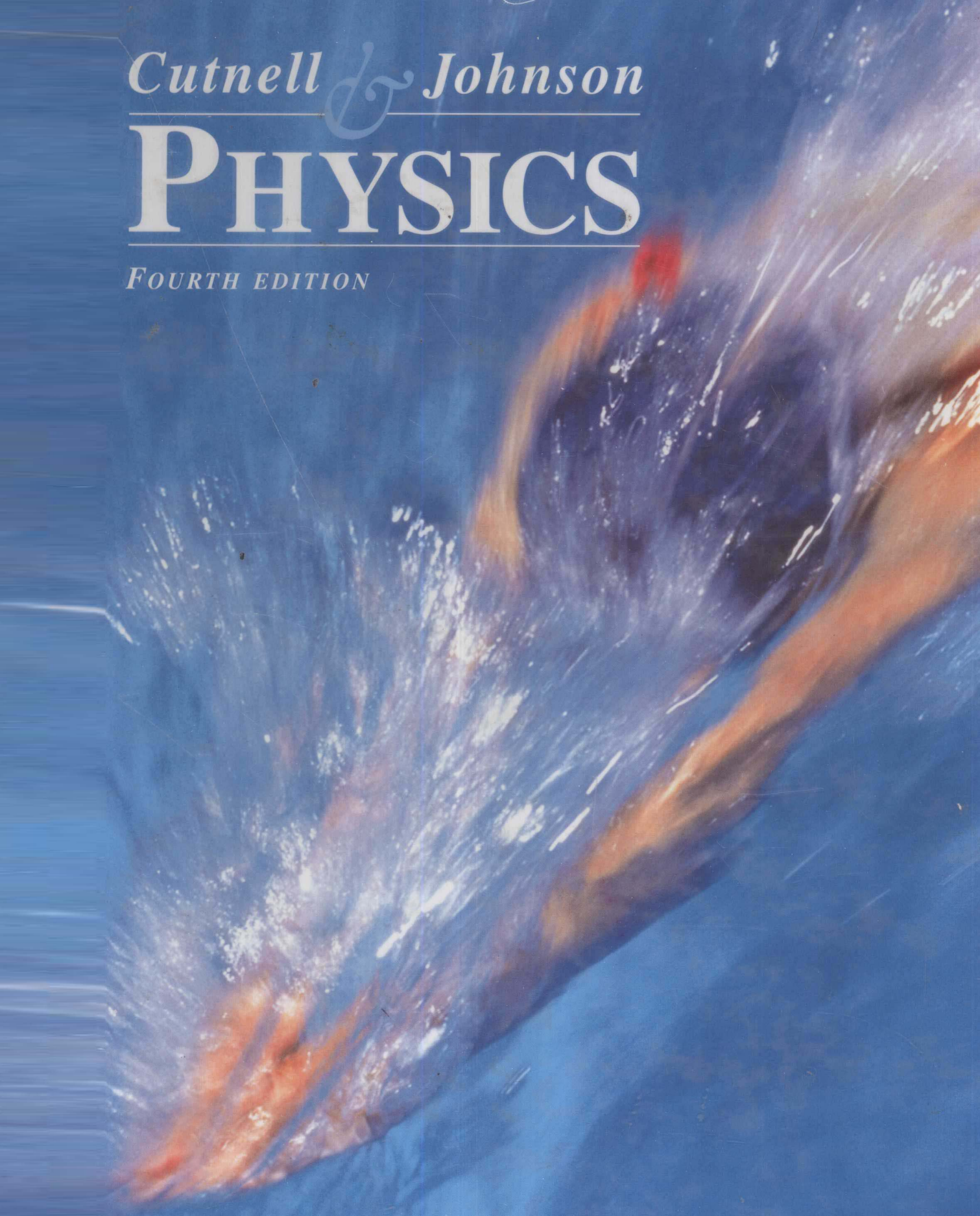
Cutnell & Johnson
PHYSICS
FOURTH EDITION

PHYSICS

FOURTH EDITION

JOHN D. CUTNELL
KENNETH W. JOHNSON

Southern Illinois University at Carbondale

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This edition is dedicated to the memory of

Stella Kupferberg,

Director of the Photo Department,
a friend, a mentor, and a pillar
of dependability and excellence.
She had a strong and
enduring influence on our work
and taught us everything
we know about using photographs
in support of physics pedagogy.
We miss you, Stella,
and shall always remember
that a well-chosen photograph
should speak for itself,
without the need for lengthy
explanations.

