

Essential Biomaterials Science

This groundbreaking single-authored textbook equips students with everything they need to know to truly understand this hugely topical field, including essential background on the clinical necessity of biomaterials, relevant concepts in biology and materials science, comprehensive and up-to-date coverage of all existing clinical and experimental biomaterials, and the fundamental principles of biocompatibility. Drawing on the author's 40 years' experience in biomaterials, this is an indispensable resource for students of biomaterials science and engineering studying these life-saving technological advances.

Featuring

- A new classification system for biomaterials, a systematized framework for biocompatibility theory, new concepts for tissue engineering templates, and applications for nanomaterials in medicine.
- Extensive case studies from a wide range of clinical disciplines, interweaved with the theory, equipping students with a practical understanding of the phenomena and mechanisms of biomaterials performance.
- A whole chapter dedicated to the biomaterials industry itself, including guidance on regulations, standards and guidelines, litigation, and ethical issues, to prepare students for industry.
- Informative glossaries of key terms, engaging end-of-chapter exercises, and up-to-date lists of recommended reading.

David Williams is a Professor at the Wake Forest Institute for Regenerative Medicine, North Carolina, with over 40 years' experience in biomaterials science. He is Editor-in-Chief of the international journal *Biomaterials*, the President of the Tissue Engineering and Regenerative Medicine International Society, and a former Director of the UK Centre for Tissue Engineering at Liverpool University, where he is now an Emeritus Professor. In addition he is Advisory Professor of Shanghai Jiao Tong University, Visiting Chair Professor of Biomedical Materials, Taipei Medical University, a Visiting Professor of the Christiaan Barnard Department of Cardiothoracic Surgery, University of Cape Town, of the National University of Singapore, Tsinghua University, Beijing, Beihang University, Beijing, the University of New South Wales, Australia, and the Sree Chitra Tirunal Institute for Medical Science and Technology, Thiruvananthapuram, India. He has travelled extensively to promote excellence in scientific research and writing. He is a Fellow of the Royal Academy of Engineering, and has received numerous awards, including the 2012 Acta Biomaterialia Gold Medal.

“This is the long overdue single-author compendium students, scientists and clinicians were waiting for. Anyone expecting a dry scientific compilation will be pleasantly surprised by the wonderfully lively style in which Prof. Williams takes the reader on an exciting journey into the world of modern biomaterials and the opportunities it offers to patients. In a field long plagued by self-sustained paradigms, wrong models and wrong questions, this book boldly introduces each chapter on the basis of true clinical needs, taking the captivated reader into the deepest depths of material science and biology and eventually leaving him in a position where his own understanding and judgment has undergone a quantum leap.”

Peter Zilla
University of Cape Town, South Africa

“This revolutionary book provides a coherent synthesis of the entire field of biomaterials, from the underlying sciences, to its practical applications. The book is the culmination of thought from one of the leading pioneers in the field, David F. Williams, who has been active for over 45 years, and is able to bring together not only the importance of the subject matter, but also its historical perspective, and future trends. With a strategic focus of thought, this unique text is a seminal contribution that provides an invaluable and thorough resource for anyone interested in the biomaterials field, not just for students, but also for scientists, and government and industry personnel.”

Anthony Atala
Wake Forest University School of Medicine, USA

“This book distils the wide-ranging field of biomaterials down to critical topics, and presents them in an accessible and user-friendly way. In writing the book, the author applies his innovative ideas, vast knowledge, and rich experience to adroitly tackle the challenge of ‘less is more’ in processing a wealth of subject matter, placing a special focus on dynamic interactions between various biomaterials with complex biological systems, and translation of tissue engineering products to the clinic. Another valuable feature of this book is the pedagogical implications contained in each topic, which begins with a clear, simple diagram to introduce the reader to the core information, and ends with a number of questions to help the reader to integrate basic concepts into practice. Accordingly, this book provides a great reference for graduate students, researchers, and doctors specializing in biomaterials science. Such empowerment will inevitably lead to advancing the state of the art in the field.”

