Preface

Between 1971 and 1973 I audited all of the courses medical students take in their first two years at the University of Minnesota. I was amazed at the amount of physics I found in those courses and how little of it is discussed in the general physics course.

I found a great discrepancy between the physics in some papers in the biological research literature and what I knew to be the level of understanding of most biology majors who had taken a year of physics. It was clear that an intermediate level physics course would help these students. It would provide the physics they needed and would relate it directly to the biological problems where it is useful. Making the connection with biology is something that we tend to leave for the student. When we do that, I think we overestimate the ability of most students to see the application and work out the details. Seeing a few applications is also a powerful motivation for mastering difficult material.

This book is the result of my having taught such a course since 1973. It is intended to serve as a text for an intermediate course taught in a physics department and taken by a variety of majors. Since its primary content is *physics*, I hope that physics faculty who might shy away from teaching a conventional biophysics course will consider using it. I also hope that research workers in biology and medicine will find it a useful reference. The course we offer at Minnesota has been taken by seniors and some graduate students in physiology, microbiology, and biomedical engineering. Some physics majors who have taken the course have found it a useful review of applied physics. Because the book is intended primarily for students interested in biology and medicine I have tried to adhere to the following principles in writing it:

1. Calculus is used without apology. When an important idea from calculus is used for the first time, it is reviewed in detail. Topics from calculus and statistics that are used in more than one chapter are introduced in appendixes.

2. It is assumed that the reader already knows some of the basic vocabularly of physics, but that a logical development of ideas from first principles is needed. Such a development can be shorter than it would be in an introductory physics course.

3. I have not intentionally left out steps in derivations. Some readers may feel that the pace of the book could be faster, particularly after a few chapters. My students have objected vociferously when I suggested this to them.

4. In general, the book does not go to the research frontiers of each field. The constraints of space and my own knowledge made this impossible. I hope that enough basic physics is presented to allow the student to read at the frontiers.

5. Each subject is approached as simply and concisely as possible. My experience has been that sophisticated mathematics, such as vector analysis or complex exponential notation, often hides physical reality from the student. I have seen electrical engineers who could not tell me what was happening in an RC circuit without using Laplace transforms! I also believe that we learn gradually, building layers of sophistication on simple models.

I have not been able to include such topics as: respiratory mechanics, transport through charged, pores, ultrasound, X-ray diffraction, and molecular biology. Even so, there is more material here than I have been able to cover in one year, lecturing four days a week.

Chapter 1 reviews mechanics. Translational and rotational equilibrium are introduced, with the forces in the hip joint as a clinical example. Hydrostatics, incompressible viscous flow, and work are presented in preparation for later chapters.

Chapter 2 is essential to nearly every other chapter in the book. It discusses exponential growth and decay, and gives examples from pharmacology and physiology (including clearance). Students are also shown how to use semilog and log-log graph paper.

Chapter 3 is a condensed *treatment* of statistical physics: average quantities, probability, thermal equilibrium, entropy, and the first and second laws of thermodynamics. The most important ideas for later chapters are the equipartition of energy and the Boltzmann factor. Gibbs free energy and the chemical potential are given a statistical basis. The emphasis of the entire chapter is statistical and microscopic, because I think this gives the best intuitive picture of thermodynamics.

Chapter 4 treats diffusion and transport of solute in an infinite medium. Fick's first and second laws of diffusion are developed. The diffusion constant is related to the viscous drag force on a solute particle.

Chapter 5 discusses transport of fluid and solute through a membrane. The phenomenological transport equations are introduced as a linear approximation. The membrane parameters are calculated for a large pore in which hydrodynamics can be used and for a small pore in which the molecules cannot get past one another. Detailed comparisons with experiment are made. The Goldmann equation for the transport of ions in a constant electric field is presented in this chapter, because the mathematical details are identical to those of solvent drag and diffusion, previously developed in this chapter.

Chapter 6 discusses nerve conduction, mainly in unmyelinated nerves, while reviewing the electrostatics and current flow necessary to understand this material. A computer program for a clamped axon is given, to show that the equations can actually be used to generated results. The chapter closes with sections on saltatory conduction and the dielectric and conductive properties of myelin and axon membrane, diffusion to small objects, and end effects in diffusion through pores.

The electrocardiogram can be understood as the potential due to the dipole moments of all the discharging myocardial cells. This simple model is presented in **Chapter 7**.