We have written this text for students and teachers who are partners in a one-year course in physics that uses algebra and trigonometry. Since each has only so much time in a given day, we have tried to produce a text that facilitates the learning and teaching processes. Considerable positive feedback from the many users of the third edition has encouraged us to make this fourth edition even more attuned to the needs of students and teachers. We have taken a fresh look at the goals and features of the third edition, adding refinements and new material that will help students learn and teachers teach. In addition, we have expanded our supplements package to include World Wide Web offerings and a CD-ROM that contains interactive problem-solving software and numerous simulations of physical phenomena.

GOALS

Our first goal is to help students develop conceptual understanding and use it in solving problems. One of the greatest challenges for teachers is to dispel the notion that physics is merely a large collection of equations that can be used to solve problems. Physicists know that the ability to reason is the cornerstone of problem solving and that this ability develops from a conceptual understanding of physical principles. The features of this edition that work toward this goal are: *Conceptual Examples*, *Explicit Reasoning Steps* in all examples, *Reasoning Strategies*, *Free-Body Diagrams*, and *Problem Solving Insights* placed in the margins.

Secondly, we want to help students see the interrelationships between the concepts of physics. In studying anything for the first time, it is easy to focus on the new details and lose sight of the overall picture. This is certainly true in physics, where the big picture consists of the relationships between basic concepts and the way in which they fit together to give a description of the physical world. To accomplish this goal, we have introduced a new feature called *Concepts at a Glance*, which consists of charts that illustrate the interrelationships diagrammatically. Each chapter also ends with a summary in the form of a condensed, but thorough, exposition of the chapter material, including equations. These reviews are intended to give the student an overview of how the chapter concepts have evolved.

Finally, we want to show students that physics principles come into play over and over again in their lives. It is always easier to learn something new when the learning has a direct relevance to our daily lives. Direct applications of physics principles are identified in the margins by a triangular-shaped icon, including the label *The Physics of. . . .* Many of these applications are biomedical in nature and deal with human physiology. We have also incorporated real-world situations into many of the worked-out examples, the line art, and the homework material at the end of each chapter.

ORGANIZATION AND COVERAGE

The text consists of 32 chapters and is organized in a fairly standard fashion according to the following sequence: (1) *Mechanics*, (2) *Thermal Physics*, (3) *Wave Motion*, (4) *Electricity and Magnetism*, (5) *Light and Optics*, and (6) *Modern Physics*. Within each chapter, material that is a likely candidate for omission is typically lo-

cated in a subsection at the end of a main section or in a separate section near the end of a chapter. Sections marked with an asterisk can be omitted with little impact on the overall development of the material.

In addition to the one-volume hardbound edition, the book is available as a two-volume paperback version. Volume 1 consists of Chapters 1-17 (*Mechanics*, *Thermal Physics*, and *Wave Motion*), while Volume 2 consists of Chapters 18-32 (*Electricity and Magnetism*, *Light and Optics*, and *Modern Physics*).

Based on feedback from users and reviewers, we have added new material, made judicial deletions, and carefully tightened other material. The net result of these efforts is a more streamlined text that is about 50 pages shorter than the third edition. We have added new material on *The Center of Mass* (Section 7.5), *Conduction of Electrical Signals in Neurons* (Section 19.6), *The Doppler Effect and Electromagnetic Waves* (Section 24.5), *Medical Applications of the Laser* (Section 30.9), and *Cosmology* (Section 32.7). In Chapter 19, we have rewritten substantially the discussion of the electric potential, in order to strengthen the analogy to the discussion of gravitational potential energy presented in Chapter 6. We have updated our applications of physics principles and added a number of new ones. Many of these illustrate biomedical applications of physics and, together with the new section on the *Conduction of Electrical Signals in Neurons*, give the text an increased emphasis on the role of physics in biology and medicine.

