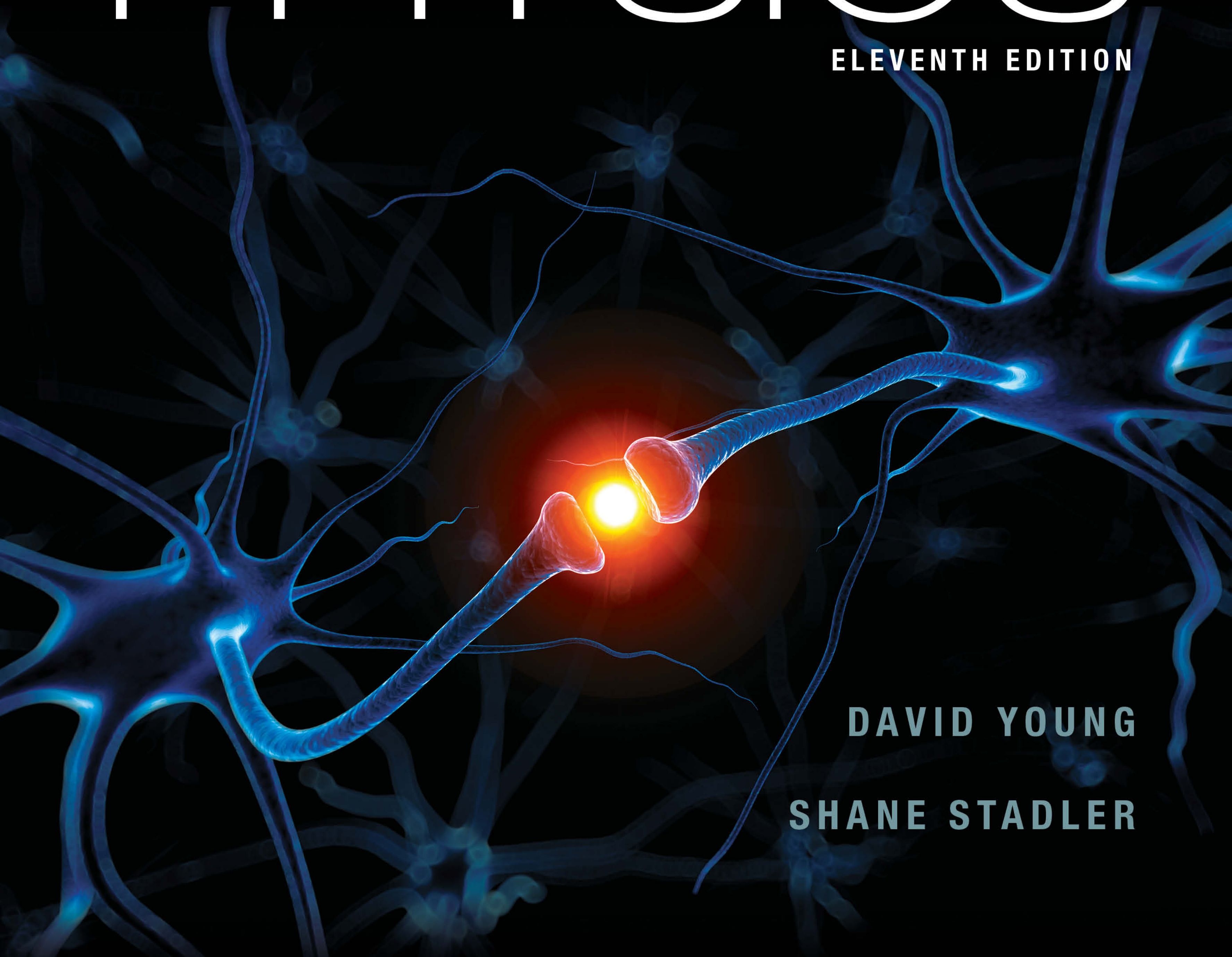
CUTNELL & JOHNSON

PHYSICS

ELEVENTH EDITION



DAVID YOUNG

SHANE STADLER

WILEY

Cutnell & Johnson Physics

Eleventh Edition

DAVID YOUNG
SHANE STADLER
Louisiana State University

WILEY

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About the Authors

Courtesy David Young

Courtesy Shane Stadler

DAVID YOUNG received his Ph.D. in experimental condensed matter physics from Florida State University in 1998. He then held a post-doc position in the Department of Chemistry and the Princeton Materials Institute at Princeton University before joining the faculty in the Department of Physics and Astronomy at Louisiana State University in 2000. His research focuses on the synthesis and characterization of high-quality single crystals of novel electronic and magnetic materials. The goal of his research group is to understand the physics of electrons in materials under extreme conditions, i.e., at temperatures close to absolute zero, in high magnetic fields, and under high pressure. He is the coauthor of over 200 research publications that have appeared in peer-reviewed journals, such as *Physical Review B, Physical Review Letters*, and *Nature*. Professor Young has taught introductory physics with the Cutnell & Johnson text since he was a senior undergraduate over 20 years ago. He routinely lectures to large sections, often in excess of 300 students. To engage such a large number of students, he uses *WileyPLUS*, electronic response systems, tutorial-style recitation sessions, and in-class demonstrations. Professor Young has received multiple awards for outstanding teaching of undergraduates. David enjoys spending his free time with his family, playing basketball, and working on his house.

I would like to thank my family for their continuous love and support.
—David Young

SHANE STADLER Shane Stadler earned a Ph.D. in experimental condensed matter physics from Tulane University in 1998. Afterwards, he accepted a National Research Council Postdoctoral Fellowship with the Naval Research Laboratory in Washington, DC, where he conducted research on artificially structured magnetic materials. Three years later, he joined the faculty in the Department of Physics at Southern Illinois University (the home institution of John Cutnell and Ken Johnson, the original authors of this textbook), before joining the Department of Physics and Astronomy at Louisiana State University in 2008. His research group studies novel magnetic materials for applications in the areas of spintronics and magnetic cooling.

Over the past fifteen years, Professor Stadler has taught the full spectrum of physics courses, from physics for students outside the sciences, to graduate-level physics courses, such as classical electrodynamics. He teaches classes that range from fewer than ten students to those with enrollments of over 300. His educational interests are focused on developing teaching tools and methods that apply to both small and large classes, and which are applicable to emerging teaching strategies, such as "flipping the classroom."

In his spare time, Shane writes science fiction/thriller novels.

I would like to thank my parents, George and Elissa, for their constant support and encouragement. —Shane Stadler

Dear Students and Instructors:

Welcome to college physics! To the students: We know there is a negative stigma associated with physics, and you yourself may harbor some trepidation as you begin this course. But fear not! We're here to help. Whether you're worried about your math proficiency, understanding the concepts, or developing your problem-solving skills, the resources available to you are designed to address all of these areas and more. Research has shown that learning styles vary greatly among students. Maybe some of you have a more visual preference, or auditory preference, or some other preferred learning modality. In any case, the resources available to you in this course will satisfy all of these preferences and improve your chance of success. Take a moment to explore below what the textbook and online course have to offer. We suspect that, as you continue to improve throughout the course, some of that initial trepidation will be replaced with excitement.

To start, we have created a new learning medium specific to this book in the form of a comprehensive set of *LECTURE VIDEOS* – one for every section (259 in all). These animated lectures (created and narrated by the authors) are 2–10 minutes in length, and explain the basic concepts and learning objectives of each section. They are assignable within WileyPLUS and can be paired with follow-up questions that are gradable. In addition to supplementing traditional lecturing, the videos can be used in a variety of ways, including flipping the classroom, a complete set of lectures for online courses, and reviewing for exams. Next, we have enhanced "The Physics of …" examples by increasing the bio-inspired examples by 40%. Although they are of general instructional value, they are also similar to what premed students will encounter in the *Chemical and Physical Foundations of Biological Systems Passages* section of the MCAT. Finally, we have introduced new "team problems" in the end-of-chapter problems that are designed for group problem-solving exercises. These are context-rich problems of medium difficulty designed for group cooperation, but may also be tackled by the individual student.

