and Robert Austin in *Biological Physics: Third International Symposium* (AIP Press/Springer-Verlag, 1999), the biological physicist "asks not what physics can do for biology, but what biology can do for physics . . . and defines biological physics as the field where one extracts interesting physics from biological systems. Much like the terms physical chemistry and chemical physics, the terminological differences represent only psychological style and current attitude; the same person at different times could be thinking as a biophysicist or as a biological physicist."

So, how can physicists climb onto the biology band wagon? The difficulties of doing this are reflected in problems faced by physicists who wish to contribute to research at the forefront of biology. Because problems in biology come from the experimental study of living systems, physicists can only decide on which problems to work on by retraining themselves as biologists, which many distinguished scientists such as Delbrück, Francis Crick, and Walter Gilbert have done. As an alternative, physicists can try to collaborate closely with biologists. In his reflections on the contributions of the late Irwin C. "Gunny" Gunsalus, who was a professor of biochemistry at the University of Illinois at Urbana–Champaign, Frauenfelder noted that "after a short time it was obvious that we physicists did not know the biochemistry and the biochemists did not really understand the physics. . . . Gunny taught us to treat the biochemical side of the experiment with the same care we used [on] our own, the physics side." However, such cooperation is fraught with difficulties, because the key ideas have to come from the biologists who, consequently, take on the leadership role in the collaboration and who see physicists as merely providing a service.

In Biological Physics, Nelson takes the point of view that one can use examples coming from biology to illustrate important physics principles. Thus his book is more an introductory physics text with emphasis on topics that come up in soft condensed matter physics rather than a text that focuses on the physical details of biological systems. Although the book contains a lot of descriptive content on biological systems, including a fairly quantitative discussion of the Hodgkin–Huxley equations, the meat of Nelson's work is in introducing the principles of statistical physics to the study of, for example, diffusion, chemical equilibrium, and properties of polymers. Specific molecules involved in biological function are described qualitatively in the book, but one finds relatively little emphasis on what many biophysicists regard as the key paradigm of biophysics: structure–function relationships for biomolecules.

One of the problems of this approach is that it covers a lot of the same ground as the traditional physics and chemistry classes for undergraduates do, which leaves less space for biological detail. So, although it does provide an introduction to biological examples for conventional physics (and to some extent chemistry), Nelson's book gives limited guidance on understanding the elucidation of the function of biomolecules. Such guidance is found, for example, in more specialized texts like Jonathan Howard's book on molecular motors, *Mechanics of Motor Proteins and the Cytoskeleton* (Sinauer Associates, 2001), or Bertil Hille's book, *Ion Channels of Excitable Membranes* (Sinauer Associates, 2001).

What is the answer for physics departments that want to provide material seen by their physics students as relevant to biology? As the interface between biology and physics evolves, physics departments may also evolve to include biology as a formal part of the curriculum. Physics departments may create a division in biophysics, or split off a separate department, as has been the case in the formation of astronomy and geophysics departments. For now, some kind of compromise must remain in which physicists who have retrained themselves as biologists can still teach in physics departments or be appointed jointly in physics and biology departments. Such decisions, when made, will probably be reflected in the way the interface between biology and physics is taught.

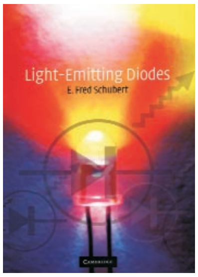
In the meantime, Nelson's *Biological Physics* is a useful teaching tool for faculty who are more on the physics end of the interface, while other books—such as those following in the tradition of Charles Cantor and Paul Schimmel's *Biophysical Chemistry* (W. H. Freeman, 1980), now sadly out of date—will provide teaching material for faculty coming from the more biologically motivated side.

Sebastian Doniach
Stanford University
Stanford, California

Light-Emitting Diodes

E. Fred Schubert
Cambridge U. Press, New York, 2003. $110.00, $60.00 paper (313 pp.). ISBN 0-521-82330-7, ISBN 0-521-53351-1 paper

Light-emitting diodes have become an integral part of our daily lives. Since their introduction in the 1960s, their light-emitting efficiency has doubled about every 2 years, and their range of colors has greatly expanded. Today, LEDs serve as bright and colorful indicators, interior and exterior automobile lights, display elements, and backlights for nearly all electronic appliances. And IR LEDs are used for communications and remote control.



Most recently, the efficiency of LEDs has grown substantially. Their emission spectra have been expanded to include white light and the entire visible range; thus they can be used for traffic signals and outdoor, full-color displays. Researchers expect that LEDs will ultimately be applied to general illumination, which could lead to tremendous energy savings. In *Light-Emitting Diodes*, E. Fred Schubert provides an excellent review of the physics and technology of semiconductor LEDs.