FEATURES OF THE FOURTH EDITION

All of the features of the fourth edition have been designed to support the goals elaborated earlier in this preface. A list of the main features follows, including a description of each and selected illustrations.

Concepts at a Glance This new feature consists of flowcharts that occur in every chapter except Chapter 1. There are 66 of these charts, and they show in a vi-

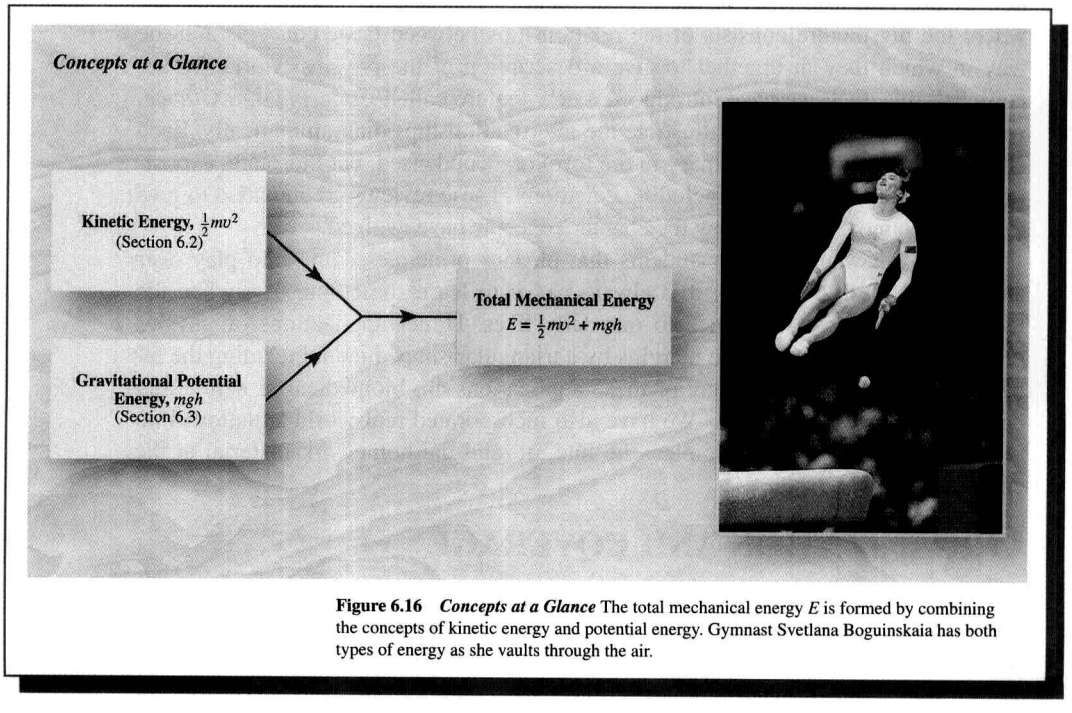

Figure 6.16 ***Concepts at a Glance*** The total mechanical energy E is formed by combining the concepts of kinetic energy and potential energy. Gymnast Svetlana Boguinskaia has both types of energy as she vaults through the air.

sual way the conceptual development of the new physics that is introduced in each chapter. Within a flowchart, the new physics concept being studied is placed in a gold panel, while the concepts presented earlier are placed in light blue panels. The flowcharts provide students with a coherent picture of how new concepts are built upon previous ones and, thus, reinforce fundamental unifying ideas. Included with each chart is at least one photograph, to help students connect the concepts being discussed with the real world.