One of the great strengths of this text is the synergistic relationship it develops between problem solving and conceptual understanding. For instance, available in *WileyPLUS* are animated *Chalkboard Videos*, which consist of short (2–3 min) videos demonstrating step-by-step practical solutions to typical homework problems. Also available are numerous *Guided Online (GO) Tutorials* that implement a step-by-step pedagogical approach, which provides students a low-stakes environment for refining their problem solving skills. One of the most important techniques developed in the text for solving problems involving multiple forces is the *free-body diagram* (FBD). Many problems in the force-intensive chapters, such as chapters 4 and 18, take advantage of the new FBD capabilities now available online in *WileyPLUS*, where students can construct the FBD's for a select number of problems and be graded on them. Finally, *ORION*, an online adaptive learning environment, is seamlessly integrated into *WileyPLUS* for Cutnell & Johnson.

The content and functionality of *WileyPLUS*, and the adaptive learning environment of *ORION* (see below), will provide students with all the resources they need to be successful in the course.

- The *Lecture Videos* created by the authors for each section include questions with intelligent feedback when a student enters the wrong answer.
- The multi-step *GO Tutorial* problems created in *WileyPLUS* are designed to provide targeted, intelligent feedback.
- The *Free-body Diagram* vector drawing tools provide students an easy way to enter answers requiring vector drawing, and also provide enhanced feedback.
- *Chalkboard Video Solutions* take the students step-by-step through the solution and the thought process of the authors. Problem-solving strategies are discussed, and common misconceptions and potential pitfalls are addressed. The students can then apply these techniques to solve similar, but different problems.

All of these features are designed to encourage students to remain within the *WileyPLUS* environment, as opposed to pursuing the "pay-for solutions" websites that short circuit the learning process. To the students – We strongly recommend that you take this honest approach to the course. Take full advantage of the many features and learning resources that accompany the text and the online content. Be engaged with the material and push yourself to work through the exercises. Physics may not be the easiest subject to understand, but with the Wiley resources at your disposal and your hard work, you CAN be successful.

We are immensely grateful to all of you who have provided feedback as we've worked on this new edition, and to our students who have taught us how to teach. Thank you for your guidance, and keep the feedback coming. Best wishes for success in this course and wherever your major may take you!

Sincerely,

David Young and Shane Stadler, Louisiana State University
email: dyoun14@gmail.com or stadler.lsu.edu@gmail.com

Brief Contents

Contents

Note: Chapter sections marked with an asterisk (*) can be omitted with little impact to the overall development of the material.

Our Vision and the WileyPLUS with ORION Advantage

Our Vision

Our goal is to provide students with the skills they need to succeed in this course, and instructors with the tools they need to develop those skills.

Skills Development

One of the great strengths of this text is the synergistic relationship between conceptual understanding, problem solving, and establishing relevance. We identify here some of the core features of the text that support these synergies.

Conceptual Understanding Students often regard physics as a collection of equations that can be used blindly to solve problems. However, a good problem-solving technique does not begin with equations. It starts with a firm grasp of physics concepts and how they fit together to provide a coherent description of natural phenomena. Helping students develop a conceptual understanding of physics principles is a primary goal of this text. The features in the text that work toward this goal are:

- *Lecture Videos* (one for each section of the text)
- *Conceptual Examples*
- *Concepts & Calculations* problems (now with video solutions)
- *Focus on Concepts* homework material
- *Check Your Understanding* questions
- *Concept Simulations* (an online feature)

Problem Solving The ability to reason in an organized and mathematically correct manner is essential to solving problems, and helping students to improve their reasoning skills is also one of our primary goals. To this end, we have included the following features:

- *Math Skills boxes* for just-in-time delivery of math support
- *Explicit reasoning steps* in all examples
- *Reasoning Strategies* for solving certain classes of problems
- *Analyzing Multiple-Concept Problems*
- *Video Support and Tutorials* (in *WileyPLUS*)
  - Physics Demonstration Videos
  - Video Help
  - Concept Simulations
- *Problem Solving Insights*

Relevance Since it is always easier to learn something new if it can be related to day-to-day living, we want to show students that physics principles come into play over and over again in their lives. To emphasize this goal, we have included a wide range of applications of physics principles. Many of these applications are biomedical in nature (for example, wireless capsule endoscopy). Others deal with modern technology (for example, 3-D movies). Still others focus on things that we take for granted in our lives (for example, household plumbing). To call attention to the applications we have used the label The Physics of.

The WileyPLUS with ORION Advantage

WileyPLUS is an innovative, research-based online environment for effective teaching and learning. The hallmark of *WileyPLUS* with ORION for this text is that the media- and text-based resources are all created by the authors of the project, providing a seamless presentation of content.

WileyPLUS builds students' confidence because it takes the guesswork out of studying by providing students with a clear roadmap: **what to do, how to do it, if they did it right**.

With *WileyPLUS*, our efficacy research shows that students improve their outcomes by as much as one letter grade. *WileyPLUS* helps students take more initiative, so you'll have greater impact on their achievement in the classroom and beyond.

With *WileyPLUS*, instructors receive:

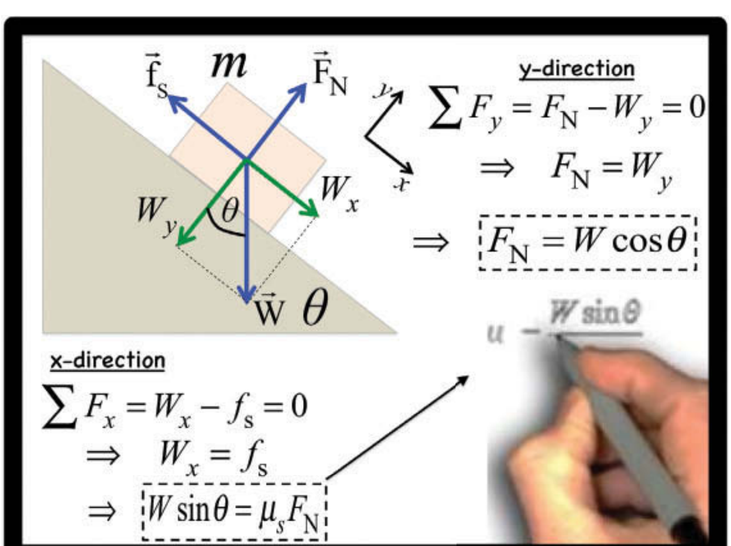
- **WileyPLUS Quickstart:** *WileyPLUS* comes with a pre-created course plan designed by the author team exclusively for this course. The course plan includes both conceptual assignments and problem-solving assignments, and is found in the Quickstart menu.
- **Breadth and Depth of Assessment:** *WileyPLUS* contains a wealth of online questions and problems for creating online homework and assessment including:
  - ALL end-of-chapter questions, plus favorites from past editions not found in the printed text, coded algorithmically, each with at least one form of instructor-controlled question assistance (GO tutorials, hints, link to text, video help)
  - Simulation, animation, and video-based questions
  - Free body and vector drawing questions
  - Test bank questions
- **Gradebook:** *WileyPLUS* provides instant access to reports on trends in class performance, student use of course materials, and progress toward learning objectives, thereby helping instructors' decisions and driving classroom discussion.

With *WileyPLUS*, students receive:

- The complete digital textbook, saving students up to 60% off the cost of a printed text
- Question assistance, including links to relevant sections in the online digital textbook
- Immediate feedback and proof of progress, 24/7
- Integrated, multimedia resources—including animations, simulations, video demonstrations, and much more—that provide multiple study paths and encourage more active learning
- GO Tutorials
- Chalkboard Videos
- Free Body Diagram/Vector Drawing Questions

New to WileyPlus for the Eleventh Edition

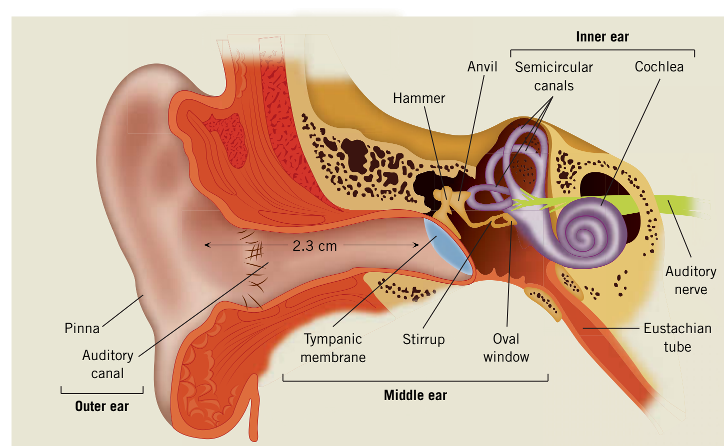
Lecture Videos Short video lectures (259 in all!) have been created and are narrated by the authors for *every section* of the book. These animated lectures are 2–10 minutes in length, and introduce the basic concepts and learning objectives of each section. Each video is accompanied by questions that can be assigned and graded within WileyPLUS, which are designed to check the students' understanding of the video lecture content. Other than providing another learning medium that can be accessed by the students at their convenience, these videos are designed to accommodate other learning strategies. For instance, an instructor can create a full video lecture by building a sequence of videos, section by section, and assigning corresponding questions that the students must complete before class. This functionality is well suited for "flipping the classroom," although it also serves a purpose for conventional lecturing, such as reading quizzes that can be administered outside of lecture. The videos also serve well for reviewing before exams. This comprehensive set of customizable lectures and questions is also suitable for online courses, where students otherwise rely solely on written content.