The first LEDs were made of Carborundum (abrasive silicon carbide crystals). The material's properties were revealed when a curious someone touched an electrical probe to a nugget of SiC made for sandpaper grit, which caused it to emit visible light. Interesting anecdotes like this one, clearly written by someone with broad perspective and expertise, appear throughout the book, making it enjoyable to read. The first few chapters summarize the physics of carrier injection and recombination in LED operation. Although the descriptions are rather terse, they provide a good introduction to the basic mechanisms underlying the light-emission process.

Chapter 2 on radiative and nonradiative recombination processes is well referenced for those who want to dig deeper into the device physics. The sections on nonradiative recombination are especially notable, because the phenomenon represents a critical limitation to LED efficiency. Schubert provides an excellent description of the undesirable recombination pathway. LEDs have an operating current density that is one to two orders of magnitude lower than that of semiconductor laser diodes, and nonradiative processes caused by defects can be dominant at such low operating current densities.

The materials and processes required for fabrication of modern, high-brightness LEDs demand perfection. Despite their ubiquity, LEDs are difficult to make because the underlying technology is enormously sophisticated. Schubert's book explains how LEDs are made, starting from raw semiconductor materials that make up a layered heterostructure, which is processed into a die and then packaged into lamps. The text also discusses advanced designs for high-efficiency LEDs.

The recent introduction of high-brightness blue and green LEDs made from nitride semiconductors has led to a family of better full-color displays. However, understanding the benefits of visible LEDs requires some knowledge of how humans perceive colors, and Schubert has included a chapter on human vision to explain how LEDs produce a wider color gamut than that of displays based on phosphors or filtered white-light sources. Likewise, he offers a self-contained chapter on optical communication, which serves as background for the description of communications LEDs and their modulation characteristics.

The considerable attention paid to resonant-cavity LEDs in chapter 10 seems disproportionate because such LEDs are relatively rare. Still, Schubert has made pioneering contributions to those devices, and this variety of LED may become more widely used in the future. The chapter on visible LEDs summarizes the evolution of the semiconductor materials, from aluminum gallium arsenide and nitrogen-doped gallium arsenide phosphide to the nitride and phosphide alloys currently used to span the visible spectrum.

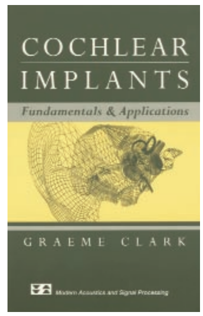
The book, however, provides relatively few details about the significant differences between nitride and phosphide semiconductors and how they impact visible-LED behavior. For example, only a brief mention is made of the apparent benefit of alloy segregation in the structurally imperfect nitride semiconductors and the role alloy segregation plays in the peculiar efficiency of nitride LEDs. Furthermore, the large polarization fields present in the nitride structures are not described. However, nitride LEDs are undergoing rapid development. Compared with more traditional materials, they are still not well explained, so such shortcomings in the book are understandable.

Overall, *Light-Emitting Diodes* is an excellent examination of the physics and technology of semiconductor LEDs. The narration is simple and direct, and the book is well referenced for those seeking a deeper understanding of the topic. Written for the graduate level, the text will appeal to a broad audience; and for specialists who make semiconductor LEDs and laser diodes, it will serve as a useful connection to the scientific literature. The book is also accessible to nonspecialists such as engineers and scientists who use LEDs or to those who simply wish to learn more about their operation and general characteristics.

David Bour
Agilent Laboratories
Palo Alto, California

Cochlear Implants: Fundamentals and Applications

Graeme Clark
AIP Press/Springer-Verlag, New York, 2003. $129.00 (830 pp.).
ISBN 0-387-95583-6



In the late 1950s, a small group of physicians and engineers proposed the idea that hearing might be restored in profoundly deaf individuals through direct electrical stimulation of the auditory nerve. At that time, however, the otology establishment was quite skeptical about the possibility of restoring hearing through electrical stimulation.

But Graeme Clark, author of *Cochlear Implants: Fundamentals and Applications*, was one of those early pioneers who was not discouraged by the establishment's criticisms or by initial failures. His lifetime of work has had enormous impact on the development and design of cochlear prostheses. Thus, Clark is well positioned to tell a wonderful success story that begins with some rudimentary hearing sensations evoked by electrical stimulation and ends with accounts of excellent speech perception by many cochlear-implant users.

In his 830-page book, Clark describes in great detail the development of cochlear prostheses and covers all aspects of cochlear implantation. The first chapter provides a good historical summary. It begins with a vivid description of Alessandro Volta's 1799 current-injection experiment and follows with the competitive efforts that have led to commercial implants that are able to restore usable hearing to individuals who are severely to profoundly hearing impaired. Readers will certainly notice that the research contributions by