Conceptual Examples Students often try to solve problems by searching for that elusive *right equation* and ignore the fact that equations are consequences of concepts, concepts that express physical ideas. We believe that good problem-solving techniques start with a foundation of conceptual understanding. Therefore, the text includes 93 examples that are entirely conceptual in nature. These examples are in addition to 282 standard quantitative examples. The *Conceptual Examples* are worked out in a rigorous, but qualitative fashion, with no (or very few) equations. The emphasis is on how to apply a physics principle to arrive at a qualitative solution to a problem. The intent is to provide students with explicit models of how to "think through" a problem before attempting to solve it numerically. The *Conceptual Examples* deal with a wide range of topics, and in them we have addressed a large number of issues that often confuse students. Wherever possible, we have focused on real-world situations that have a direct relationship to physical principles and have structured the examples so that they lead naturally to homework material found at the ends of the chapters. At the end of most examples are explicit references to the related homework material, and that material contains a cross reference that encourages the student to review the pertinent *Conceptual Example*. Teachers can stress the importance of conceptual understanding by assigning the indicated homework material.

CONCEPTUAL EXAMPLE 9 • Deceleration Versus Negative Acceleration

A car is traveling along a straight road and is decelerating. Does the car's acceleration a necessarily have a negative value?

Reasoning and Solution We begin with the meaning of the term "decelerating," which has nothing to do with whether the acceleration a is positive or negative. The term means only that the acceleration vector points opposite to the velocity vector and indicates that the moving object is slowing down. When a moving object slows down, its instantaneous speed (the magnitude of the instantaneous velocity) decreases. One possibility is that the velocity vector of the car points to the right, in the positive direction, as Figure 2.14*a* shows. The term "decelerating" implies that the acceleration vector points opposite, or to the left, which is the negative direction. Here, the value of the acceleration a would indeed be negative. However, there is another possibility. The car could be traveling to the left, as in Figure 2.14*b*. Now, since the velocity vector points to the left, the acceleration vector would point opposite or to the right, according to the meaning of the term "decelerating." But right is the positive direction, so the acceleration a would have a positive value in Figure 2.14*b*. We see, then, that ***a decelerating object does not necessarily have a negative acceleration.***

Related Homework Material: *Problems 22 and 40*

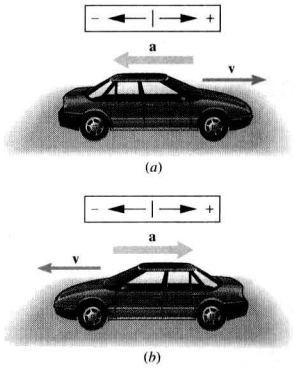

Figure 2.14 When a car decelerates along a straight road, the direction of the acceleration vector depends on the direction in which the car is traveling, as Conceptual Example 9 discusses.

Explicit Reasoning Steps Since careful reasoning is the cornerstone of problem solving, we believe that students will benefit from seeing the reasoning stated explicitly. Therefore, the format in which examples are worked out includes an explicit reasoning step. In this step, we explain what motivates our procedure for solving the problem before any algebraic or numerical work is done. Teachers have applauded this feature of the third edition, and we have carefully reexamined each of the examples with a view toward improving the clarity of the reasoning steps. The *Conceptual Examples* and their associated homework material also strengthen our focus on reasoning as an essential part of problem solving.

REASONING STRATEGY

Applying the Equations of Kinematics

1. Make a drawing to represent the situation being studied. When solving kinematics problems, few of us can do without the aid of a drawing to help develop our reasoning and explain it to our coworkers.
2. Decide which directions are to be called positive (+) and negative (−) relative to a conveniently chosen coordinate origin. Do not change your decision during the course of a calculation.
3. In an organized way, write down the values (with appropriate plus and minus signs) that are given for any of the five kinematic variables (x, a, v, v_0, and t). Be on the alert for "implied data," such as the phrase "starts from rest," which means that the value of the initial velocity is $v_0 = 0$. The data summary boxes used in the examples in the text are a good way of keeping track of this information. In addition, identify the variables that you are being asked to determine.