Team Problems In each chapter we have introduced two new "team problems" in the end-of-chapter problems that are designed for group problem-solving exercises. These are context-rich problems of medium difficulty designed for group cooperation, but may also be tackled by the individual student. Many of these problems read like parts of an adventure story, where the student (or their team) is the main character. The motivation for each problem is clear and personal—the pronoun "you" is used throughout, and the problem statements often start with "You and your team need to …". Pictures and diagrams are not given with these problems except in rare cases. Students must visualize the problems and discuss strategies with their team members to solve them. The problems require two or more steps/multiple concepts (hence the "medium" difficulty level) and may require basic principles learned earlier. Sometimes, there is no specific target variable given, but rather questions like *Will it work?* or *Is it safe?* Suggested solutions are given in the Instructor Solutions Manual.

The Physics of Problems The text now contains 294 real-world application examples that reflect our commitment to showing students how relevant physics is in their lives. Each application is identified in the text with the label The Physics of. A subset of these examples focuses on biomedical applications, and we have increased their number by 40% in the new edition. Students majoring in biomedical and life sciences will find new examples in every chapter covering topics such as cooling the human brain, abdominal aortic aneurysms, the mechanical properties of bone, and many more! The application of physics principles to biomedical problems in these examples is similar to what premed students will encounter in the *Chemical and Physical Foundations of Biological Systems Passages* section of the MCAT. All biomedical examples and end-of-chapter problems will be marked with the BIO icon.

EXAMPLE 7 | BIO The Physics of Hearing Loss—Standing Waves in the Ear



Interactive Graphics The online reading experience within WileyPLUS has been enhanced with the addition of "Interactive Graphics." Several static figures in each chapter have been transformed to include interactive elements. These graphics drive students to be more engaged with the extensive art program and allow them to more easily absorb complex and/or long multi-part figures.

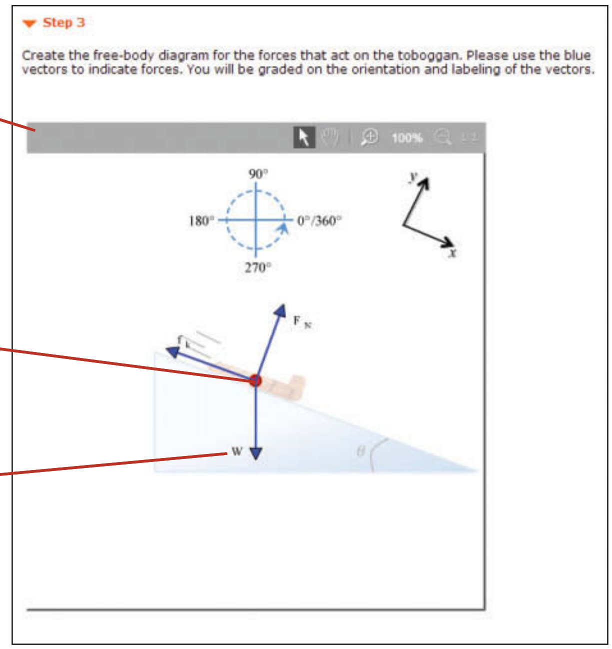
Also Available in *WileyPLUS*

Free-Body Diagram (FBD) Tools For many problems involving multiple forces, an interactive free-body diagram tool in *WileyPLUS* is used to construct the diagram. It is essential for students to practice drawing FBDs, as that is the critical first step in solving many equilibrium and non-equilibrium problems with Newton's second law.

Free-body diagram window

Easy to use "snap-to-grid functionality"

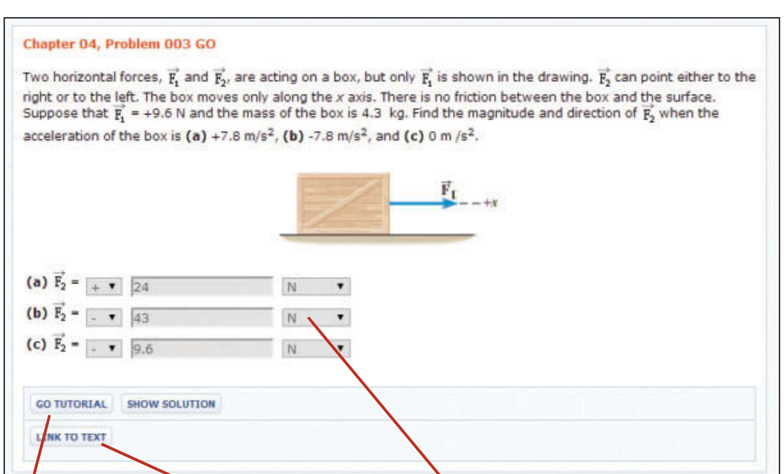
Students are graded on the orientation and labeling of the forces

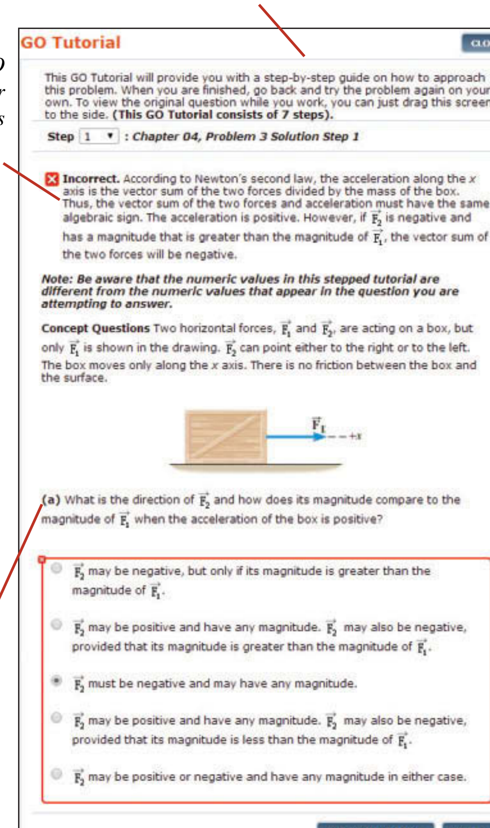


GO Tutorial Problems Some of the homework problems found in the collection at the end of each chapter are marked with a special GO icon. All of these problems are available for assignment via an online homework management program such as *WileyPLUS* or WebAssign. There are now 550 GO problems in the tenth edition. Each of these problems in *WileyPLUS* includes a guided tutorial option (not graded) that instructors can make available for student access with or without penalty.

The GO tutorial

Multiple-choice questions in the GO tutorial include extensive feedback for both correct and incorrect answers



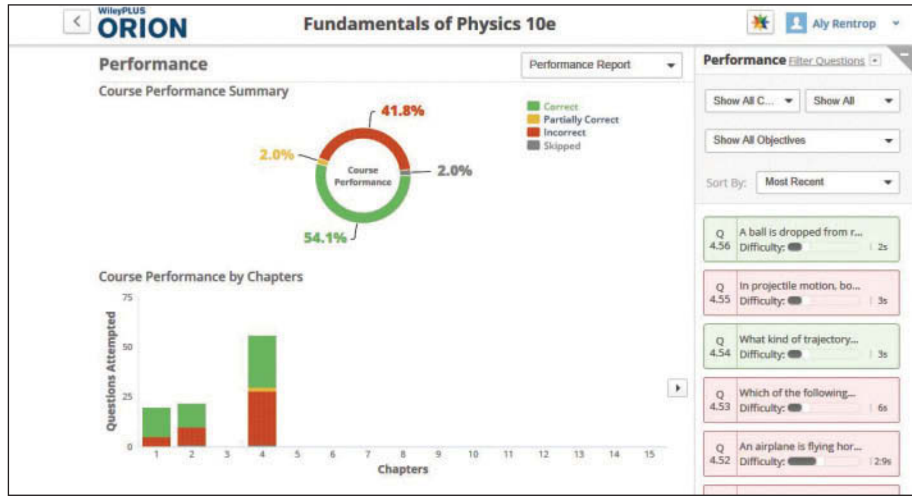


Access to the GO tutorial

Access to a relevant text example

Answer input, including direction and units

Multiple-choice questions guide students to the proper conceptual basis for the problem. The GO tutorial also includes calculational steps



***WileyPLUS* with ORION** provides students with a personal, adaptive learning experience so they can build their proficiency on concepts and use their study time effectively.

