Introduction to Biomaterials

This textbook gives students the perfect introduction to the world of biomaterials, linking the fundamental properties of metals, polymers, ceramics, and natural biomaterials to the unique advantages and limitations surrounding their biomedical applications.

- Clinical concerns such as sterilization, surface modification, cell–biomaterial interactions, drug delivery systems, and tissue engineering are discussed in detail, giving students practical insight into the real-world challenges associated with biomaterials engineering.
- Key definitions, equations and concepts are concisely summarized alongside the text, allowing students to quickly and easily identify the most important information.
- Bringing together elements from across the book, the final chapter discusses modern commercial implants, challenging students to consider future industrial possibilities.

Concise enough to be taught in a single semester, and requiring only a basic understanding of biology, this balanced and accessible textbook is the ideal introduction to biomaterials for students of engineering, materials science, and medicine.

C. Mauli Agrawal is the Vice President for Research at the University of Texas at San Antonio (UTSA), and the Peter Flawn Professor of Biomedical Engineering. Previously, he served as the Dean of the College of Engineering at UTSA. He specializes in orthopedic and cardiovascular biomaterials and implants and his inventions have been licensed to various companies. He is a member of the International College of Fellows of Biomaterials Science and Engineering, a Fellow of the American Institute for Medical and Biological Engineering, a former President of the Society for Biomaterials, and was awarded the 2010 Julio Palmaz Award for Innovation in Healthcare and the Biosciences.

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C. Mauli Agrawal, Joo L. Ong, Mark R. Appleford and Gopinath Mani
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CAMBRIDGE TEXTS IN BIOMEDICAL ENGINEERING

Cambridge Texts in Biomedical Engineering provide a forum for high-quality textbooks targeted at undergraduate and graduate courses in biomedical engineering. It covers a broad range of biomedical engineering topics from introductory texts to advanced topics, including biomechanics, physiology, biomedical instrumentation, imaging, signals and systems, cell engineering, and bioinformatics, as well as other relevant subjects, with a blending of theory and practice. While aiming primarily at biomedical engineering students, this series is also suitable for courses in broader disciplines in engineering, the life sciences and medicine.

"This is a book that is destined to be a classic in biomaterials education. Written by leading bioengineers and scientists, it can serve not only as a textbook to support a semester-long undergraduate course, but also as an introduction to graduate-level classes. It is a well-written, comprehensive compendium of traditional and also modern knowledge on all aspects of biomaterials, and I am sure that both students and instructors will embrace it and use it widely."

Kyriacos A. Athanasiou

University of California, Davis

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Basic Theory with Engineering Applications

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I dedicate this work to my parents who taught me to love excellence, and to my wife and children (Sue, Ethan and Serena), who have always supported my pursuit of it.

C. Mauli Agrawal

To my family, who have put up with me all these years. Joo L. Ong

I express my deepest appreciation for my wife Lindsey, best friend, greatest love, supplier of green limes and good joss. Mark R. Appleford

I dedicate this work to my wife Priya Devendran, my daughter Manushri Gopinath, and my parents Mani and Bagyam Mani. Gopinath Mani

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Preface

Biomaterials have helped millions of people achieve a better quality of life in almost all corners of the world. Although the use of biomaterials has been common over many millennia, it was not until the twentieth century that the field of biomaterials finally gained recognition. With the advent of polymers, new processing and machining processes for metals and ceramics, and general advances in technology, there has been an exponential growth in biomaterials-related research and development activity over the past few decades. This activity has led to a plethora of biomaterials-based medical devices, which are now commercially available.

For students in the area of biomaterials, this is an especially exciting time. On the one hand, they have the opportunity to meet and learn from some of the stalwarts and pioneers of the field such as Sam Hulbert, one of the founders of the Society for Biomaterials (SFB). Other greats include Allan Hoffman and Buddy Ratner (biomaterials surfaces), Robert Langer (polymers and tissue engineering), Nicholas Peppas (hydrogels), Jack Lemons (orthopedic/dental implants), Joseph Salamone (contact lenses), and Julio Palmaz (intracoronary stents). Most of these individuals are still active in research and teaching. The authors of this book have been privileged to interact and learn from them in various forums, and students today have the same opportunities. On the other hand, with the current availability of sophisticated processing and characterization technologies, present day students also have the tools to take the field to unprecedented new levels of innovation.

This book has been written as an introduction to biomaterials for college students. It can be used either at the junior/senior levels of undergraduate education or at the graduate level for biomedical engineering students. It is best suited for students who have already taken an introductory course in biology. We have felt the need for a textbook that caters to *all* students interested in biomaterials and does not assume that every student intends to become a biomaterials scientist. This book is a balance between science and engineering, and presents both scientific principles and engineering applications. It does not assume that the student has a background in any particular field of study. Therefore, we first cover the basics of materials in Chapters 1 and 2 followed by basic biological principles in Chapter 3.

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After presenting various techniques for the characterization of biomaterials in Chapter 4, we dedicate a chapter each to the discussion of metals, polymers, ceramics, and natural biomaterials (Chapters 5–8). Surface modification methods are presented in Chapter 9, followed by sterilization techniques in Chapter 10. The success of any biomaterial depends on the biological response to it and so protein chemistry, cell–biomaterial interactions, and the effect of biomaterials on tissue response are addressed in Chapter 11. The last three chapters (Chapters 12–14) cover the application of biomaterials in the clinical world; specifically drug delivery systems, tissue engineering, and clinical applications are presented and discussed.

This book has been designed to present enough material so that it can be comfortably covered during a regular length semester-long course. It should provide the student with a concise but comprehensive introduction to biomaterials and lays the foundation for more advanced courses.

The authors would like to thank the following individuals for assisting in a variety of ways in compiling this book: Jordan Kaufmann, Ethan Agrawal, Serena Agrawal, Tim Luukkonen, Amita Shah, Steve Lin, Angee Ong, Kevin Ong, Lisa Actis, Marcello Pilia, and Stefanie Shiels.