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Fields, Forces, and Flows in Biological Systems.

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she regulates not only herself but also her environment, within limits. She is depicted as having had an infancy and as expecting an old age—one that may not include us. We human beings depend on her; we are Gaia's children and also a part of her.

I suspect that some readers who are encountering the concept of Gaia for the first time will be drawn to how it frames a relationship between humans and a motherly nature. For those who find the Gaia imagery appealing, this book may be persuasive, but it will not suit everyone's taste. The Gaia concept aptly serves Rice's purpose for writing *Life of Earth*, however, by presenting the history of Earth on a human scale. Rice helps us to care for Earth's systems of photosynthesis and respiration and temperature regulation by treating them as analogous to human bodily functions. Yet Gaia's value lies in accomplishing what people cannot seem to do naturally: establishing and maintaining the conditions of life for our species and every other one. This is wondrous and also superhuman. But is it more impressive when anthropomorphized?

Although it is not a book for biologists or for classroom use, *Life of Earth* can be persuasive in its message. In helping readers comprehend the history of life on Earth, it reveals the indispensability of Earth's living systems, and through the central figure of Gaia, encourages us to care about them.

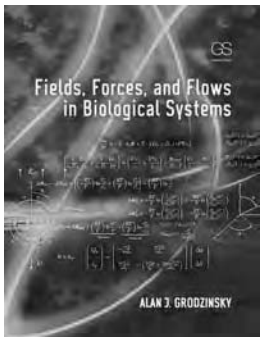
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ELECTROMECHANICS FOR THE TWENTY-FIRST CENTURY

Fields, Forces, and Flows in Biological Systems. Alan J. Grodzinsky. Garland Science, 2011. 308 pp., illus. $120.00 (ISBN 9780815342120 cloth).

> "If people do not believe that mathematics is simple, it is only because they do not realize how complicated life is."
>
> John Louis von Neumann

In 1974, Alan Grodzinsky wrote his doctoral thesis at the Massachusetts Institute of Technology (MIT) on membrane electromechanics at a time when computers were scarce and interest in biophysics was just starting to explode. In the following decades, biology saw the invention of fantastic new tools like magnetic resonance imaging, the scanning tunneling microscope, and the atomic force microscope, made possible by the application of physics to biology. Today, mathematical methods for studying biology are more important than ever. *Fields, Forces, and Flows in Biological Systems*, Grodzinsky's well-illustrated mathematical primer on bioengineering, will stand as a guide for the next generation of electrical engineers interested in biology.



Grodzinsky is well qualified to write a textbook on the principles of bioengineering. He directs the MIT Center for Bioengineering and teaches in the three departments that together span the intended breadth of this book—mechanical, electrical, and biological engineering. Through his research, he has made contributions to cartilage-tissue engineering—particularly its mechanical, chemical, and electrical properties, which have helped researchers to understand and cure bone diseases such as osteoarthritis. Moreover, Grodzinsky is a member of the first generation of scientists and engineers, which includes Leroy Hood and Robert Nerem, to work in the area of bioengineering. His presence during the development of bioengineering into its own discipline gives Grodzinsky a historical perspective, which is evident in the text.

Electromechanics, which is the subject of this book, is composed of the interplay between three subjects—electromagnetism, electrical engineering, and mechanics. The primary contribution of the book is the unified presentation of all the laws of electromechanics within the context of bioengineering systems. Professors and graduate students previously had to gather this material from lecture notes or from articles in *Biophysical Journal* or *Journal of Biophysics*. This book provides all this information in a single place.

In *Fields, Forces, and Flows*, successive chapters present the governing laws of magnetism, electricity, and fluid flow, with numerous examples and a few end-of-chapter problems added to demonstrate their application in biological systems. The author approaches each topic from the perspective of an electrical engineer, starting from first principles, introducing the balance of forces and conservation of energy and momentum, and then proceeding to derive the governing equations. The most important governing equations are derived from scratch, including those of Maxwell and Navier-Stokes, which are presented in the form of vectorial differential equations. Next, he presents the rare analytical solutions to these equations, with initial and boundary conditions given in the context of previously solved bioengineering problems. One oversight is the neglect of computational approaches. However, the most important part of the problem-solving process—a discussion of the physical interpretation of the mathematical solution—is usually given.