Unique to ORION, students begin by taking a quick diagnostic for any chapter. This will determine each student's baseline proficiency on each topic in the chapter. Students see their individual diagnostic report to help them decide what to do next with the help of ORION's recommendations.

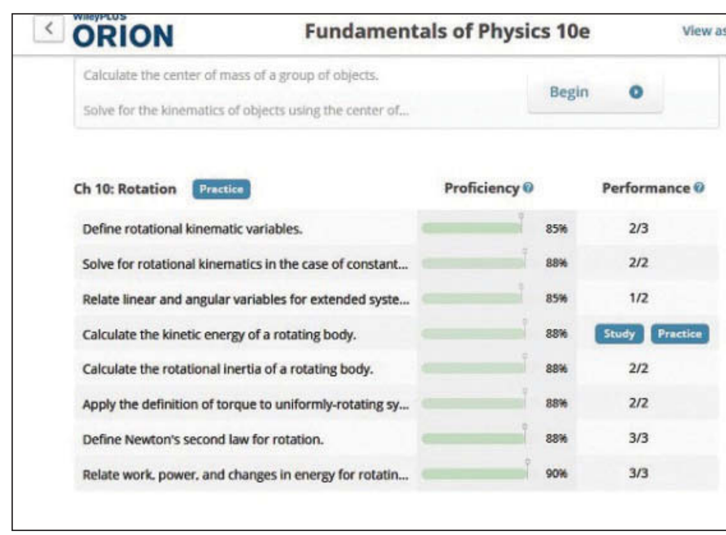
For each topic, students can either Study or Practice. **Study** directs the student to the specific topic they choose in *WileyPLUS,* where they can read from the e-textbook, or use the variety of relevant resources available there. Students can also **Practice**, using questions and feedback powered by ORION's adaptive learning engine. Based on the results of their diagnostic and ongoing practice, ORION will present students with questions appropriate for their current level of understanding, and will continuously adapt to each student, helping them build their proficiency.

ORION includes a number of reports and ongoing recommendations for students to help them maintain their proficiency over time for each topic. Students can easily access ORION from multiple places within *WileyPLUS*. It does not require any additional registration, and there is not any additional cost for students using this adaptive learning system.

About the Adaptive Engine ORION includes a powerful algorithm that feeds questions to students based on their responses to the diagnostic and to the practice questions. Students who answer questions correctly at one difficulty level will soon be given questions at the next difficulty level. If students start to answer some of those questions incorrectly, the system will present questions of lower difficulty. The adaptive engine also takes into account other factors, such as reported confidence levels, time spent on each question, and changes in response options before submitting answers.

The questions used for the adaptive practice are numerous and are not found in the *WileyPLUS* assignment area. This ensures that students will not be encountering questions in ORION that they may also encounter in their *WileyPLUS* assessments.

ORION also offers a number of reporting options available for instructors, so that instructors can easily monitor student usage and performance.



How to access *WileyPLUS* with ORION

To access *WileyPLUS*, students need a *WileyPLUS* registration code. This can be purchased stand-alone or the code can be bundled with the book. For more information and/or to request a *WileyPLUS* demonstration, contact your local Wiley sales representative or visit **www.wileyplus.com**.

Acknowledgments

The publishing world is changing rapidly! The digital age is here, and college textbooks must evolve with the times. How today's students obtain and process information is very different than it was just 10 years ago. Our goal as authors is to provide the best content we can and deliver it to today's students in ways that are both efficient and pedagogically effective. This paradigm shift in textbook publishing from largely print-based media to both print and digital content leads to uncharted waters, and we rely, now more than ever, on a talented team of people who are essential in completing such an enormous and multifaceted project. As the authors, we are immensely grateful for their guidance and insight.

We would like to especially acknowledge Jessica Fiorillo, our Executive Editor. We depend upon her experience and vast knowledge of the industry, as well as her encouragement and suggestions. Creating the new content for this edition has been, at times, tedious, to say the least. Her infectious enthusiasm has kept us going, and we are certainly grateful for that.

We had the pleasure of working with our Production Editor, Elizabeth Swain, on the previous edition of the book and during the early stages of this new edition. She has been a consummate professional during the copyediting process. While our interaction with Elizabeth was relatively short, considering her long career at Wiley, we and the title have benefited greatly from her hard work and experience.

We owe a tremendous thank you to our Project Manager, Jennifer Yee, for managing our revision timeline and assuming much of the responsibility of a production editor. She did a wonderful job in providing us with up-to-date information throughout the process. We must also acknowledge Mahtab Khan and Suresh Srinivasan with Aptara Corporation, who seamlessly assumed much of the production editor's responsibilities and kept us on track.

We are lucky to work with such a talented Product Design Manager as Geraldine Osnato. She is a "digital diva"! Her expertise with the online environment and her knowledge of the pedagogy combine to form a web-based platform that enhances student learning. Geraldine is so good at her job that there is little possibility she will leave to become a professional bull rider. Thank you also to Lindsey Meyers, Assistant Development Editor, for taking the reins on the new *Interactive Graphics* feature of the online text. Some of the functionality we designed was difficult to implement, but she made it work. Thank you!

We are very fortunate to work with Kristy Ruff, who is the Executive Market Development Manager for Science at Wiley. She understands the needs of our students and promotes the vision of the text by focusing on what we do best—content! This title would not have the success it does without her efforts in guiding the marketing strategy. Thank you, Kristy!

The final and polished version of the text represents the culmination of the efforts by many team members, including Copy Editor and Proofreader, Bret Workman; Senior Photo Editor, Mary Ann Price; Media Specialist, Patricia Gutierrez; Senior Content Manager, Lana Barskaya; Marketing Assistant, Maggie Joest; and Text Designer and Cover Designer, Wendy Lai.

One of the many facets of the book is the extensive supplemental package, including the solutions manuals. We are grateful to Editorial Assistant, Ayantika Chatterjee, and Assistant Development Editor, Lindsey Myers, for the flawless assembly of these important components.

We are also grateful to Ayantika Chatterjee, Editorial Assistant, for help in facilitating the flow of the manuscript through its various production stages.

We owe a special thank you to Petra Recter, who was a former publisher on this title and who now is the Vice President & Director of Science. Thank you for staying committed to the Cutnell franchise, providing us such a great team to improve the text, and being such a strong advocate for the physics program at Wiley.

Last, but certainly not least, we thank the sales representatives of John Wiley & Sons, Inc. You are very special members of our team. Your professionalism and knowledge of the book's features, the online content, and its functionality is pivotal to the success of the book. We are very grateful for your tireless promotional efforts.

We are particularly indebted to Dayna Leaman. More than just our local Account Manager, she is also our friend. You have been supportive on so many levels, and we are absolutely certain that we would not have been afforded this wonderful opportunity had it not been for your support. Managing multiple adoptions across several states is not easy, and we benefit greatly from your hard work. Thank you, Dayna!

Many of our physics colleagues and their students have generously shared their ideas about good pedagogy with us and improved the text by pointing out our errors. For all of their suggestions, we are grateful. They have helped us to write more clearly and accurately and have influenced markedly the evolution of this text. To the reviewers of this and previous editions, we especially owe a large debt of gratitude. Specifically, we thank:

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Deepshikha Shukla, Rockford University
Jennifer Snyder, San Diego Mesa College
Richard Taylor, University of Oregon
Beth Thacker, Texas Tech University
Anne Topper, Queen's University
David Ulrich, Portland Community College

About the cover: The cover image shows an artist's rendition of a synaptic gap between an axon and a dendrite of a human nerve cell. Just like the wires in the electrical system of your home, the nerve cells make connections in circuits called neural pathways. The transmission of chemical signals between the axon and dendrite relies on the electrical potential difference across the gap, which is a topic in Volume 2 of the text. Our hope is that this book and its resources will help you develop some new neural pathways of your own!