Xiaosong Gu
Nantong University, China

“David Williams is one of the leading international authorities in biomaterials. Drawing on his vast multidisciplinary experience in the field, Prof. Williams presents in this attractive textbook not only a comprehensive view of biomaterials in their various facets, but also innovative ideas, along with the clarity of thought and precision of expression that those who know him well have come to expect of him. Although written primarily for students in biomaterials curricula, I see this book as ‘a must’ for the personal and institutional library.”

C. James Kirkpatrick
Johannes Gutenberg University of Mainz, Germany

“This book provides the reader with the most up-to-date information on the ground-breaking revolutions in biomaterials sciences, and huge application potentials to overcome the most acute clinical challenges in the 21st-century. Reading this book is an academic enjoyment!”

Yan Li

Zhongnan Hospital of Wuhan University, China

“It is a remarkable achievement for any one individual, even if that individual is David Williams, to construct such an accomplished and authoritative text. Based on a lifetime spent in the field, this book is comprehensive, thought-provoking, and forward-looking, and is beautifully written and illustrated. While intended, primarily, as a student text, it is certain that there will be biocompatibility between this work and academics, clinicians, regulators, and industry practitioners alike, and it is destined to become a definitive biomaterials science text.”

Keith McLean

CSIRO, Australia

“As the advancement of medical science cures various diseases, the role of biomaterials and their applications in medicine is recognized as growing. Almost every week, new biomaterials are announced and launched in the market. This book is composed of several chapters containing important information with many beautiful illustrations and photographs, which help students to understand biomaterials from very basic to near clinical applications. As one of the unique points of this book, each chapter has a brief glossary of biological and medical terms, which may be unfamiliar for students.”

Teruo Okano

Tokyo Women’s Medical University, Japan

“Williams’ *Essential Biomaterials Science* combines comprehensive scope, single-authored consistency, and contemporary translational practicality in this novel textbook on biomaterials. The book clusters detailed considerations of materials, pathobiology, applications, regenerative therapeutics, and considerations of commercialization and clinical implementation, with an overriding focus on biocompatibility and concepts of biomaterial–tissue interactions, a key theme of Williams’ many contributions to and leadership in this field. Well-illustrated, particularly with conceptual graphics, well-referenced with suggested readings, and with end-of-chapter questions, the book is most likely to be most useful to university students at an advanced undergraduate or graduate level, and nicely complements other available references in adding to the richness and usefulness of literature in the field.”

Frederick Schoen

Brigham and Women’s Hospital, Harvard Medical School, USA

“This is an extraordinary, impressively thorough reference source and textbook. David Williams has a rare knack for clear communication. He draws on a unique combination of outstanding knowledge, remarkable experience, and a rare appreciation of the key concepts. This book is an absolutely essential, superbly comprehensive, and valuable resource for anyone who wants to truly understand the field of biomaterials.”

Tony Weiss

University of Sydney, Australia

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Essential Biomaterials Science

DAVID WILLIAMS

Wake Forest Institute for Regenerative Medicine



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PREFACE

Biomaterials are crucial components of many health care products. They are in the news daily as we hear of new devices that allow deaf people to hear, and of techniques to return patients to a near normal life after a heart attack. Headlines tell us of titanium dental implants, ceramic artificial hips, carbon heart valves, collagen cosmetic injections and clear plastic lenses in the eye. Science magazines talk of new drug–biomaterial combinations that are radically altering cancer chemotherapy and immunotherapy and of nanoscale contrast agents that give far more power to MRI and CT imaging systems for better and earlier disease diagnosis. Biomaterials save lives and improve the quality of life for millions of people.

The science that underpins these advances is, not surprisingly, called biomaterials science. It has grown and developed from tentative beginnings half a century ago into a major academic and clinical discipline today. This science is both multidisciplinary and interdisciplinary since it brings together many classical disciplines of science, engineering and medicine, but also adds new knowledge that fits within the gaps between the classical subjects.

Biomaterials science is one of the most attractive subjects in any curriculum and is taught in colleges and universities across the globe. Students of biomaterials science go on to become research scientists at the forefront of medical technologies, clinicians who actually use biomaterials-based products on a daily basis, industrialists who manufacture the products, regulators who decide what can and can't be used in clinical practice or a practitioner of any one of the other contributory professions. It is obvious that these students need a textbook to guide them through the complexities of the individual components that make up biomaterials science. That is the rationale for this book, *Essential Biomaterials Science*.