Fields, Forces, and Flows is a wonderfully thin stand-alone reference. The author's concise prose allows him to

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fit this body of work into a volume only a half-inch thick—far slimmer than most biology textbooks. Its small size and completeness make it best suited as a desk reference or as a set of lecture notes for highly mathematically trained graduate-level students in a bioengineering class. Its style is a mixture of formal and informal, in the manner of the most-effective engineering teachers. The derivations and proofs are quite formal, as they should be, but in the examples given, the author inserts numerous caveats. At times, one can almost hear Grodzinsky speaking, a seasoned practitioner of biomathematics imparting his years of experience.

It is noteworthy that the author compromises neither on the rigor of the mathematics nor on the biological and chemical aspects of its application. Other interdisciplinary texts in bioengineering usually present simplified equations with the absence of vector notation. Grodzinsky's book, by comparison, is most thorough and complete in its mathematical presentation. Units are given for all variables throughout the text, which aid the reader in understanding the material. Moreover, mathematical tools are taught alongside stunning microscopy images, tables of chemical formulas, and properties of the most important biomolecules and schematic diagrams of the problem at hand. This biological data will save the reader hours of Internet surfing and page turning through other texts.

Exciting examples of electromechanics, such as an analysis of the electric eel or of magnetically driven bone healing, distinguish this book from rigorous mathematics texts. Numerous images also provide a historical tour of recent bioengineering inventions, such as electrophoresis and microelectromechanical systems. The inclusion of photos of certain instruments, however, may date the text as the number and sophistication of bioengineering technologies advances. Similar to many books used at MIT, this one has a strong mathematics prerequisite. To fully appreciate *Fields, Forces, and Flows*, the reader should not only have studied multivariable calculus but he should also be proficient in its application. Such a facility is usually neglected in mathematics courses but is taught well in engineering and physics courses.

The statement on the back cover describes the book as intended "for students in [both] engineering and bioscience." I disagree. The use of vector notation throughout the book precludes the current generation of biology students from incorporating this book into their courses. Biology audiences with a good grasp of single-variable calculus might consider other bioengineering textbooks, such as *Transport Phenomena in Biological Systems* (Truskey, Yuan, and Katz), a text that focuses on biological fluid mechanics rather than on electromagnetism.

This book is clearly written for those with a bent toward and training in electromagnetic issues. In the first five of the book's seven chapters, the author presents applications of electromagnetism, with those of fluid and solid mechanics making up the remaining two chapters. Perhaps this unequal partitioning is justified by the kind of problems important to bioengineers. However, at least half of all bioengineering graduate students have undergraduate degrees in mechanical, rather than electrical, engineering. Therefore, a section highlighting the importance of fluidic and rheological phenomena would have been especially useful to these readers.

Two shortcomings to mention are the lack of color images in the book and the fact that the number of worked examples far exceeds the number of end-of-chapter problems, but both issues can be ameliorated by supplementing this text with MIT's online resource, Open Course Ware, which provides multiple homework problems, as well as exams for all MIT classes. A course with the same title as this book is taught yearly at MIT, and the course's Web site includes color movies and images, as well as references to other textbooks that are less mathematical in nature.

Fields, Forces, and Flows will be most appreciated by those students with electrical engineering backgrounds who will be graduating within the next 10 years. For this audience, the book is an excellent and concise example of an interdisciplinary text on mathematical methods in bioengineering. Not only does the book present all the laws of electromechanics in a single place but it brags justifiably about the numerous applications of these laws in bioengineering technologies. It is historically relevant to note that Grodzinsky's doctoral advisor, James Melcher, was an MIT electrical engineer known for rediscovering and popularizing the entire field of continuum electromechanics and its application. In some ways, Grodzinsky is this century's Melcher, resurrecting electromechanics for the second time and showing clearly and inspiringly its successful application to bioengineering problems.

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WHAT VERY BIG TEETH YOU HAVE

Mammal Teeth: Origin, Evolution, and Diversity. Peter S. Ungar. Johns Hopkins University Press, 2010. 320 pp., illus. $95.00 (ISBN 9870801896682 cloth).

Mammal teeth are a fascinating combination of intricate microstructure and supreme strength. They are at the pointy end of the animal–food relationship in that they are the key tools used in the daily acquisition of energy and nutrients in mammals. As such, teeth are magnificent

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