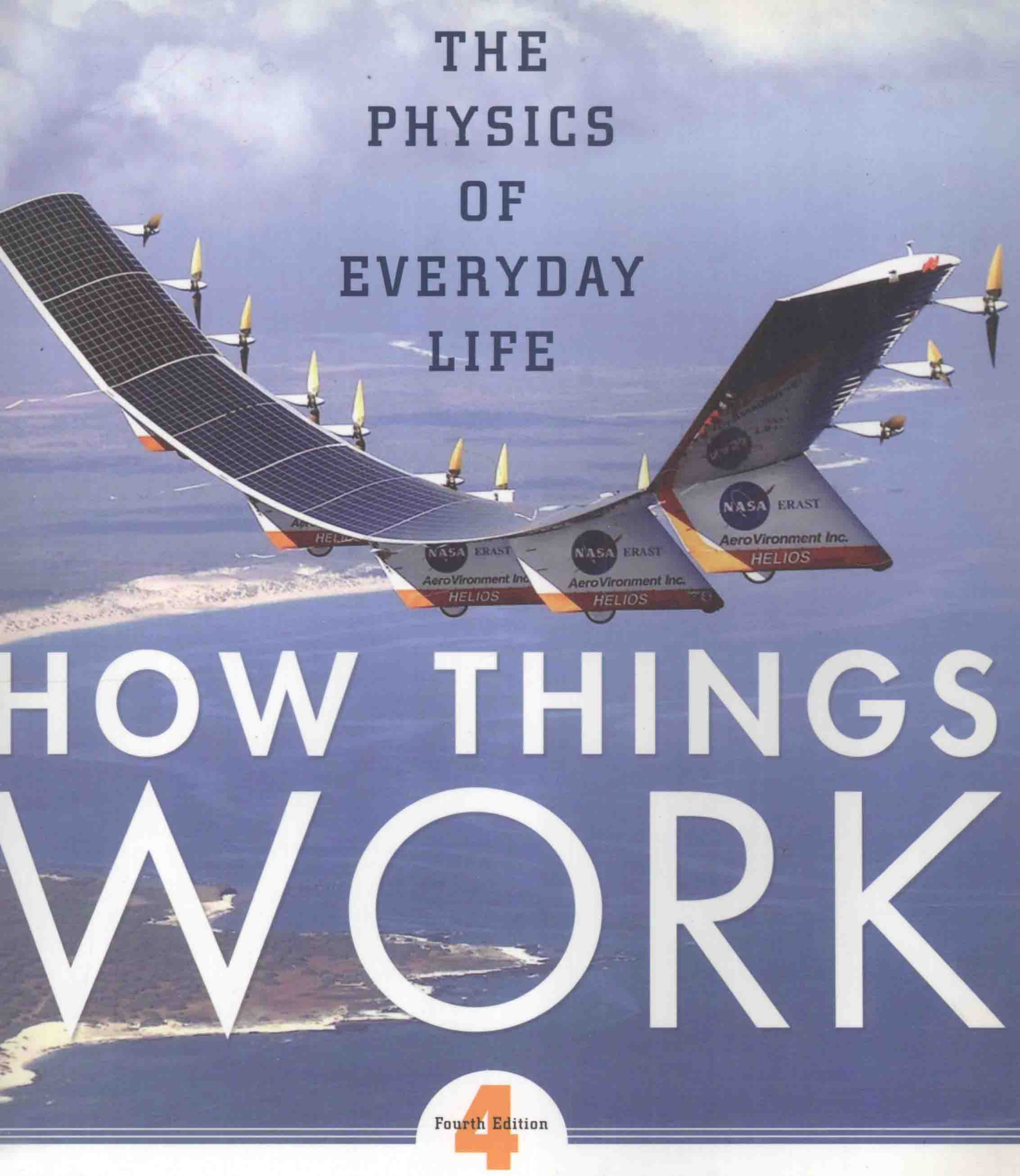

THE PHYSICS OF EVERYDAY LIFE

HOW THINGS WORK

Fourth Edition 4

OUIS A. BLOOMFIELD

how things work

THE PHYSICS OF EVERYDAY LIFE

Louis A. Bloomfield
The University of Virginia

4th Edition

WILEY

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To Elana and Aaron for doing such interesting, exciting, and thoughtful things