In spite of our best efforts to produce an error-free book, errors no doubt 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. Please feel free to write us care of Physics Editor, Global Education, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, or contact the authors at **dyoun14@gmail.com** or **sstadler23@gmail.com**.

Photo 12/Alamy Stock Photo

The animation techniques and special effects used in the film *The Avengers* rely on computers and mathematical concepts such as trigonometry and vectors. Such mathematical concepts will be very useful throughout this book in our discussion of physics.

Introduction and Mathematical Concepts

LEARNING OBJECTIVES

After reading this module, you should be able to...

1.1 Describe the fundamental nature of physics.

1.2 Describe different systems of units.

1.3 Solve unit conversion problems.

1.4 Solve trigonometry problems.

1.5 Distinguish between vectors and scalars.

1.6 Solve vector addition and subtraction problems by graphical methods.

1.7 Calculate vector components.

1.8 Solve vector addition and subtraction problems using components.

1.1 The Nature of Physics

Physics is the most basic of the sciences, and it is at the very root of subjects like chemistry, engineering, astronomy, and even biology. The discipline of physics has developed over many centuries, and it continues to evolve. It is a mature science, and its laws encompass a wide scope of phenomena that range from the formation of galaxies to the interactions of particles in the nuclei of atoms. Perhaps the most visible evidence of physics in everyday life is the eruption of new applications that have improved our quality of life, such as new medical devices, and advances in computers and high-tech communications.

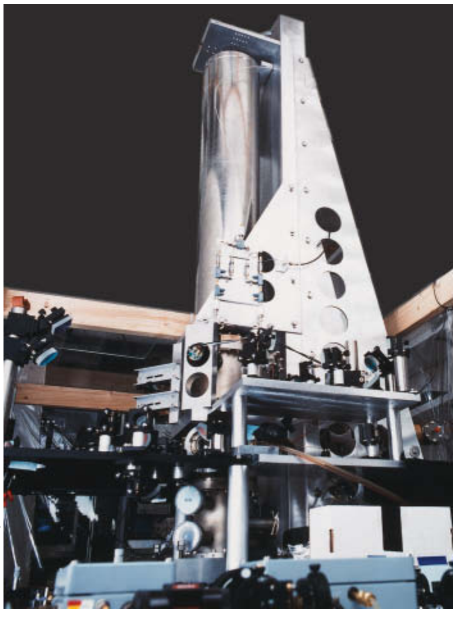
The exciting feature of physics is its capacity for predicting how nature will behave in one situation on the basis of experimental data obtained in another situation. Such predictions place physics at the heart of modern technology and, therefore, can have a tremendous impact on our lives. Rocketry and the development of space travel have their roots firmly planted in the physical laws of Galileo Galilei (1564–1642) and Isaac Newton (1642–1727). The transportation industry relies heavily on physics in the development of engines and the design of aerodynamic vehicles. Entire electronics and computer industries owe their existence to the invention of the transistor, which grew directly out of the laws of physics that describe the electrical behavior of solids. The telecommunications industry depends extensively on electromagnetic waves,

Courtesy NIST Archives

FIGURE 1.1 The standard platinum–iridium meter bar.

Science Source

FIGURE 1.2 The standard platinum–iridium kilogram is kept at the International Bureau of Weights and Measures in Sèvres, France. This copy of it was assigned to the United States in 1889 and is housed at the National Institute of Standards and Technology.



© Geoffrey Wheeler

FIGURE 1.3 This atomic clock, the NIST-F1, keeps time with an uncertainty of about one second in sixty million years.

TABLE 1.1 Units of Measurement

	System		
	SI	**CGS**	**BE**
Length	Meter (m)	Centimeter (cm)	Foot (ft)
Mass	Kilogram (kg)	Gram (g)	Slug (sl)
Time	Second (s)	Second (s)	Second (s)

whose existence was predicted by James Clerk Maxwell (1831–1879) in his theory of electricity and magnetism. The medical profession uses X-ray, ultrasonic, and magnetic resonance methods for obtaining images of the interior of the human body, and physics lies at the core of all these. Perhaps the most widespread impact in modern technology is that due to the laser. Fields ranging from space exploration to medicine benefit from this incredible device, which is a direct application of the principles of atomic physics.

Because physics is so fundamental, it is a required course for students in a wide range of major areas. We welcome you to the study of this fascinating topic. You will learn how to see the world through the "eyes" of physics and to reason as a physicist does. In the process, you will learn how to apply physics principles to a wide range of problems. We hope that you will come to recognize that physics has important things to say about your environment.

1.2 Units

Physics experiments involve the measurement of a variety of quantities, and a great deal of effort goes into making these measurements as accurate and reproducible as possible. The first step toward ensuring accuracy and reproducibility is defining the units in which the measurements are made.

In this text, we emphasize the system of units known as **SI units,** which stands for the French phrase "Le **S**ystème **I**nternational d'Unités." By international agreement, this system employs the **meter** (m) as the unit of length, the **kilogram** (kg) as the unit of mass, and the **second** (s) as the unit of time. Two other systems of units are also in use, however. The CGS system utilizes the centimeter (cm), the gram (g), and the second for length, mass, and time, respectively, and the BE or British Engineering system (the gravitational version) uses the foot (ft), the slug (sl), and the second. **Table 1.1** summarizes the units used for length, mass, and time in the three systems.

Originally, the meter was defined in terms of the distance measured along the earth's surface between the north pole and the equator. Eventually, a more accurate measurement standard was needed, and by international agreement the meter became the distance between two marks on a bar of platinum–iridium alloy (see **Figure 1.1**) kept at a temperature of 0 °C. Today, to meet further demands for increased accuracy, the meter is defined as the distance that light travels in a vacuum in a time of 1/299 792 458 second. This definition arises because the speed of light is a universal constant that is defined to be 299 792 458 m/s.

The definition of a kilogram as a unit of mass has also undergone changes over the years. As Chapter 4 discusses, the mass of an object indicates the tendency of the object to continue in motion with a constant velocity. Originally, the kilogram was expressed in terms of a specific amount of water. Today, one kilogram is defined to be the mass of a standard cylinder of platinum–iridium alloy, like the one in **Figure 1.2**.

As with the units for length and mass, the present definition of the second as a unit of time is different from the original definition. Originally, the second was defined according to the average time for the earth to rotate once about its axis, one day being set equal to 86 400 seconds. The earth's rotational motion was chosen because it is naturally repetitive, occurring over and over again. Today, we still use a naturally occurring repetitive phenomenon to define the second, but of a very different kind. We use the electromagnetic waves emitted by cesium-133 atoms in an atomic clock like that in **Figure 1.3**. One second is defined as the time needed for 9 192 631 770 wave cycles to occur.*

The units for length, mass, and time, along with a few other units that will arise later, are regarded as **base** SI units. The word "base" refers to the fact that these units are used along with

*See Chapter 16 for a discussion of waves in general and Chapter 24 for a discussion of electromagnetic waves in particular.

various laws to define additional units for other important physical quantities, such as force and energy. The units for such other physical quantities are referred to as **derived** units, since they are combinations of the base units. Derived units will be introduced from time to time, as they arise naturally along with the related physical laws.

The value of a quantity in terms of base or derived units is sometimes a very large or very small number. In such cases, it is convenient to introduce larger or smaller units that are related to the normal units by multiples of ten. **Table 1.2** summarizes the prefixes that are used to denote multiples of ten. For example, 1000 or 10^3 meters are referred to as 1 kilometer (km), and 0.001 or 10^{-3} meter is called 1 millimeter (mm). Similarly, 1000 grams and 0.001 gram are referred to as 1 kilogram (kg) and 1 milligram (mg), respectively. Appendix A contains a discussion of scientific notation and powers of ten, such as 10^3 and 10^{-3}.

TABLE 1.2 Standard Prefixes Used to Denote Multiples of Ten

Prefix	Symbol	Factor[a]
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

[a]Appendix A contains a discussion of powers of ten and scientific notation.

1.3 The Role of Units in Problem Solving

The Conversion of Units

Since any quantity, such as length, can be measured in several different units, it is important to know how to convert from one unit to another. For instance, the foot can be used to express the distance between the two marks on the standard platinum–iridium meter bar. There are 3.281 feet in one meter, and this number can be used to convert from meters to feet, as the following example demonstrates.

EXAMPLE 1 | The World's Highest Waterfall

The highest waterfall in the world is Angel Falls in Venezuela, with a total drop of 979.0 m (see **Figure 1.4**). Express this drop in feet.