Reasoning Strategies A number of the examples in the text deal with well-defined strategies for solving certain types of problems. In such cases, we have included summaries of the steps involved. These summaries, which are titled *Reasoning Strategies*, encourage frequent review of the techniques involved and help students focus on the concepts on which the techniques are based.

Important Definitions, Laws, and Theorems One of the tasks facing students is to distinguish between the basic concepts of physics and other, less fundamental, relations. To highlight the basic concepts, we have enclosed them within a gold panel. When the concept involves an equation, the meaning of each term in the equation is also explained. Since applying these concepts entails using correct units, the appropriate SI units have been included. The panels are used sparingly, only for the most important concepts.

The Physics of...
Applications of Physics Principles

The Physics of . . . This edition contains over 200 real-world applications. These applications reflect our commitment to show students how prevalent physics is in their lives. We have added many new ones that are currently in the "headlines," such as Next Generation Weather Radar (NEXRAD), the Global Positioning Satellite system, digital satellite system TV, and the discovery of photoevaporation and star formation in the Eagle nebula. In addition, the number of biomedical applications has been increased to include Gamma Knife radiosurgery, cochlear implants, arthroscopic surgery, heart pacemakers, impedance plethysmography, endoscopy, defibrillators, and photorefractive keratectomy, and others. Each application is identified in the margin with the label **The Physics of . . .**, and those that illustrate a biomedical application are further marked with an icon in the shape of a microscope . A complete list of the applications can be found on pages xxi–xxiii.

Free-Body Diagrams Teachers are familiar with the importance of free-body diagrams when using Newton's laws of motion. We use free-body diagrams throughout the text, not just in the early chapters where Newton's laws are introduced. For instance, when the relation between pressure and depth in a fluid is developed in Chapter 11, a free-body diagram clarifies the discussion considerably. Free-body diagrams are also used in worked-out examples, as in Example 4 in Chapter 18, when we calculate the electrostatic forces that electric charges exert on each other.

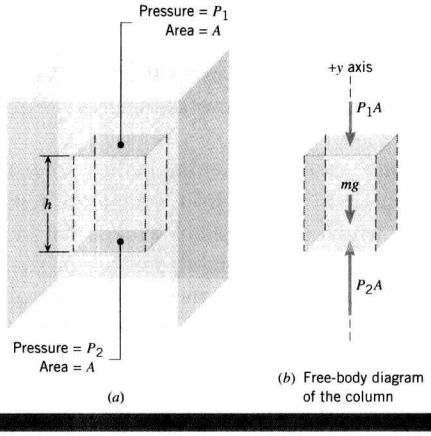

Figure 11.7 (*a*) A container of fluid in which one particular column of the fluid is outlined. The fluid is at rest. (*b*) The free-body diagram, showing the vertical forces acting on the column.

Problem Solving Insights To reinforce the problem-solving techniques illustrated in the carefully worked-out examples, we have included short statements in the margins, identified by a gold circle and the label **PROBLEM SOLVING INSIGHT**. These insights help students to develop good problem-solving skills by providing the kind of advice that a teacher would give when explaining a calculation in detail.

• PROBLEM SOLVING INSIGHT
When nonconservative forces are perpendicular to the motion, we can still use the principle of conservation of mechanical energy, because such "perpendicular" forces do no work.

Homework Problems and Conceptual Questions The fourth edition contains nearly 2400 problems and 600 conceptual questions for assignment as homework. About 25% of the problems are new or modified. In providing so many problems and questions, we have used a wide variety of real-world situations with realistic data. Building problem-solving skills involves the use of homework problems that progress from relatively easy to moderate to challenging levels of difficulty. In this spirit, we have ranked the homework problems according to difficulty. The most difficult are marked with a double asterisk (**), while those of intermediate difficulty are marked with a single asterisk (*). The easiest are unmarked. Those whose solutions appear in the *Student Solutions Manual* are identified with the label **ssm**. Those whose solutions are available on the World Wide Web **(http://www.wiley.com/college/cutnell)** are marked with the label **www**. Some of the problems are organized by section, whereas others are grouped without reference to any particular section under the heading **Additional Problems.** Problems and conceptual questions that are biomedical in nature are marked with an icon in the shape of a microscope.