To Sadie for having so much personality per pound

To the students of the University of Virginia for making teaching, research, and writing fun

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Library of Congress Cataloging-in-Publication Data

Bloomfield, Louis.
How things work: the physics of everyday life/Louis A. Bloomfield.—4th ed.
p. cm.
Includes index.
ISBN 978-0-470-22399-4 (pbk.)
1. Physics—Textbooks. I. Title.
QC21.3.B56 2008
530—dc22

2008036128

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

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Foreword

In today's world we are surrounded by science and by the technology that has grown out of that science. For most of us, this is making the world increasingly mysterious and somewhat ominous as technology becomes ever more powerful. For instance, we are confronted by many global environmental questions such as the dangers of greenhouse gases and the best choices of energy sources. These are questions that are fundamentally technical in nature and there is a bewildering variety of claims and counterclaims as to what is "the truth" on these and similar important scientific issues. For many people, the reaction is to throw up their hands in hopeless frustration and accept that the modern world is impossible to understand and one can only huddle in helpless ignorance at the mercy of its mysterious and inexplicable behavior.

In fact, much of the world around us and the technology of our everyday lives is governed by a few basic physics principles, and once these principles are understood, the world and the vast array of technology in our lives become understandable and predictable. How does your microwave oven heat up food? Why is your radio reception bad in some places and not others? And why can birds happily land on a high voltage electrical wire? The answers to questions like these are obvious once you know the relevant physics. Unfortunately, you are not likely to learn that from a standard physics course or physics textbook. There is a large body of research showing that instead of providing this improved understanding of everyday life, most introductory physics courses are doing quite the opposite. In spite of the best intentions of the teachers, most students are "learning" that physics is abstract, uninteresting, and unrelated to the world around them.

How Things Work is a dramatic step toward changing that by presenting physics in a new way. Instead of starting out with abstract principles that leave the reader with the idea that physics is about artificial and uninteresting ideas, Lou Bloomfield starts out talking about real objects and devices that we encounter in our everyday lives. He then shows how these seemingly magical devices can be understood in terms of the basic physics principles that govern their behavior. This is much the way that most physics was discovered in the first place: people asked why the world around them behaved as it did and as a result discovered the principles that explained and predicted what they observed.

I have been using this book in my classes for several years and I continue to be impressed with how Lou can take seemingly highly complex devices and strip away the complexity to show how at their heart are simple physics ideas. Once these ideas are understood, they can be used to understand the behavior of many devices we encounter in our daily lives, and often even fix things that before had seemed impossibly complex. In the process of teaching from this book, I have increased my own understanding of the physics behind much of the world around me. In fact, after consulting *How Things Work*, I have had the confidence to confront both plumbers and airconditioner repairmen to tell them (correctly as it turned out) that their diagnosis did not make sense and they needed to do something different to solve my plumbing and AC problems. Now I am regularly amused at the misconceptions some trained physicists have about some of the physics they encounter in their daily lives, such as how a microwave oven works and why it can be made out of metal walls, but putting aluminum foil in it is bad. It has convinced me that we need to take the approach used in this book in far more of our science texts.

Of course, the most important impact is on the students in my classes that use this book. These are typically nonscience students majoring in fields such as film studies, classics, English, business, etc. They often come to physics with considerable trepidation.

It is inspiring to see many of them discover to their surprise that physics is very different from what they thought—that physics can actually be interesting and useful and makes the world a much less mysterious and more understandable place. I remember many examples of seeing this in action: the student who, after learning how both speakers and TVs work, was suddenly able to understand that it was not magic that putting his large speaker next to the TV distorted the picture but in fact it was just physics, and now he knew just how to fix it; the young woman scuba diver who, after learning about light and color, suddenly interrupted class to announce that now she understood why it was that you could tell how deep you were by seeing what color lobsters appeared; or the students who announced that suddenly it made sense that the showers on the first floor of the dorm worked better than those on the second floor. In addition, of course everyone is excited to learn how a microwave oven works and why there are these strange rules as to what you can and cannot put in it. These examples are particularly inspiring to a teacher, because they tell you that the students are not just learning the material presented in class, but they are then able to apply that understanding to new situations in a useful way, something that happens far too seldom in science courses.

Whether a curious layperson, a trained physicist, or a beginning physics student, most everyone will find this book an interesting and enlightening read and will go away comforted in that the world is not so strange and inexplicable after all.

