

PREFACE TO THE SECOND EDITION

Focus, Organization, and Content

This book, like the first edition, deals with the mass transport processes that take place in living systems, with a focus on the normal behavior of eukaryotic cells and the organisms they constitute, in their normal physiological environment. As a consequence of this focus, the structure and content of the book differ from those of traditional transport texts. We do not start with the engineering principles of mass transport (which are well presented elsewhere) and then seek biological applications of these principles; rather, we begin with the biological processes themselves, and then develop the models and analytical tools that are needed to describe *them*.

This approach has several consequences. First of all, it drives the content of the text in a direction distinctively different from conventional transport texts. This is because the tools and models needed to describe complex biological processes are often different from those employed to describe more well-characterized inanimate systems. Many biological processes must still be described phenomenologically, using methodologies like nonequilibrium thermodynamics. Simple electrical analogs employing a paucity of parameters can be more useful for characterization and prediction than complex theories based on the behavior of more well-defined systems on a laboratory bench. By allowing the biology to drive the choice of analysis tools and models, the latter are consistently presented in the context of real biological systems, and analysis and biology are interwoven throughout.

Owing to its more biological focus, the book includes more biology and physiology than most texts on engineering in the life sciences, and some parts will be easier to follow for readers with some background in biology. To keep the text self-contained in this respect, an early chapter is devoted to those aspects of cell biology most relevant to biological transport systems.

A few words on the use of the term “models” in the title. The explosive growth of molecular biology in the past several decades demands that space be devoted to the molecular-level events that underlie the observables of biological transport. This means that “models” must now be understood to include *physical* and *structural* models of transport systems and processes at the molecular level, as well as the *mathematical* models of transport that continue to be developed to describe biological transport mechanisms at all levels.

The text includes chapters that deal primarily with fundamental transport principles, including thermodynamics (Chapters 1, 2, 6); the cell, including intracellular transport (Chapter 3); the biological transport mechanisms, such as channels and carriers, employed by living organisms (Chapters 4, 5, 7), and applications of these mechanisms in control and in the function of tissues and organs such as kidney and

lung (Chapters 8–11). A more thorough overview of the text can be gained by reviewing the detailed Table of Contents that follows. The models in latter chapters are derived using the principles presented in earlier ones, so the student appreciates the assumptions that underlie them, and their consequent limitations. Those aspects of transport that are closely associated with specific tissues — for instance, the Hodgkin-Huxley theory of axonal conduction — are presented in these latter chapters.

Certain topics are dealt with less thoroughly in this text, or are outside its scope. Experimental techniques used in transport research are well described in the extensive methods literature and are not discussed here in great detail. Experimental data are presented primarily to illustrate specific transport mechanisms, so the selection of data is representative rather than complete. Transport phenomena that exist only in experimental settings — for instance, isotope interaction effects — are not discussed. On the other hand, the text *will* provide guidance to the experimenter regarding the appropriate tools to interpret experimental data, and the limits on their applicability.

The emphasis of the text is on *mass* transfer. Both convection and diffusion are included, but purely convective transport, such as the transport of oxygen in large blood vessels or gas flow in the early generations of the respiratory tree, is not. The transfer of *momentum*, i.e., fluid mechanics, is not dealt with in any depth. Fortunately, there are several recent texts on biological fluid mechanics, particularly in the cardiovascular area. Heat transfer is also outside the scope.

Some final comments on style:

- the system of units used in the text is centimeter-gram-second (cgs) rather than Système International (SI), since the former units still dominate the literature. Conversions between the two systems are presented in Chapter 1.
- the valences of ions are not shown in the text; sodium ion is designated by Na, not Na^+ . The reader is assumed to know that metals and halogens are ionized in the biological milieu.

Use in the Classroom

The text is designed for a first course in biological mass transport and is based on courses I have taught to students primarily, but not exclusively, in biomedical engineering at Johns Hopkins, Ohio State, and Duke. As is appropriate for an engineering course, the student is assumed to have a certain facility with modeling and mathematics. The material is presented at a level easily accessible to upper-class undergraduates or early graduate students. The combination of biological content and engineering approach should be attractive not only to biomedical engineering students, but also to students in chemical, mechanical, and environmental engineering who are interested in the life sciences. The text can also be used to provide a broader perspective for students in physiology and biophysics, or with students in the biological sciences who are interested in a more quantitative approach to transport.

Though mathematical modeling is an essential component of the text, the equations are not exceptionally complex, for several reasons. Most biological transport

processes can be described by steady-state equations, and even transients are generally quasisteady with respect to mass transfer. Most membrane transport models assume no variation in the variables of interest in the plane of the barrier. As a consequence, with rare exceptions (most notably Chapter 11 and to a lesser extent Chapter 9), the mathematics is limited to ordinary differential equations.

On the life science side, an introductory knowledge of biology and chemistry is assumed, a requisite which my current students meet with a first college course in biology. A third discipline that supports the models developed in the text is thermodynamics, a subject not always included in the crowded curriculum. Accordingly, separate chapters are devoted to equilibrium thermodynamics in solution and nonequilibrium thermodynamics, prior to the treatment of diffusional and coupled transport, respectively.

In addition to supporting a core or elective biological transport course, this text could also provide a framework for teaching biology and physiology per se, as well as biological modeling, to students in biomedical, chemical, and mechanical engineering. Transport is relevant to most biological systems and, in contrast to many other subdisciplines within biology, lends itself well to mathematical modeling and engineering analysis. The book includes examples that relate to the cardiovascular system, nerve transmission, kidney function, control systems, secretory activity, and other biological systems and functions. It should be possible to design an undergraduate course in engineering physiology that covers much of the subject in the context of biological transport, perhaps supplemented with a module on cardiovascular fluid mechanics that could be based on any of several recent texts in this area.

To support the use of the text in class, exercises are included at the end of each chapter. Some of the exercises are thought problems; some require the student to apply the presented material quantitatively, and others encourage the student to explore beyond the boundaries of the book itself.

More exciting and, if it meets its objectives, more useful, a website for the book has been set up on the server at the Pratt School of Engineering at Duke. The URL of the site is

<http://biotrans.pratt.duke.edu/>

The site will be accessible to students, instructors, and other users and is intended to create a “community of the book” that will enhance both teaching and learning. Using the site, community members will be able to post additional exercises; suggest new material for inclusion in courses based on the text, either in general terms or with a link to a specific publication; and share course syllabi. It can also be used to post corrections or amendments to the text itself.

Users will be encouraged to register on a listserv so that they can be alerted when something new has been posted on the site. If there is interest, the site can support forums on issues of common concern among the users. The website is intended to complement the text and be a continuing resource in this important field.

In Appreciation

In a sense, this book has many authors besides myself. It reflects the research efforts of numerous investigators in biology and transport science, and insights from the authors of many former texts. Many of the figures are gifts from colleagues and their publishers, who graciously permitted me to reproduce or adapt their illustrations. Most of the exercises have been vetted by my students at Ohio State and Duke. I would like to single out a few people who either suffered through the writing or without whom it would never have been completed:

- the students in my laboratory, to whom I was not always as available as I would have liked during the past few years, particularly Yun Liang, who found and copied all the references that had escaped digitization, and Ji Zhang, who computed and produced all the new numerical plots in this edition;
- Tim Oliver, who managed the project and patiently translated my computer files into the pages that follow; the folks at HFS Imaging, who transformed my often ambiguous sketches into the precise figures that appear throughout; and my wife, Ann, who obtained the permissions that allowed us to reproduce the excellent artwork of earlier authors.

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