Reasoning When converting between units, we write down the units explicitly in the calculations and treat them like any algebraic quantity. In particular, we will take advantage of the following algebraic fact: Multiplying or dividing an equation by a factor of 1 does not alter an equation.

Solution Since 3.281 feet = 1 meter, it follows that (3.281 feet)/(1 meter) = 1. Using this factor of 1 to multiply the equation "Length = 979.0 meters," we find that

$$\text{Length} = (979.0\text{ m})(1) = (979.0\ \cancel{\text{meters}})\left(\frac{3.281\text{ feet}}{1\ \cancel{\text{meter}}}\right) = \boxed{3212\text{ feet}}$$

The colored lines emphasize that the units of meters behave like any algebraic quantity and cancel when the multiplication is performed, leaving only the desired unit of feet to describe the answer. In this regard, note that 3.281 feet = 1 meter also implies that (1 meter)/(3.281 feet) = 1. However, we chose not to multiply by a factor of 1 in this form, because the units of meters would not have canceled.

A calculator gives the answer as 3212.099 feet. Standard procedures for significant figures, however, indicate that the answer should be rounded off to four significant figures, since the value of 979.0 meters is accurate to only four significant figures. In this regard, the "1 meter" in the denominator does not limit the significant figures of the answer, because this number is precisely one meter by definition of the conversion factor. Appendix B contains a review of significant figures.

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FIGURE 1.4 Angel Falls in Venezuela is the highest waterfall in the world.

Problem-Solving Insight In any conversion, if the units do not combine algebraically to give the desired result, the conversion has not been carried out properly.

With this in mind, the next example stresses the importance of writing down the units and illustrates a typical situation in which several conversions are required.

EXAMPLE 2 | Interstate Speed Limit

Express the speed limit of 65 miles/hour in terms of meters/second.

Reasoning As in Example 1, it is important to write down the units explicitly in the calculations and treat them like any algebraic quantity. Here, we take advantage of two well-known relationships—namely, 5280 feet = 1 mile and 3600 seconds = 1 hour. As a result, (5280 feet)/(1 mile) = 1 and (3600 seconds)/(1 hour) = 1. In our solution we will use the fact that multiplying and dividing by these factors of unity does not alter an equation.

Solution Multiplying and dividing by factors of unity, we find the speed limit in feet per second as shown below:

$$\text{Speed} = \left(65\,\frac{\text{miles}}{\text{hour}}\right)(1)(1) =$$

$$\left(65\,\frac{\cancel{\text{miles}}}{\cancel{\text{hour}}}\right)\left(\frac{5280\text{ feet}}{1\ \cancel{\text{mile}}}\right)\left(\frac{1\ \cancel{\text{hour}}}{3600\text{ seconds}}\right) = 95\,\frac{\text{feet}}{\text{second}}$$

To convert feet into meters, we use the fact that (1 meter)/(3.281 feet) = 1:

$$\text{Speed} = \left(95\,\frac{\text{feet}}{\text{second}}\right)(1) =$$

$$\left(95\,\frac{\cancel{\text{feet}}}{\text{second}}\right)\left(\frac{1\text{ meter}}{3.281\ \cancel{\text{feet}}}\right) = \boxed{29\,\frac{\text{meters}}{\text{second}}}$$

In addition to their role in guiding the use of conversion factors, units serve a useful purpose in solving problems. They can provide an internal check to eliminate errors, if they are carried along during each step of a calculation and treated like any algebraic factor.

Problem-Solving Insight In particular, remember that only quantities with the same units can be added or subtracted.

Thus, at one point in a calculation, if you find yourself adding 12 miles to 32 kilometers, stop and reconsider. Either miles must be converted into kilometers or kilometers must be converted into miles before the addition can be carried out.

A collection of useful conversion factors is given on the page facing the inside of the front cover. The reasoning strategy that we have followed in Examples 1 and 2 for converting between units is outlined as follows:

REASONING STRATEGY Converting Between Units

1. **In all calculations, write down the units explicitly.**
2. **Treat all units as algebraic quantities. In particular, when identical units are divided, they are eliminated algebraically.**
3. **Use the conversion factors located on the page facing the inside of the front cover. Be guided by the fact that multiplying or dividing an equation by a factor of 1 does not alter the equation. For instance, the conversion factor of 3.281 feet = 1 meter might be applied in the form (3.281 feet)/(1 meter) = 1. This factor of 1 would be used to multiply an equation such as "Length = 5.00 meters" in order to convert meters to feet.**
4. **Check to see that your calculations are correct by verifying that the units combine algebraically to give the desired unit for the answer. Only quantities with the same units can be added or subtracted.**

Sometimes an equation is expressed in a way that requires specific units to be used for the variables in the equation. In such cases it is important to understand why only certain units can be used in the equation, as the following example illustrates.

EXAMPLE 3 | BIO The Physics of the Body Mass Index

The body mass index (BMI) takes into account your mass in kilograms (kg) and your height in meters (m) and is defined as follows:

$$\text{BMI} = \frac{\text{Mass in kg}}{(\text{Height in m})^2}$$

However, the BMI is often computed using the weight* of a person in pounds (lb) and his or her height in inches (in.). Thus, the expression for the BMI incorporates these quantities, rather than the mass in kilograms and the height in meters. Starting with the definition above, determine the expression for the BMI that uses pounds and inches.

*Weight and mass are different concepts, and the relationship between them will be discussed in Section 4.7.

Reasoning We will begin with the BMI definition and work separately with the numerator and the denominator. We will determine the mass in kilograms that appears in the numerator from the weight in pounds by using the fact that 1 kg corresponds to 2.205 lb. Then, we will determine the height in meters that appears in the denominator from the height in inches with the aid of the facts that 1 m = 3.281 ft and 1 ft = 12 in. These conversion factors are located on the page facing the inside of the front cover of the text.

Solution Since 1 kg corresponds to 2.205 lb, the mass in kilograms can be determined from the weight in pounds in the following way:

$$\text{Mass in kg} = (\text{Weight in lb})\left(\frac{1\text{ kg}}{2.205\text{ lb}}\right)$$

Since 1 ft = 12 in. and 1 m = 3.281 ft, we have

$$\text{Height in m} = (\text{Height in in.})\left(\frac{1\text{ }\cancel{\text{ft}}}{12\text{ in.}}\right)\left(\frac{1\text{ m}}{3.281\text{ }\cancel{\text{ft}}}\right)$$

Substituting these results into the numerator and denominator of the BMI definition gives

$$\text{BMI} = \frac{\text{Mass in kg}}{(\text{Height in m})^2} = \frac{(\text{Weight in lb})\left(\frac{1\text{ kg}}{2.205\text{ lb}}\right)}{(\text{Height in in.})^2\left(\frac{1\text{ }\cancel{\text{ft}}}{12\text{ in.}}\right)^2\left(\frac{1\text{ m}}{3.281\text{ }\cancel{\text{ft}}}\right)^2}$$

$$= \left(\frac{1\text{ kg}}{2.205\text{ lb}}\right)\left(\frac{12\text{ in.}}{1\text{ }\cancel{\text{ft}}}\right)^2\left(\frac{3.281\text{ }\cancel{\text{ft}}}{1\text{ m}}\right)^2\frac{(\text{Weight in lb})}{(\text{Height in in.})^2}$$

$$\boxed{\text{BMI} = \left(703.0\frac{\text{kg}\cdot\text{in.}^2}{\text{lb}\cdot\text{m}^2}\right)\frac{(\text{Weight in lb})}{(\text{Height in in.})^2}}$$

For example, if your weight and height are 180 lb and 71 in., your body mass index is 25 kg/m^2. The BMI can be used to assess approximately whether your weight is normal for your height (see **Table 1.3**).

TABLE 1.3 The Body Mass Index

BMI (kg/m^2)	Evaluation
Below 18.5	Underweight
18.5–24.9	Normal
25.0–29.9	Overweight
30.0–39.9	Obese
40 and above	Morbidly obese

Dimensional Analysis

We have seen that many quantities are denoted by specifying both a number and a unit. For example, the distance to the nearest telephone may be 8 meters, or the speed of a car might be 25 meters/second. Each quantity, according to its physical nature, requires a certain *type* of unit. Distance must be measured in a length unit such as meters, feet, or miles, and a time unit will not do. Likewise, the speed of an object must be specified as a length unit divided by a time unit. In physics, the term **dimension** is used to refer to the physical nature of a quantity and the type of unit used to specify it. Distance has the dimension of length, which is symbolized as [L], while speed has the dimensions of length [L] divided by time [T], or [L/T]. Many physical quantities can be expressed in terms of a combination of fundamental dimensions such as length [L], time [T], and mass [M]. Later on, we will encounter certain other quantities, such as temperature, which are also fundamental. A fundamental quantity like temperature cannot be expressed as a combination of the dimensions of length, time, mass, or any other fundamental dimension.