Carl Wieman
Nobel Laureate in Physics 2001
CASE/Carnegie US University Professor
of the Year 2004

Preface

Physics is a remarkably practical science. Not only does it explain how things work or why they don't, it also offers great insight into how to create, improve, and repair those things. Because of that fundamental relationship between physics and real objects, introductory physics books are essentially users' manuals for the world in which we live.

Like users' manuals, however, introductory physics books are most accessible when they're based on real-world examples. Both users' manuals and physics texts tend to go unread when they're written like reference works, organized by abstract technical issues, indifferent to relevance, and lacking in useful examples. For practical guidance, most readers turn to "how to" books and tutorials instead; they prefer the "case-study" approach.

How Things Work is an introduction to physics and science that starts with whole objects and looks inside them to see what makes them work. It follows the case-study method, exploring physics concepts on a need-to-know basis in the context of everyday objects. More than just an academic volume, this book is intended to be interesting, relevant, and useful to non-science students.

Most physics texts develop the principles of physics first and present real-life examples of these principles reluctantly if at all. That approach is abstract and inaccessible, providing few conceptual footholds for students as they struggle to understand unfamiliar principles. After all, the comforts of experience and intuition lie in the examples, not in the principles. While a methodical and logical development of scientific principles can be satisfying to the seasoned scientist, it's alien to someone who doesn't even recognize the language being used.

In contrast, *How Things Work* brings science to the reader rather than the reverse. It conveys an understanding and appreciation for physics by finding physics concepts and principles within the familiar objects of everyday experience. Because its structure is defined by real-life examples, this book necessarily discusses concepts as they're needed and then revisits them whenever they reappear in other objects. What better way is there to show the universality of the natural laws?

I wrote this book to be read, not merely referred to. It has always been for nonscientists and I designed it with them in mind. In the seventeen years I have been teaching *How Things Work*, many of my thousands of students have been surprised at their own interest in the physics of everyday life, have asked insightful questions, have experimented on their own, and have found themselves explaining to friends and family how things in their world work.

Changes in the Fourth Edition

Content Changes

- **A new emphasis on sustainable energy and the environment.** Society is facing a number of critical challenges that this generation of students will have to overcome. Since physics defines many of those challenges and will play a key role in solving them, it's important that this book help prepare its readers for a difficult century. Toward that end, this edition now includes such relevant topics as *wind turbines*, *clothing*, *insulation*, *climate*, *hybrid automobiles*, and *nuclear reactors*.

- **Changing objects for a changing world.** While physics at the introductory level changes fairly slowly, the objects in which that physics appears change almost daily. I have brought topics such as *discharge lamps* and *automobiles* up to date and replaced others completely. Making an exit this edition are *seesaws*—which have all but vanished from playgrounds—and energy-inefficient *incandescent lightbulbs*—which can't vanish soon enough.

- **Section reorganizations.** Each section tells a story, so the order of presentation matters.

Finding the best linear storyline is difficult and there is always room for improvement. I have reorganized some sections, particularly *carousels and roller coasters*, and I have removed or added scenes to others. For example, *spring scales* omits a distracting digression on how to use several scales at once, while *sunlight* adds an important discussion of solar power.

- **Improved discussions of many physics concepts.** No one book can or should cover all of physics, but whatever physics is included should be presented carefully enough to be worthwhile. In this edition, I have refined the discussions of many physics issues and added some new ones. Look for improved coverage of concepts such as net force, rotational work, balance, emissivity, and waves, to name just a few.
- **Additional art.** Some ideas are best understood visually, so good figures are an essential part of this book. I have added images where they were missing, notably in *air conditioners* while explaining thermodynamics and in *musical instruments* while explaining transverse and longitudinal waves. I have also labeled some of the photographs and improved many of the illustrations.
- **Additional formulas.** Sometimes the best way to understand a physical quantity is by examining an algebraic formula that relates it to other quantities. Although I believe that excessive algebra can distract students from the task of learning concepts such as inertia, I now realize that it can be quite helpful when trying to understand quantities such as density and pressure. This edition includes many new formulas in places where they are likely to be more helpful than distracting.

