Introductory Physics for Biological Scientists

Why do elephants have sturdier thigh bones than humans? Why can't ostriches fly? How do bacteria swim through fluids?

With each chapter structured around relevant biological case studies and examples, this engaging, full-color book introduces fundamental physical concepts essential in the study of biological phenomena. Optics is introduced within the context of butterfly wing coloration, electricity is explained through the propagation of nerve signals, and accelerated motion is conveniently illustrated using the example of the jumping armadillo. Other key physical concepts covered include waves, mechanical forces, thermodynamics, and magnetism, and important biological techniques are also discussed within this context, such as gel electrophoresis and fluorescence microscopy. A detailed appendix provides further discussion of the mathematical concepts utilized within the book, and numerous exercises and quizzes allow readers to test their understanding of key concepts. This book is invaluable to students aiming to improve their quantitative and analytical skills and understand the deeper nature of biological phenomena.

Christof M. Aegerter is a professor of physics at the University of Zurich. He has extensive research experience in biological and soft condensed matter physics, specifically bioimaging and the dynamics of biological growth. He currently teaches a course for first-year biology students, demonstrating introductory physics with examples from the biological sciences.

Cambridge University Press
978-1-108-42334-2 — Introductory Physics for Biological Scientists
Christof M. Aegerter
Frontmatter
More Information

Introductory Physics for Biological Scientists

CHRISTOF M. AEGERTER
University of Zurich

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India

79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/aegerter
DOI: 10.1017/9781108525862

First published 2018

Printed and bound in Great Britain by Clays Ltd, Elcograf S.p.A.

A catalogue record for this publication is available from the British Library.

Library of Congress Cataloging-in-Publication Data
Names: Aegerter, Christof M., author.
Title: Introductory physics for biological scientists /
Christof M. Aegerter, Universität Zürich.
Description: Cambridge, United Kingdom ; New York, NY : Cambridge University
Press, 2018. | Includes bibliographical references and index.
Identifiers: LCCN 2018018453 | ISBN 9781108423342 (hardback)
Subjects: LCSH: Physics.
Classification: LCC QC21.3 .A36 2018 | DDC 530–dc23
LC record available at https://lccn.loc.gov/2018018453

ISBN 978-1-108-42334-2 Hardback

Additional resources for this publication at www.cambridge.org/aegerter

Contents

Preface: How to Use This Book

This book grew out of an introductory lecture for first-year biology students at the University of Zurich that I have been giving for a couple of years. The entire material covered in the book I would teach in a year-long course (28 weeks of term) with three hours of lectures per week. Given the fact that physics is a prerequisite for biology students, which is usually not very popular, I have started to gradually change the standard curriculum of the introductory physics class by introducing the same concepts on biological examples and in this way also give insights to these biological problems that would not be covered in a biology class. In this way, the course is tailored to biology students in that the basic goal of the course actually is to gain an understanding of biological systems and common techniques in biology, which just happens to introduce all of the concepts usually also introduced in a basic physics course. This however does not mean that the physics is treated less rigorously or less quantitatively. In order to actually reach an understanding of the biological problems, a fully quantitative description of the processes and thus the introduction of the corresponding concepts need to be provided, which is why the course and the book are unapologetically quantitative where needed.

This is mirrored in the fact that biological research is currently becoming ever more quantitative, and as it happens, the methods used in such a quantitative treatment of biological problems are often more complex than what is usually treated in an introductory course. This is the reason that the present book contains advanced mathematical tools such as differential equations, Fourier-series, and statistics, which are used early on. All of these tools are, however, introduced in a very applied fashion on examples directly stemming from biology, such that their use can be immediately grasped. In addition, there is an appendix describing all of the basic concepts used, and this may be useful to turn back to or to study in advance to make sure all of the needed concepts are understood. One further reason for the use of mathematical descriptions throughout is that, when we are trying to understand the workings of magnetic resonance imaging (MRI) or how patterns form during embryogenesis, there is often a deeper level of understanding that we can gain by a mathematical treatment, such that we can make definite predictions. However, a qualitative understanding can be obtained without following any of the derivations, and often the result can even be guessed at by an understanding of the relevant parameters determining the behavior of a system. This can be seen throughout the book where in almost all instances a qualitative understanding of problems in terms of proportionalities and power-law dependencies is obtained from an understanding of the basic physics that determines the question at hand. In fact, the initial chapters introduce the tools of such a qualitative description in terms of scaling laws and dimensional analysis. Sections that go beyond the basic treatment, sometimes even of an introductory physics class for physics majors, are marked with an asterisk (*). However, given the nature of biological problems, these sections tend to be biologically even more interesting, concerning subjects such as population dynamics, blood flow, the conduction of nerve signals, or the properties of biomolecules or the cytoskeleton and electrophoresis. While the treatment of this needs some more advanced mathematical tools, these sections are still interesting to biologists for their conclusions regarding the biological problem at hand.

Given the importance of biological problems and physics-based methods used in biology, the order in which subjects are introduced does not follow the standard canon of an introductory physics class. Given the great importance of optical phenomena, in particular scattering and microscopy as biological tools, and vision, coloration, and navigation by the polarized sky as biological problems, we start with a discussion of waves, oscillations, and optics after an introductory chapter laying the foundations of why physics is important and how quantitative tools can help making predictions. This grasps the imagination of biology students from the beginning. Therefore, when it is time to discuss mechanics, heat, and electrical phenomena, the students already know that this is going to be important. In addition to biological problems, some important biological techniques, such as gel electrophoresis, fluorescence microscopy, MRI, and mass spectrometry are discussed in detail in the context of the corresponding physics concepts, in order to get biology students to understand the basic principles behind them and therefore make them appreciate what these experimental methods can and cannot do. In places, the text goes further than a usual introductory physics course, where it is biologically relevant. Thus there is an introduction to statistical physics, soft matter, viscoelasticity, nonequilibrium and nonlinear dynamics, as well as pattern formation, all of which have direct applications in biology. These typically are the final sections with an asterisk of the corresponding chapter on heat, mechanics, elasticity, or fluid dynamics. In all of this, it is important to not only study the theory but to solve problems oneself. Therefore, every chapter closes with problem sets, including basic qualitative questions and more advanced problems directly describing an interesting biological question. Solutions for these problems are available for download at www.cambridge.org/aegerter