Chapter 8 introduces feedback systems. After discussing graphical methods for finding the operating point and open loop gain, it presents the time behavior of linear systems with one and two time constants. The chapter closes with a qualitative example of nonlinear feedback.

Chapter 9 shows how to use the method of least squares to fit curves to data. This technique is then used to introduce Fourier series, power spectra, correlation functions, and the Fourier integral. The closing sections demonstrate *that a simple linear system* can be analyzed in terms of its frequency and phase response instead of in the time domain, as was done in Chapter 8. Finally, mathematical techniques for reconstructing two-dimensional images in computer-assisted tomography are introduced.

Light and atomic physics are the subjects of **Chapter 10**. The first half of the chapter presents material based on light as photons: infrared radiation and thermography, ultraviolet light from the sun, fluorescence, atomic and molecular spectra, and quantum effects in vision. The remainder of the chapter treats light as an electromagnetic wave. It deals mainly with polarization phenomena: dichroism, polarization by scattering, and birefringence. The closing sections examine line width in emission and absorption and electron spin resonance.

Chapter 11 describes how X-rays interact with matter, how doses are calculated, how photon detectors work, and how diagnostic X-rays are made. It also discusses computerized tomography (with the material on image reconstruction presented at the end of Chapter 9). The closing sections present the target theory of radiation damage and give examples of the therapeutic use of X-rays.

Chapter 12 describes the medical uses of nuclear physics. The different types of radioactive decay are explained. Dose calculations are made using the fractional absorbed dose method recommended by the Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine. The energy loss by charged particles is developed in some detail, and a section shows how this theory can be used to relate the radiation damage by charged particles to that by photons. The medical uses of mass spectroscopy are also described.

I have taught this course as three separate one-quarter courses which can be taken independently. The first quarter covers Chapters 1 to 5; the second covers 6 to 9, and the third covers 10 to 12. It is necessary to review Chapter 2 in the second and third quarters. A semester course based on Chapters 1 to 7 would be better, since the material on the Goldmann equation in Chapter 5 relates closely to Chapter 6.

I feel strongly that students in a course at this level should have access to the problem solutions. In many cases the problems are an extension of the text and the solutions are useful for reference. In other cases they use mathematical techniques with which some of the students may be unfamiliar. One must assume that the students are mature enough to try the problems without first looking at the solutions. The publisher has agreed to make the solutions manual available for sale to students.

One technique which has been very successful in these courses has been to require a term paper on a subject in biology of interest to the student. The student reads in the biology literature, narrows down the topic, and then fills in (and in some cases corrects) the gaps in the physics. This serves two purposes: it shows the student that it is possible to read the literature and, given enough effort, understand the physics behind it. It also shows the student that one should not blindly take results and apply them without understanding the limits of validity.

Through the term papers, the students learn that one should not take results in the literature for granted. They sometimes find errors, typographical or worse. This book is no exception; I would be grateful to learn of any mistakes you find, or of any suggestions for how it can be improved.

There are many people who made this book possible. If W. Albert Sullivan, Jr., M.D., Assistant Dean of the University of Minnesota Medical School, had not suggested that I attend class, the book would never have been written. Richard L. Reece, M.D. has answered many questions helped in ways too numerous to count. I am particularly indebted to my colleagues in the School of Physics and Astronomy and the Institute of Technology for their support of a new course and for two George Taylor Teaching Development Awards. These awards enabled me to attend short courses offered at M.I.T. on nuclear medicine and computer-assisted tomography, and at Boulder, Colorado by the American Association of Physicists in Medicine on the medical uses of nonionizing radiation.

Professors David Levitt, John Johnson, and Richard Poppele in the Department of Physiology have taught me a lot. I am grateful to Dr. Elizabeth Wood for reading some sections of the manuscript. Chapter 11 has been improved by a lengthy correspondence with Dr. John H. Hubbell of the X-Ray and Ionizing Radiation Data Center, National Bureau of Standards.

I am grateful to Pamela Goett for her copyediting, to Mark Safran for the design of the book, and to Donald Deneck for his support and encouragement.

Illustrations for the book have been done by Steven Teske. I thank my daughter, Lynn, for typing the manuscript.

Every list of acknowledgments seems to close with thanks to a long-suffering family. I never knew what these words really meant, nor how deep the indebtedness, until I wrote this book.

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