Feature Changes

- **Inline answers to inline examples.** Every page or so, the presentation pauses to ask an instructive question in a feature called a Check Your Understanding or Check Your Figures. In this edition, each of these questions is followed immediately by an answer and an explanation. While hiding the answers elsewhere in the book makes it less likely that a student will simply read the answer, it makes it even more likely that the student will skip the question altogether.
- **Colored callouts for asides.** There are many short asides located in the book margins and each one is called out somewhere in the text. Those callouts are now color-coded to make it easier to find the appropriate aside.
- **No printed solutions to exercises and problems.** In the era before the internet, it made sense to include brief solutions to some exercises in a print book. With no other educational resources available, those solutions were one of the few ways students could assess their understanding of the material. Because the solutions were terse and oversimplified, however, they provided insufficient help and often misled students about what their instructors expected as complete answers. The advent of the web has made that entire approach obsolete. The website for this book provides an infinitely richer source of self-assessment, feedback, and tutorial support.

The Goals of This Book

As they read this book, students should:

1. Begin to see science in everyday life. Science is everywhere; we need only open our eyes to see it. We're surrounded by things that can be understood in terms of science, much of which is within a student's reach. Seeing science doesn't mean that when viewing an oil painting they should note only the selective reflection of incident light waves by organic and inorganic molecules. Rather, they should realize that there's a beauty to science that complements aesthetic beauty. They can learn to look at a glorious red sunset and appreciate both its appearance and why it exists.

2. Learn that science isn't frightening. The increasing technological complexity of our world has instilled within most people a significant fear of science. As the gulf widens between those who create technology and those who use it, their ability to understand one another and communicate diminishes. The average person no longer tinkers with anything and many modern devices are simply disposable, being too complicated to modify or repair. To combat the anxiety that accompanies unfamiliarity, this book shows students that most objects can be examined and understood, and that the science behind them isn't scary after all. The more we understand how others think, the better off we'll all be.

3. Learn to think logically in order to solve problems. Because the universe obeys a system of well-defined rules, it permits a logical understanding of its behaviors. Like mathematics and computer science, physics is a field of study where logic reigns supreme. Having learned a handful of simple rules, students can combine them logically to obtain more complicated rules and be certain that those new rules are true. So the study of physical systems is a good place to practice logical thinking.

4. Develop and expand their physical intuition. When you're exiting from a highway, you don't have to consider velocity, acceleration, and inertia to know that you should brake gradually—you already have physical intuition that tells you the consequences of doing otherwise. Such physical intuition is essential in everyday life, but it ordinarily takes time and experience to acquire. This book aims to broaden a student's physical intuition to situations they normally avoid or have yet to encounter. That is, after all, one of the purposes of reading and scholarship: to learn from other people's experiences.

5. Learn how things work. As this book explores the objects of everyday life, it gradually uncovers most of the physical laws that govern the universe. It reveals those laws as they were originally discovered: while trying to understand real objects. As they read this book and learn these laws, students should begin to see the similarities between objects, shared mechanisms, and recurring themes that are reused by nature or by people. This book reminds students of these connections and is ordered so that later objects build on their understanding of concepts encountered earlier.

6. Begin to understand that the universe is predictable rather than magical. One of the foundations of science is that effects have causes and don't simply occur willy-nilly. Whatever happens, we can look backward in time to find what caused it. We can also predict the future to some extent, based on insight acquired from the past and on knowledge of the present. And where predictability is limited, we can understand those limitations. What distinguishes the physical sciences and mathematics from other fields is that there are often absolute answers, free from inconsistency, contraindication, or paradox. Once students understand how the physical laws govern the universe, they can start to appreciate that perhaps the most magical aspect of our universe is that it is not magic; that it is orderly, structured, and understandable.

7. Obtain a perspective on the history of science and technology. None of the objects that this book examines appeared suddenly and spontaneously in the workshop of a single individual who was oblivious to what had been done before. These objects were developed in the context of history by people who were generally aware of what they were doing and usually familiar with any similar objects that already existed. Nearly everything is discovered or developed when related activities make their discoveries or developments inevitable and timely. To establish that historical context, this book describes some of the history behind the objects it discusses.