• • •

In spite of our best efforts to produce an error-free book, there are no doubt errors that still remain. They are solely our responsibility, and we would appreciate hearing of any that you find. We hope that this text makes learning and teaching physics easier and more enjoyable, and we look forward to hearing about your experiences with it.

JOHN D. CUTNELL
KENNETH W. JOHNSON
Carbondale, Illinois, 1997

SUPPLEMENTS

An extensive package of supplements to accompany *Physics*, 4th edition, is available to assist both the teacher and the student.

Student Study Guide, prepared by John D. Cutnell, Kenneth W. Johnson and Mark J. Comella. The Guide, which is designed to be used in close conjunction with the text, aids students with chapter previews, lists of important terms, discussions and explanations of commonly misunderstood topics, worked-out examples, practice problems, and chapter quizzes. Each chapter also has problems especially designed to help students study for the MCAT exam.

Student Solutions Manual, prepared by John D. Cutnell, Kenneth W. Johnson and Mark J. Comella. This manual contains carefully worked out solutions for approximately 600 of the odd-numbered problems located at the ends of the chapters. In the text, these problems are identified with the label **ssm**.

Instructor's Solutions Manual, Volume 1, chapters 1–17 and Instructor's Solutions Manual Volume 2, Chapters 18–32, for instructors only, prepared by John D. Cutnell, Kenneth W. Johnson and Mark J. Comella. This manual contains detailed solutions to all homework problems in the text. It also contains answers to the conceptual questions that are located at the ends of chapters.

Instructor's Solutions Disk, a computer disk version of the *Instructor's Solutions Manual*, for instructors only, is available in Microsoft Word for Windows and Macintosh.

Instructor's Resource Guide, prepared by David T. Marx of Southern Illinois University at Carbondale. The Guide contains an extensive listing of physics resources on the World Wide Web. It also includes teaching suggestions, lecture notes, demonstration suggestions, alternative syllabi for courses of different lengths and emphasis, strategies for incorporating supplements and materials from other texts, as well as conversion notes allowing the instructor to use class notes from other texts. For instructors who have homework problems from the third edition that they especially like to assign, there is a problem locator guide. This locator guide provides an easy way to correlate third-edition problem numbers with the corresponding fourth-edition numbers.

Test Bank, prepared by David T. Marx of Southern Illinois University at Carbondale. The test bank contains 2006 short-answer questions and problems, which represents about a 15% increase relative to those available in the third edition.

Computerized Test Bank PC and Macintosh versions of the entire *Test Bank* are available with full editing features to help you customize tests.

Homework Disk, for instructors only. Teachers of large classes often use a computer-graded, multiple-choice homework format. As part of the *Computerized Test Bank*, David T. Marx has converted nearly 1200 of the chapter-ending problems into a multiple-choice format, so teachers can generate their homework assignments in a convenient and effective way.

Four-color Transparency Acetates Nearly 300 four-color illustrations from the text have been resized and edited for maximum effectiveness, so that they can easily be projected in the classroom.

CD-ROM Contains the complete text, the *Student Solutions Manual*, the *Student Study Guide*, and *Learning Ware,* all connected with extensive hyperlinking. In addition, *Learning Ware* software guides students through solutions of a wide variety of problems. The solution process is developed interactively, with appropriate feedback and access to error-specific help for the most common mistakes. The *CD-ROM* also contains numerous simulations that allow students to explore various physics-related phenomena by varying parameters and observing the corresponding effects.

