Preface

SCOPE AND PURPOSE

This textbook describes the fundamental driving forces for mass transport, electric current, and fluid flow as they apply to the biology and biophysics of molecules, cells, tissues, and organs. Basic mathematical and engineering tools are presented in the context of biology and physiology. The chapters are structured in a framework that moves across length scales from molecules to membranes to tissues. Examples throughout the text deal with applications involving specific biological tissues, cells, and macromolecules. In addition, a variety of applications focus on sensors, actuators, diagnostics, and microphysical measurement devices (e.g., bioMEMS/NEMS microfluidic devices) in which transport and electrokinetic interactions are critical.

The book is written for beginning graduate students and advanced undergraduates and is aimed at an audience that has seen basic freshman physics (mechanics, electricity, and magnetism) as well as undergraduate exposure to differential operators and differential equations. In addition, it is hoped that the textbook will be a valuable resource for interdisciplinary researchers, including biophysicists, physical chemists, materials scientists, and chemical, electrical, and mechanical engineers seeking a common language for the subject.

PHILOSOPHY OF THE TEXTBOOK

A primary objective of this text is to integrate the fundamental principles of transductive coupling between chemical, electrical, and mechanical forces and flows that are intrinsic to transport within biological tissues, membranes, macromolecules, and biomaterials. These principles are applied and interpreted in the context of state-of-the-art discoveries and challenges in biology, physiology, and macromolecular science. Thus, a balanced presentation of selected, basic principles from chemical, electrical, mechanical, and materials engineering and science is intended, in order to establish a common language for biological and biomedical engineering students, rather than the disparate languages often used by chemical, electrical, or mechanical engineers alone. However, this text is not intended as simply a compilation of examples in which traditional engineering techniques are applied to problems in physiology. Rather, current problems in biology and biophysics are used to motivate quantitative engineering approaches applicable from the nanometer length scale of biomacromolecules up through the complex structural organization of tissues and organs.

While the global aim of bioengineering curricula is to integrate engineering fundamentals with modern biological and medical science, the underlying interdisciplinary nature of the engineering components themselves can be a blessing and a curse. Some specialized texts by necessity are focused on one or two engineering disciplines connected to physiology. However, there is also a need for foundational bioengineering courses and texts that are cross-disciplinary even within the engineering fundamentals. The topic of transport is an ideal medium in which to achieve this objective.

At the same time, this text is not focused on transport alone. Rather, our objective is to describe more broadly the intra- and intermolecular *fields* and *forces* that affect the biology, physiology, and biophysics of molecules, cells, tissues, and organs. Most biological tissues and macromolecules (e.g., proteins, polysaccharides, and nucleic acids) are electrically charged under physiological conditions. Therefore, it is necessary to describe electrical forces and interactions from first principles, just as fundamentals laws are needed to describe fluid velocity fields and chemical transport. In this way, electrical interactions at multiple length scales can be addressed on an equal footing with forces that derive from local chemical and mechanical gradients. Thus, electrical forces at the nanoscale are fundamental components underlying the integration of molecular structure and biochemistry with tissue-level mechanics, transport, biophysics, and biology.

ORGANIZATION OF THE TEXTBOOK

The organization of the book derives from the order of major topics covered in the MIT Biological Engineering core curriculum subject: chemical transport in electrolyte media (Chapter 1); electrical fields and electrochemically mediated transport (selected sections from Chapters 2 and 3), the concepts of stress and the stress tensor (the early sections of Chapter 4); fluid mechanics and convective transport (Chapter 5); and integrative case studies involving physicochemical interactions at the macromolecular and cellular levels (examples in Chapter 4) and electrokinetic examples fundamental to MEMS and physical chemistry (Chapter 6). At the same time, many sections in Chapters 1, 4, and 7 are also essential components of MIT's undergraduate and graduate courses in molecular, cellular, and tissue biomechanics, including the rheological and deformational behavior of tissues and gels. Thus, the coverage of the textbook is broader than that used solely in a one-term course, and is intended to allow flexibility in choosing the order and content to adapt to the breadth of topics and courses of interest to biological and biomedical engineering students and instructors.

The course at MIT has evolved over many years, and is now typically taken each term by students in biological engineering, mechanical, chemical, and electrical engineering, materials science and engineering, and other departments. Thus, while each student has seen aspects of some of the material, none has seen the breadth of topics covered, and therefore no assumptions are made concerning the students' background, except for exposure to undergraduate-level mathematics and physics. Pedagogically, starting with chemical transport enables the mathematical treatment to focus initially on diffusion of a scalar (solute concentration) before the added complexities of dealing with vector fields (fluid velocity and electric fields). The spirit of the course is such that the instructor focuses each lecture using a current problem from the biological or medical literature, and then uses the text material as the fundamental basis for discussing, modeling, and critically analyzing and interpreting the results. The numerous examples and homework problems in the book are used by the students to gain additional experience and further insight. A solutions manual and figures from the book are available to qualified adopters of the text, and additional homework problems will be available to students on the book web site.