Features

This printed book contains 42 sections, each of which discusses how something works. The sections are grouped together in 16 chapters according to the major physical themes developed. In addition to the discussion itself, the sections and chapters include a number of features intended to strengthen the educational value of this book. Among these features are:

- **Chapter introductions, experiments, and itineraries.** Each of the 16 chapters begins with a brief introduction to the principal theme underlying that chapter. It then presents an experiment that students can do with household items to observe firsthand some of the issues associated with that physical theme. Lastly, it presents a general itinerary for the chapter, identifying some of the physical issues that will come up as the objects in the chapter are discussed.
- **Section introductions, questions, and experiments.** Each of the 42 sections explains how something works. Often that something is a

specific object or group of objects, but it is sometimes more general. A section begins by introducing the object and then asks a number of questions about it, questions that might occur to students as they think about the object and that are answered by the section. Lastly, it suggests some simple experiments that students can do to observe some of the physical concepts that are involved in the object.

- **Check your understanding and check your figures.** Sections are divided into a number of brief segments, each of which ends with a "Check Your Understanding" question. These questions apply the physics of the preceding segment to new situations and are followed by answers and explanations. Segments that introduce important equations also end with a "Check Your Figures" question. These questions show how the equations can be applied and are also followed by answers and explanations.
- **Chapter epilogue and explanation of experiment.** Each chapter ends with an epilogue that reminds the students of how the objects they studied in that chapter fit within the chapter's physical theme. Following the epilogue is a brief explanation of the experiment suggested at the beginning of the chapter, using physical concepts that were developed in the intervening sections.
- **Chapter summary and laws and equations.** The sections covered in each chapter are summarized briefly at the end of the chapter, with an emphasis on how the objects work. These summaries are followed by a restatement of the important physical laws and equations encountered within the chapter.
- **Chapter exercises and problems.** Following the chapter summary material is a collection of questions dealing with the physics concepts in that chapter. Exercises ask the students to apply those concepts to new situations. Problems ask the students to apply the equations in that chapter and to obtain quantitative results.
- **Three-way approach to the equation of physics.** The laws and equations of physics are the groundwork on which everything else is built. But because each student responds differently to the equations, this book presents them carefully and in context. Rather than making one size fit all, these equations are presented in three different forms. The first is a word equation, identifying each physical quantity by name to avoid any ambiguities. The second is a symbolic equation, using the standard format and notation. The third is a sentence that conveys the meaning of the equation in simple terms and often by example. Each student is likely to find one of these three forms more comfortable, meaningful, and memorable than the others.
- **Glossary.** The key physics terms are assembled into a glossary at the end of the book. Each glossary term is also marked in bold in the text when it first appears together with its contextual definition.
- **Historical, technical, and biographical asides.** To show how issues discussed in this book fit into the real world of people, places, and things, a number of brief asides have been placed in the margins of the text. An appropriate time at which to read a particular aside is marked in the text by a color-coded mark such as ■.

WileyPLUS

WileyPLUS is a homework management system that allows for easy course management. The instructor can assign, collect, and grade homework automatically. All problems assigned in *WileyPLUS* have a link to an online version of the text. The links give students quick access to context-sensitive help for assigned problems.

The fourth edition brings with it a dramatically improved student *WileyPLUS* course. These improvements allow the web to do what it does best: provide an interactive, multimedia learning environment.

- **Online book with extensive video annotation.** Although this book aims to be complete and self-contained, its pages can certainly benefit from additional explanations, answers to open questions, discussions of figures and equations, and real-life demonstrations of objects, ideas, and concepts. Using the web, I can provide all of those features. The online version of this book is annotated with hundreds, even thousands, of short videos that bring it to life and enhance its ability to teach.

- **Computer simulations of the book's objects.** One of the best ways to learn how a violin or nuclear reactor works is to experiment with it, but that's not always practical or safe. Computer simulations are the next best thing and the student website includes many simulations of the book's objects. Associated with each simulation is a sequence of interactive questions that turn it into a virtual laboratory experiment. In keeping with the *How Things Work* concept, the student is then able to explore the concepts of physics in the context of everyday objects themselves.
- **Interactive exercises and problems.** Homework is most valuable when it's accompanied by feedback and guidance. By providing that assistance immediately, along with links to videos, simulations, the online book, and even additional questions, the website transforms homework from mere assessment into a tutorial learning experience.

Student Companion Website

Also available is a book companion site – www.wiley.com/college/bloomfield – that offers select free resources for the student.