Learning Ware Software A separate software package containing the *Learning Ware* component of the *CD-ROM.*

Student's Pocket Companion A pocket-sized book that contains, on a section-by-section basis, a concise summary of all definitions, laws, theorems, reasoning strategies, and concepts. We believe students will find this quick reference extremely handy when doing homework assignments and studying for exams.

ACKNOWLEDGMENTS

It is a great pleasure to acknowledge the help of the team that brought this text to life. We are very fortunate in being associated with outstanding professionals, people who are talented, highly motivated, and take great pride in their work.

We are particularly grateful to our editor, Stuart Johnson. He came to Wiley at the onset of the fourth edition, quickly took the helm, and guided us through all phases of the book's development. We would also like to acknowledge our former editor, Cliff Mills, for the many important contributions that he made to this project over many years.

Barbara Heaney is our developmental editor, and, in a word, she's a gem. We have worked with her on two editions now, and greatly respect and admire her talents. She provided numerous ideas and continuous feedback, and many of the book's features have benefited from her help.

Hilary Newman and Ramón Rivera-Moret are the best photo researchers in the world, period. With a remarkable "sixth" sense, they selected photos that not only convey just the right physics but are beautiful as well. Sit back, relax, and just browse through the photographs (don't forget the cover photo!). We think you too will enjoy their work.

Our sincerest appreciation goes to Sigmund Malinowski and Ishaya Monokoff of the illustration department. All the illustrations were redrawn for this edition, which brought us into constant communication with Sigmund. He is professional, knowledgeable, cooperative and one of the nicest people we've ever met.

We are also indebted to Karin Kincheloe and Maddy Lesure of the design department. The beautiful design of the book and its cover is Karin's work. She united the wide array of features into a single whole that has a wonderful sense of color, balance, and openness.

Our thanks go to Katharine Rubin, Pam Kennedy, and Ann Berlin for coordinating the all-electronic production of the book and helping us achieve a result that adheres to the highest standards of production. It would not have been possible without their help.

Hats off to Lee Goldstein, master juggler. Page by page, she brought together the countless pieces of text, line art, photos, and margin elements to create a book that has a spacious look. We especially appreciate her patience and willingness to try out our many suggestions. It was a genuine pleasure working with Lee.

One of the most important aspects of producing a book is to have outstanding proofreaders. The eyes of Georgia Kamvosoulis Mederer and Betty Pessagno were absolutely invaluable in catching all types of errors, from typos, awkwardly worded sentences, wrong fonts, and, yes, even an incorrect equation or two. We are grateful for their conscientious work.

Catherine Faduska, Executive Marketing Manager, has been a friend of ours and of the book for many years. She's extremely knowledgeable about the marketing of college texts and has had a profound influence on the book's success. For all in the past and the future to come, thank you, Cathy.

Ethan Goodman and Catherine Beckham have also been a source of great help in keeping us abreast of the latest marketing developments. We appreciate their efforts

in planning strategies and providing ideas on how to deal with the needs of an ever-changing market.

Our gratitude goes to Cynthia Rhoads for coordinating the extensive supplements package and to Virginia Dunn for copyediting the manuscript.

Jane Doub is a senior sales representative for John Wiley & Sons, Inc. and, fortunately, is the "rep" for our area. She stops by numerous times during the year and gives us valuable user feedback. Because of her great sales and marketing sense, we always take these opportunities to bounce new ideas off her. A true professional and a classy person, Jane is the best "rep" we've ever met.

The sales representatives of John Wiley & Sons, Inc. are in constant contact with physics departments throughout the country. They are a very knowledgeable and hard-working group, and we are most appreciative of their efforts.

