Problems for Biomedical Fluid Mechanics and Transport Phenomena

How does one deal with a moving control volume? What is the best way to make a complex biological transport problem tractable? Which principles need to be applied to solve a given problem? How do you know whether your answer makes sense?

This unique resource provides over 200 well-tested biomedical engineering problems that can be used as classroom and homework assignments, quiz material, and exam questions. Questions are drawn from a wide range of topics, covering fluid mechanics, mass transfer, and heat transfer applications. These problems, which are motivated by the philosophy that mastery of biotransport is learned by practice, will aid students in developing the key skills of determining which principles to apply and how to apply them.

Each chapter starts with basic problems and progresses to more difficult questions. Lists of material properties, governing equations, and charts provided in the appendices make this book a fully self-contained resource. Solutions to problems are provided online for instructors.

Mark Johnson is Professor of Biomedical Engineering, Mechanical Engineering, and Ophthalmology at Northwestern University. He has made substantial contributions to the study of the pathogenesis of glaucoma and of age-related macular degeneration of the retina. His academic interests include biofluid and biotransport issues, especially those related to ocular biomechanics.

C. Ross Ethier holds the Lawrence L. Gellerstedt, Jr. Chair in Bioengineering and is a Georgia Research Alliance Eminent Scholar in Biomechanics and Mechanobiology at Georgia Tech and Emory University. His academic interests include cell and tissue biomechanics and mechanobiology. He is co-author of *Introductory Biomechanics: From Cells to Organisms*, one of the Cambridge Texts in Biomedical Engineering.

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Mark Johnson
Northwestern University, Illinois
C. Ross Ethier
Georgia Institute of Technology and Emory University

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To my wife, son, parents, and family,
and to my mentors, colleagues, and students,
who have all in their own ways contributed to this book
Mark Johnson

To my students, colleagues, and family,
who have all taught me so much.
C. Ross Ethier

"A tremendously valuable resource for bioengineering students and instructors that contains problems scaling from the molecular to whole body level. Nearly every system in the body is included, as well as a variety of clinically and industrially relevant situations. The problems are aimed at instruction in applying basic physical principles in a variety of settings, and include entertaining topics such as squid swimming, elephant ear heat transfer, whistling to spread germs, and air friction over a bicyclist. What fun!"

James E. Moore Jr., Imperial College London

"The problems and solutions represent an invaluable resource for instructors. In addition, the step-by-step procedure described in section 1.3 is a wonderfully insightful reminder of what students really need to know to be successful in solving fluid mechanics problems. Instructors would do well to teach this procedure at the beginning and to refer to it consistently throughout the course."

M. Keith Sharp, University of Louisville

"A book devoted solely to biologically relevant problems in fluid mechanics and transport is a very welcome addition to the teaching armamentarium in this area. Problems related to cardiovascular, respiratory and ocular physiology are emphasized, deriving from the substantial research expertise of the authors. The problems are very interesting and in many cases very challenging. They cover a range of difficulty that should be appropriate for both undergraduate and graduate level courses and more than enough topics to provide substantial breadth. Overall excellent! Now I'm looking forward to working out my own solutions and maybe peeking at the solution manual."

John M. Tarbell, The City College of New York

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Preface

This book arose out of a need that frequently faced us, namely coming up with problems to use as homework in our classes and to use for quizzes. We have found that many otherwise excellent textbooks in transport phenomena are deficient in providing challenging but basic problems that teach the students to apply transport principles and learn the crucial engineering skill of problem solving. A related challenge is to find such problems that are relevant to biomedical engineering students.

The problems included here arise from roughly the last 20–30 years of our collective teaching experiences. Several of our problems have an ancestry in a basic set of fluid mechanics problems first written by Ascher Shapiro at MIT and later extended by Ain Sonin, also at MIT. Roger Kamm at MIT also generously donated some of his problems that are particularly relevant to biomedical transport phenomena. Thanks are due to Zdravka Cankova and Nirajan Rajkarnikar, who helped with proof-reading of the text and provided solutions for many of the problems.

For the most part, the problems in this book do not involve detailed mathematics or theoretical derivations. Nor do they involve picking a formula to use and then plugging in numbers to find an answer. Instead, most of the problems presented require skills in problem solving. That is, much of the challenge in these problems involves deciding how to approach them and what principle or principles to apply.

Students will need to understand how to pick a control volume, and that multiple control volumes are necessary for some problems. How does one deal with a moving control volume? How many principles need to be applied to solve a given problem? How do you know whether your answer makes sense? Students who are struggling or stuck on a particular problem will want to know how they should proceed in such cases. The problems presented here will raise all of these issues for students.

In the first chapter, we give general principles of problem solving, and present the Reynolds transport theorem. We also show an example of how we would approach and solve one problem. However, problem solving is best learned by doing problems. Seeing someone else solve a problem is not nearly as educational. We hope that we have provided a wide variety of problems in different areas of transport phenomena, most at the basic level, that aids in the development of problem-solving skills for students in these areas. Each chapter of problems is organized such that the easier problems are at the beginning of the chapter, and then the problems become progressively harder. The exception to this rule is that heat transfer problems are to be found at the end of each chapter.