The student's website provides access to:

- **Additional web-based chapters**
- **Video mini-lectures that answer questions posed in the text**
- **Link to the author's website**

Instructor Companion Website

The instructor's website, accessible from the same URL, provides everything described above, plus:

- **Test questions and solutions**
- **Organizational ideas for designing a course**
- **Demonstration ideas for each section**
- **Video demonstrations and associated clicker questions**
- **Lecture slides for each section**
- **Clicker questions for each section**
- **Artwork to use in presentations**
- **Resource lists**

ACKNOWLEDGMENTS

Many people have contributed to this book in one way or another and I am enormously grateful for their help. First among them is my editor, Stuart Johnson, who has guided this project and supported me for more than a decade. Geraldine Osnato and Veronica Armour have been amazingly generous with their time and attention in helping me develop this fourth edition, and Elizabeth Swain has done a fantastic job of shepherding it through production. I'm delighted to have had

Harry Nolan working on the graphic design, Anne Melhorn on the art, and Jennifer MacMillan on the photographs. The new online component that accompanies the print book would not have been possible or even conceivable without the help of Tom Kulesa and Evelyn Levich. And none of this could have happened without the support, guidance, and encouragement of Amanda Wainer, Kaye Pace, Petra Rector, and Aly Rentrop. To my numerous other friends and collaborators at John Wiley, many thanks.

I continue to enjoy tremendous assistance from colleagues here and elsewhere who have supported the *How Things Work* concept, discussed it with me, and often taught the course themselves. They are now too many to list, but I appreciate them all. I am particularly grateful, however, to my colleagues in AMO physics at Virginia, Tom Gallagher, Bob Jones, Olivier Pfister, and Cass Sackett, for more than making up for my reduced scientific accomplishments while working on this project, and to Carl Weiman for his vision of physics education as outlined in the foreword to this book. I must also thank our talented lecture-demonstration group, Mike Timmins, Nikolay Sandev, and Roger Staton, for help to bring physics to life in my class and in the videos for this book.

I am always looking for new insight into how things work and the year I spent co-hosting the series *Some Assembly Required* was outstanding in that regard. Thanks to Jeanine Butler for giving me that opportunity, and to my fellow travelers Brian Unger, Tom Inskeep, Brian Leonard, Pip Gilmour, Mark Johnston, Jeanne Bernard, Faith Gaskins, Steve Tejada, Brett Wiley, and Dennis Towns for making it an awesome and enlightening adventure. And to the people at all the companies we visited and with whom we talked and worked for a day or two, you're wonderful and I learned more from you than you can imagine.

Of course, the best way to discover how students learn science is to teach it. I am ever so grateful to the students of the University of Virginia for being such eager, enthusiastic, and interactive participants in this long educational experiment. It has been a delight and a privilege to get to know so many of them as individuals, and their influence on this enterprise has been immeasurable.

Lastly, this book has benefited more than most from the constructive criticism of a number of talented reviewers. Their candid, insightful comments were sometimes painful to read or hear, but they invariably improved the book. Not only did their reviews help me to present the material more effectively, but they taught me some interesting physics as well. My deepest thanks to all of these fine people:

Brian DeMarco,
University of Illinois, Urbana Champaign

Dennis Duke
Florida State University

Donald R. Francesschetti
University of Memphis

Alejandro Garcia
San Jose State University

Richard Gelderman
Western Kentucky University

Robert B. Hallock
University of Massachusetts, Amherst

Mark James
Northern Arizona University

Tim Kidd
University of Northern Iowa

Judah Levine
University of Colorado, Boulder

Darryl J. Ozimek
Duquesne University

Michael Roth
University of Northern Iowa

Anna Solomey
Wichita State University

Bonnie Wylo
Eastern Michigan University

We would like to thank the following who participated in a focus group on the issues and challenging in the teaching of physics to non-science students.

Alejandro Garcia
San Jose State University

Thomas Bruekner
University of Central Florida

Richard Gelderman
Western Kentucky University

David Kaplan
Southern Illinois University

Teresa Larkin
American University

Harry Plypyiw
Quinnipiac University

Kenneth Shriver
Vanderbilt University

Michael Sobel
Brooklyn College

Anna Solomey
Wichita State University

The real test of this book, and of any course taught from it, is its impact on students' lives long after their classroom days are done. Theirs is a time both exciting and perilous; one in which physics will play an increasingly important and multifaceted role. It is my sincere hope that their encounter with this book will leave those students better prepared for what lies ahead and will help them make the world a better place in the years to come.

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