It will be evident from the above comments that the compilation of all of the essential features of biomaterials science in a single book is not a trivial task, since these essentials cover so many different themes. For this reason, most books on this subject are multi-author books, with individual contributions from many different scientists and clinicians, brought together by a panel of editors. *Essential Biomaterials Science* is different. It is the work of a single author. It brings together, with one style, the various components of biomaterials science and integrates them, hopefully with little repetition and few gaps, into a logical story. It covers the essential underlying sciences, both materials/engineering sciences and biological sciences, and the clinical applications.

I have spent over 40 years working in the area of biomaterials science, developing the understanding of the subject that allows such a book to be written. I wrote one of the first textbooks on biomaterials and medical devices in the early 1970s (Williams and Roaf, *Implants in Surgery*, W.B. Saunders) and my own research work, writing and teaching has covered many of the scientific areas that are discussed in this book. In addition I have been the Editor-in-Chief of the premier research journal in this field,

Biomaterials, since 2001, a position that has allowed me to monitor and influence the developments on a global basis.

Essential Biomaterials Science is primarily intended as a textbook for students who are studying biomaterials at senior undergraduate and postgraduate levels. It should also serve as a reference source for anyone, at any level, who utilizes biomaterials in the course of their professional work. This especially includes those at post-doctoral or early faculty levels whose major disciplines have not been materials science, but also those in industry, regulatory or legal professions who regularly deal with health care products.

The book starts with an introduction to the world of biomaterials and medical devices served through a series of exemplars of current clinical practices that employ health care products routinely. Chapter 2 covers the essentials of materials science that underpin these clinical uses. In many ways Chapter 3 can be considered as the heart of the book since it deals with the mechanisms whereby the materials science and biology intersect, that is within the subject of biocompatibility; here a new unified framework of biocompatibility mechanisms is presented. Chapters 4 to 7 deal with the four main clinical applications, of implantable medical devices and artificial organs, tissue engineering and regenerative medicine, drug and gene delivery, and imaging and diagnostic systems. Chapter 8 comprehensively guides the reader through the array of current and potential biomaterials, with a new system for their classification. The final chapter discusses some of the infrastructure issues, including ethics, regulation and litigation.

In each chapter there are summaries of learning outcomes, glossaries, lists of recommended further reading and sample questions. The reading matter includes some other textbooks (marked *) but mainly provides citations to major review and opinion papers that take the reader more deeply into critical issues. All of these have been carefully chosen, mostly from the current literature and each citation includes a brief summary of the content of the work. Since this is a textbook, there are no references to support individual statements. I have also resisted the temptation to refer to commercial products and trade names since these are often ephemeral and become out-dated quickly. Occasionally a trade name becomes a generic descriptor and these are sparingly introduced. The glossaries are included in order to supply definitions of key individual terms, whose meanings may not be intuitively obvious.

The views expressed in this book mostly reflect my own beliefs, philosophies and prejudices and I therefore take full responsibility for the whole of the contents. Naturally I have been influenced by the writing and lectures of very many individuals, in many different countries and cultures. It is inappropriate to single out any such individuals here, but hopefully many of them will read or glance at this book and recognize where their thoughtful contributions have had an impact. Several of these colleagues have generously provided original artwork for illustrations; their collective support is gratefully acknowledged here and full credit is given to each in the relevant captions. I am very grateful to the staff at Cambridge University Press, especially Michelle Carey and Elizabeth Horne, for their guidance during the five years it has taken to prepare the book.

Most people who work in the area of biomaterials science will be aware that I have been supported in all of my endeavors by my wife, Peggy. Contributors to the journal *Biomaterials* will recognize her role, as Managing Editor of the journal, in coordinating much of the work that is published on this subject. Countless others have met her on our many biomaterials-related journeys around the world. Without her constant and unwavering support this book could not have been written. Too many days and nights have been spent, in North Carolina, South Africa and elsewhere, researching, writing and compiling the book, and her support, both practical and emotional, has been invaluable. My debt to Peggy is publicly acknowledged here.