Dimensional analysis is used to check mathematical relations for the consistency of their dimensions. As an illustration, consider a car that starts from rest and accelerates to a speed v in a time t. Suppose we wish to calculate the distance x traveled by the car but are not sure whether the correct relation is $x = \frac{1}{2}vt^2$ or $x = \frac{1}{2}vt$. We can decide by checking the quantities on both sides of the equals sign to see whether they have the same dimensions. If the dimensions are not the same, the relation is incorrect. For $x = \frac{1}{2}vt^2$, we use the dimensions for distance [L], time [T], and speed [L/T] in the following way:

$$x = \tfrac{1}{2}vt^2$$

Dimensions $$[\text{L}] \stackrel{?}{=} \left[\frac{\text{L}}{\cancel{\text{T}}}\right][\text{T}]^{\cancel{2}} = [\text{L}][\text{T}]$$

Dimensions cancel just like algebraic quantities, and pure numerical factors like $\frac{1}{2}$ have no dimensions, so they can be ignored. The dimension on the left of the equals sign does not match those on the right, so the relation $x = \frac{1}{2}vt^2$ cannot be correct. On the other hand, applying dimensional analysis to $x = \frac{1}{2}vt$, we find that

$$x = \tfrac{1}{2}vt^2$$

Dimensions $$[\text{L}] \stackrel{?}{=} \left[\frac{\text{L}}{\cancel{\text{T}}}\right][\cancel{\text{T}}] = [\text{L}]$$

Problem-Solving Insight You can check for errors that may have arisen during algebraic manipulations by performing a dimensional analysis on the final expression.

The dimension on the left of the equals sign matches that on the right, so this relation is dimensionally correct. If we know that one of our two choices is the right one, then $x = \frac{1}{2}vt$ is it. In the absence of such knowledge, however, dimensional analysis cannot identify the correct relation. It can only identify which choices *may be* correct, since it does not account for numerical factors like $\frac{1}{2}$ or for the manner in which an equation was derived from physics principles.

Check Your Understanding

(The answers are given at the end of the book.)

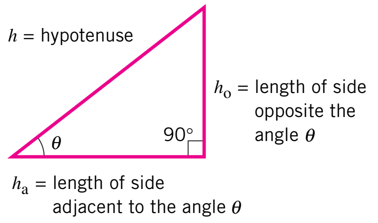
1. **(a)** Is it possible for two quantities to have the same dimensions but different units?
   (b) Is it possible for two quantities to have the same units but different dimensions?
2. You can always add two numbers that have the same units (such as 6 meters + 3 meters). Can you always add two numbers that have the same dimensions, such as two numbers that have the dimensions of length [L]?
3. The following table lists four variables, along with their units:

Variable	Units
x	Meters (m)
v	Meters per second (m/s)
t	Seconds (s)
a	Meters per second squared (m/s^2)

These variables appear in the following equations, along with a few numbers that have no units. In which of the equations are the units on the left side of the equals sign consistent with the units on the right side?

(a) $x = vt$ **(d)** $v = at + \frac{1}{2}at^3$
(b) $x = vt + \frac{1}{2}at^2$ **(e)** $v^3 = 2ax^2$
(c) $v = at$ **(f)** $t = \sqrt{\frac{2x}{a}}$

4. In the equation $y = c^n at^2$ you wish to determine the integer value (1, 2, etc.) of the exponent n. The dimensions of y, a, and t are known. It is also known that c has no dimensions. Can dimensional analysis be used to determine n?



INTERACTIVE FIGURE 1.5 A right triangle.

1.4 Trigonometry

Scientists use mathematics to help them describe how the physical universe works, and trigonometry is an important branch of mathematics. Three trigonometric functions are utilized throughout this text. They are the sine, the cosine, and the tangent of the angle θ (Greek theta), abbreviated as sin θ, cos θ, and tan θ, respectively. These functions are defined below in terms of the symbols given along with the right triangle in **Interactive Figure 1.5**.

DEFINITION OF SIN θ, COS θ, AND TAN θ

$$\sin\theta = \frac{h_o}{h} \quad (1.1)$$

$$\cos\theta = \frac{h_a}{h} \quad (1.2)$$

$$\tan\theta = \frac{h_o}{h_a} \quad (1.3)$$

h = length of the **hypotenuse** of a right triangle
h_o = length of the side **opposite** the angle θ
h_a = length of the side **adjacent** to the angle θ

The sine, cosine, and tangent of an angle are numbers without units, because each is the ratio of the lengths of two sides of a right triangle. Example 4 illustrates a typical application of Equation 1.3.

EXAMPLE 4 | Using Trigonometric Functions

On a sunny day, a tall building casts a shadow that is 67.2 m long. The angle between the sun's rays and the ground is $\theta = 50.0°$, as **Figure 1.6** shows. Determine the height of the building.

Reasoning We want to find the height of the building. Therefore, we begin with the colored right triangle in **Figure 1.6** and identify the height as the length h_o of the side opposite the angle θ. The length of the shadow is the length h_a of the side that is adjacent to the angle θ. The ratio of the length of the opposite side to the length of the adjacent side is the tangent of the angle θ, which can be used to find the height of the building.

Solution We use the tangent function in the following way, with $\theta = 50.0°$ and $h_a = 67.2$ m:

$$\tan\theta = \frac{h_o}{h_a} \tag{1.3}$$

$$h_o = h_a \tan\theta = (67.2\text{ m})(\tan 50.0°) = (67.2\text{ m})(1.19) = \boxed{80.0\text{ m}}$$

The value of tan 50.0° is found by using a calculator.

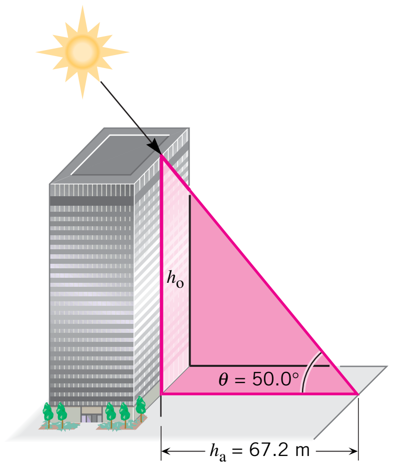


FIGURE 1.6 From a value for the angle θ and the length h_a of the shadow, the height h_o of the building can be found using trigonometry.

The sine, cosine, or tangent may be used in calculations such as that in Example 4, depending on which side of the triangle has a known value and which side is asked for.

Problem-Solving Insight However, the choice of which side of the triangle to label h_o (opposite) and which to label h_a (adjacent) can be made only after the angle θ is identified.

Often the values for two sides of the right triangle in **Interactive Figure 1.5** are available, and the value of the angle θ is unknown. The concept of **inverse trigonometric functions** plays an important role in such situations. Equations 1.4–1.6 give the inverse sine, inverse cosine, and inverse tangent in terms of the symbols used in the drawing. For instance, Equation 1.4 is read as "θ equals the angle whose sine is h_o/h."

$$\theta = \sin^{-1}\left(\frac{h_o}{h}\right) \tag{1.4}$$

$$\theta = \cos^{-1}\left(\frac{h_a}{h}\right) \tag{1.5}$$

$$\theta = \tan^{-1}\left(\frac{h_o}{h_a}\right) \tag{1.6}$$

The use of -1 as an exponent in Equations 1.4–1.6 *does not mean* "take the reciprocal." For instance, $\tan^{-1}(h_o/h_a)$ does not equal $1/\tan(h_o/h_a)$. Another way to express the inverse trigonometric functions is to use arc sin, arc cos, and arc tan instead of $\sin^{-1}$, $\cos^{-1}$, and $\tan^{-1}$. Example 5 illustrates the use of an inverse trigonometric function.