To all of the physicists who have reviewed our work, both in this edition and in all previous editions, we owe a special debt. They have helped us to write more clearly and to remove ambiguities and inaccuracies. They have offered many suggestions that have influenced our decisions in producing this text. We have great respect for their work, and to each of them we extend our sincerest thanks. In particular, we thank the reviewers who helped us prepare the fourth edition:

Paul D. Beale, *University of Colorado at Boulder*
Roger Bland, *San Francisco State University*
Neal Cason, *University of Notre Dame*
Thomas Cobb, *Bowling Green State University*
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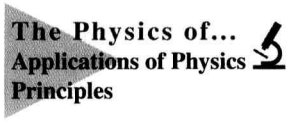
Rolf Vatne, *Portland Community College*



To show students that physics has a widespread impact on their lives, we have included a large number of applications of physics principles. Many of these applications are not found in other texts. The most important ones are listed below along with the page number locating the corresponding discussion. They are identified in the margin of the page on which they occur with a blue triangle and the title "**The Physics of...**" Biomedical applications are marked with an icon in the shape of a microscope. The discussions are integrated into the text, so that they occur as a natural part of the physics being presented. It should be noted that the list is not a complete list of all the applications of physics principles to be found in the text. There are many additional applications that are discussed only briefly or occur in the homework questions and problems.

TO THE STUDENT

Students like you have helped us prepare this 4th edition of *Physics.* Through focus groups held at several campuses with students using the 3rd edition, they have told us what aspects of the book work well for them and where improvements could be made. They also gave us excellent advice on the new features incorporated into this edition. As a result, the authors and John Wiley & Sons feel that this is the most user-friendly edition of the book that we have published, working equally well for instructors and students. The "Student to Student" letter printed below, for example, gives you advice from a fellow student on how well this book works and how best to study from it.

We invite you to share your comments and suggestions with us for the next edition. Please feel free to write us care of Physics Editor, College Division, John Wiley & Sons, Inc., 605 Third Avenue, New York, NY 10158-0012 or send us an e-mail at cutnell@wiley.com

STUDENT TO STUDENT

Annette Adams is a biology major, class of '98, at the College of William and Mary. She chose to attend the College of William and Mary because it's in such a beautiful part of Virginia, has a great dance program, and has a prestigious pre-medicine program. Her long-term career goal is to become a physician and possibly to pursue a Ph.D in biomedical sciences.

Hi there. *For many of you, Physics probably seems like a giant mountain of equations and formulas you have to get over to get where you're going in life. (Or at least to get a decent GPA for the semester.) I know that's how I thought of it at first. I plan to go to medical school when I graduate and Physics is one necessary step to take before I get there. It's also a step I put off until my junior year due to recurring nightmares of high school physics. Although I am a science major, Biology, I can definitely empathize with those of you who shy away from classes requiring long-drawn-out equations—and calculations. Let's face it, memorizing formulas and cranking out numbers on a calculator isn't too exciting. And that's exactly why I think this book will be one of your greatest assets as you tackle Physics this semester.*

You see, this book makes blatant, bland memorization unnecessary, because it explains the concepts in simple, easy-to-understand terms. It's so much easier to recall a formula when you understand how and why it is used. I found that the best way to use the text was to read through each section and try the Example problems. They have detailed explanations if you need help! Also, pay close attention to the Conceptual Examples and any "Problem Solving Insights" or "Reasoning Strategies." These can be key to understanding something that confused you in the text and/or in lecture. The Concept Charts that have been added to the fourth edition are a really neat idea. I didn't have them when I used the third edition, but I think that they will help you a lot in understanding the overall picture.

Surprisingly, I ended up really liking my Physics class. I was fortunate enough to have both a terrific, easy-to-read textbook AND a great professor. The whole point of a text for nonphysics majors is to demonstrate that physics doesn't apply just to physics—it applies to everything. This text definitely gets that point across. As a life-science major, I guarantee that random facts in chemistry and biology that you've accepted at face value will start to have a rhyme and reason behind them. And all of you, science and nonscience majors alike, will begin to look at the processes in the world around you with a new understanding. Who couldn't benefit from understanding a little bit more about what goes on around them?

Well, if you've been kind enough to humor me and read all the way to the bottom of "my" page, I thank you. I hope you get as much out of your Physics class as I did. Good luck to you!

BRIEF CONTENTS