EXAMPLE 5 | Using Inverse Trigonometric Functions

A lakefront drops off gradually at an angle θ, as **Figure 1.7** indicates. For safety reasons, it is necessary to know how deep the lake is at various distances from the shore. To provide some information about the depth, a lifeguard rows straight out from the shore a distance of 14.0 m and drops a weighted fishing line. By measuring the length of the line, the lifeguard determines the depth to be 2.25 m. **(a)** What is the value of θ? **(b)** What would be the depth d of the lake at a distance of 22.0 m from the shore?

Reasoning Near the shore, the lengths of the opposite and adjacent sides of the right triangle in **Figure 1.7** are $h_o = 2.25$ m and $h_a = 14.0$ m, relative to the angle θ. Having made this identification, we can use the inverse tangent to find the angle in part (a). For part (b) the opposite and adjacent sides farther from the shore become $h_o = d$ and $h_a = 22.0$ m. With the value for θ obtained in part (a), the tangent function can be used to find the unknown depth. Considering the way in which the lake bottom drops off in **Figure 1.7**, we expect the unknown depth to be greater than 2.25 m.

Solution **(a)** Using the inverse tangent given in Equation 1.6, we find that

$$\theta = \tan^{-1}\left(\frac{h_o}{h_a}\right) = \tan^{-1}\left(\frac{2.25 \text{ m}}{14.0 \text{ m}}\right) = \boxed{9.13°}$$

(b) With $\theta = 9.13°$, the tangent function given in Equation 1.3 can be used to find the unknown depth farther from the shore, where $h_o = d$ and $h_a = 22.0$ m. Since $\tan\theta = h_o/h_a$, it follows that

$$h_o = h_a \tan\theta$$
$$d = (22.0 \text{ m})(\tan 9.13°) = \boxed{3.54 \text{ m}}$$

which is greater than 2.25 m, as expected.

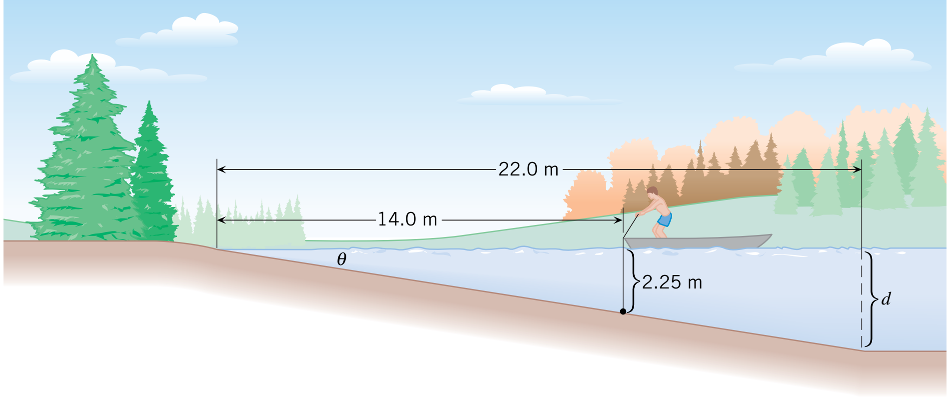


FIGURE 1.7 If the distance from the shore and the depth of the water at any one point are known, the angle θ can be found with the aid of trigonometry. Knowing the value of θ is useful, because then the depth d at another point can be determined.

The right triangle in **Interactive Figure 1.5** provides the basis for defining the various trigonometric functions according to Equations 1.1–1.3. These functions always involve an angle and two sides of the triangle. There is also a relationship among the lengths of the three sides of a right triangle. This relationship is known as the **Pythagorean theorem** and is used often in this text.

PYTHAGOREAN THEOREM

The square of the length of the hypotenuse of a right triangle is equal to the sum of the squares of the lengths of the other two sides:

$$h^2 = h_o^2 + h_a^2 \tag{1.7}$$

1.5 Scalars and Vectors

The volume of water in a swimming pool might be 50 cubic meters, or the winning time of a race could be 11.3 seconds. In cases like these, only the size of the numbers matters. In other words, *how much* volume or time is there? The 50 specifies the amount of water in units of cubic meters, while the 11.3 specifies the amount of time in seconds. Volume and time are examples of scalar quantities. A **scalar quantity** is one that can be described with a single number (including any units) giving its size or magnitude. Some other common scalars are temperature (e.g., 20 °C) and mass (e.g., 85 kg).

While many quantities in physics are scalars, there are also many that are not, and for these quantities the magnitude tells only part of the story. Consider **Figure 1.8**, which depicts a car that has moved 2 km along a straight line from start to finish. When describing the motion, it is incomplete to say that "the car moved a distance of 2 km." This statement would indicate only that the car ends up somewhere on a circle whose center is at the starting point and whose radius is 2 km. A complete description must include the direction along with the distance, as in the statement "the car moved a distance of 2 km in a direction 30° north of east." A quantity that deals inherently with *both magnitude and direction* is called a **vector quantity**. Because direction is an important characteristic of vectors, arrows are used to represent them; ***the direction of the arrow gives the direction of the vector***. The colored arrow in **Figure 1.8**, for example, is called the *displacement vector,* because it shows how the car is displaced from its starting point. Chapter 2 discusses this particular vector.

The length of the arrow in **Figure 1.8** represents the magnitude of the displacement vector. If the car had moved 4 km instead of 2 km from the starting point, the arrow would have been drawn twice as long. ***By convention, the length of a vector arrow is proportional to the magnitude of the vector***.

In physics there are many important kinds of vectors, and the practice of using the length of an arrow to represent the magnitude of a vector applies to each of them. All forces, for instance, are vectors. In common usage a force is a push or a pull, and the direction in which a force acts is just as important as the strength or magnitude of the force. The magnitude of a force is measured in SI units called newtons (N). An arrow representing a force of 20 newtons is drawn twice as long as one representing a force of 10 newtons.

The fundamental distinction between scalars and vectors is the characteristic of direction. Vectors have it, and scalars do not. Conceptual Example 6 helps to clarify this distinction and explains what is meant by the "direction" of a vector.

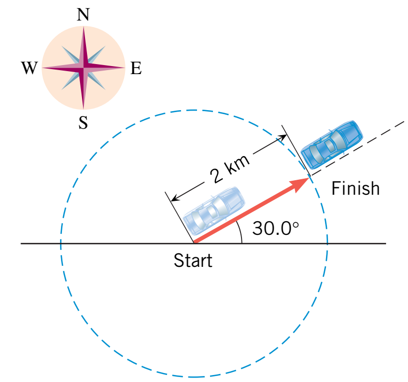


FIGURE 1.8 A vector quantity has a magnitude and a direction. The colored arrow in this drawing represents a displacement vector.

CONCEPTUAL EXAMPLE 6 | Vectors, Scalars, and the Role of Plus and Minus Signs

There are places where the temperature is +20 °C at one time of the year and −20 °C at another time. Do the plus and minus signs that signify positive and negative temperatures imply that temperature is a vector quantity? **(a)** Yes **(b)** No

Reasoning A hallmark of a vector is that there is both a magnitude and a physical direction associated with it, such as 20 meters due east or 20 meters due west.

Answer (a) is incorrect. The plus and minus signs associated with +20 °C and −20 °C do not convey a physical direction, such as due east or due west. Therefore, temperature cannot be a vector quantity.

Answer (b) is correct. On a thermometer, the algebraic signs simply mean that the temperature is a number less than or greater than zero on the temperature scale being used and have nothing to do with east, west, or any other physical direction. Temperature, then, is not a vector. It is a scalar, and scalars can sometimes be negative.

Often, for the sake of convenience, quantities such as volume, time, displacement, velocity, and force are represented in physics by symbols. In this text, we write vectors in boldface symbols (**this is boldface**) with arrows above them* and write scalars in italic symbols (*this is italic*). Thus, a displacement vector is written as "$\vec{\mathbf{A}} = 750$ m, due east," where the $\vec{\mathbf{A}}$ is a boldface symbol. By itself, however, separated from the direction, the magnitude of this vector is a scalar quantity. Therefore, the magnitude is written as "$A = 750$ m," where the A is an italic symbol without an arrow.

Check Your Understanding

(The answer is given at the end of the book.)

5. Which of the following statements, if any, involves a vector? **(a)** I walked 2 miles along the beach. **(b)** I walked 2 miles due north along the beach. **(c)** I jumped off a cliff and hit the water traveling at 17 miles per hour. **(d)** I jumped off a cliff and hit the water traveling straight down at a speed of 17 miles per hour. **(e)** My bank account shows a negative balance of −25 dollars.

*Vectors are also sometimes written in other texts as boldface symbols without arrows above them.