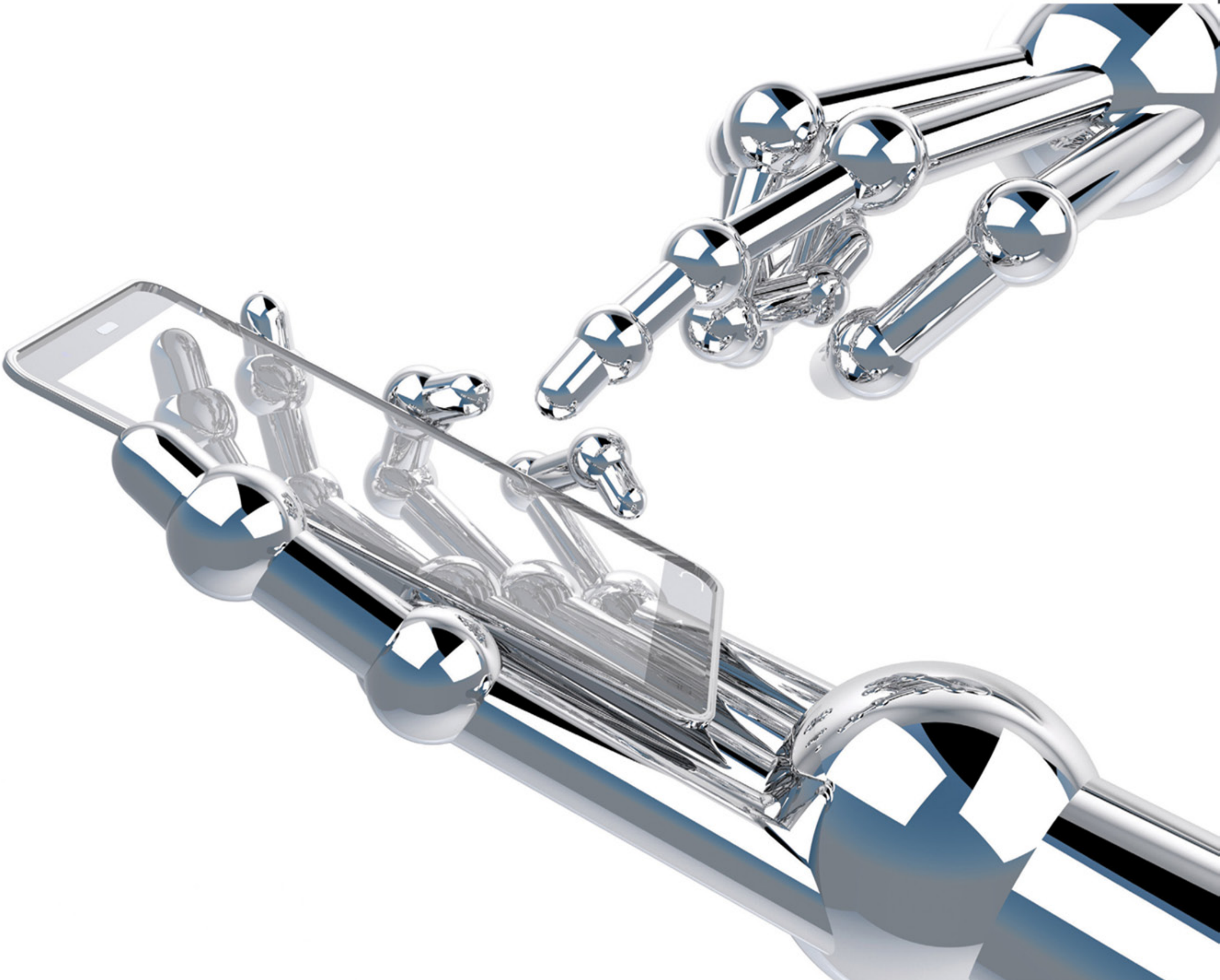
Cutnell & Johnson

physics 10e



David Young | Shane Stadler

WILEY

Fundamental Constants

Quantity	Symbol	Value*
Avogadro's number	N_A	$6.022\ 141\ 79 \times 10^{23}\ \text{mol}^{-1}$
Boltzmann's constant	k	$1.380\ 6504 \times 10^{-23}$ J/K
Electron charge magnitude	e	$1.602\ 176\ 487 \times 10^{-19}$ C
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T · m/A
Permittivity of free space	ϵ_0	$8.854\ 187\ 817 \times 10^{-12}\ \text{C}^2/(\text{N} \cdot \text{m}^2)$
Planck's constant	h	$6.626\ 068\ 96 \times 10^{-34}$ J · s
Mass of electron	m_e	$9.109\ 382\ 15 \times 10^{-31}$ kg
Mass of neutron	m_n	$1.674\ 927\ 211 \times 10^{-27}$ kg
Mass of proton	m_p	$1.672\ 621\ 637 \times 10^{-27}$ kg
Speed of light in vacuum	c	$2.997\ 924\ 58 \times 10^{8}$ m/s
Universal gravitational constant	G	$6.674 \times 10^{-11}\ \text{N} \cdot \text{m}^2/\text{kg}^2$
Universal gas constant	R	8.314 472 J/(mol · K)

*2006 CODATA recommended values.

Useful Physical Data

Acceleration due to earth's gravity	$9.80\ \text{m/s}^2 = 32.2\ \text{ft/s}^2$
Atmospheric pressure at sea level	$1.013 \times 10^5\ \text{Pa} = 14.70\ \text{lb/in.}^2$
Density of air (0 °C, 1 atm pressure)	$1.29\ \text{kg/m}^3$
Speed of sound in air (20 °C)	343 m/s
Water	
Density (4 °C)	$1.000 \times 10^3\ \text{kg/m}^3$
Latent heat of fusion	3.35×10^5 J/kg
Latent heat of vaporization	2.26×10^6 J/kg
Specific heat capacity	4186 J/(kg · C°)
Earth	
Mass	5.98×10^{24} kg
Radius (equatorial)	6.38×10^6 m
Mean distance from sun	1.50×10^{11} m
Moon	
Mass	7.35×10^{22} kg
Radius (mean)	1.74×10^6 m
Mean distance from earth	3.85×10^8 m
Sun	
Mass	1.99×10^{30} kg
Radius (mean)	6.96×10^8 m

Frequently Used Mathematical Symbols

Symbol	Meaning
$=$	is equal to
$\neq$	is not equal to
$\propto$	is proportional to
$>$	is greater than
$<$	is less than
$\approx$	is approximately equal to
$\lvert x \rvert$	absolute value of x (always treated as a positive quantity)
Δ	the difference between two variables (e.g., ΔT is the final temperature minus the initial temperature)
Σ	the sum of two or more variables (e.g., $\sum_{i=1}^{3} x_i = x_1 + x_2 + x_3$)

Conversion Factors

Length
1 in. = 2.54 cm

1 ft = 0.3048 m

1 mi = 5280 ft = 1.609 km

1 m = 3.281 ft

1 km = 0.6214 mi

1 angstrom (Å) = 10^{-10} m

Mass
1 slug = 14.59 kg

1 kg = 1000 grams = 6.852×10^{-2} slug

1 atomic mass unit (u) = 1.6605×10^{-27} kg

(1 kg has a weight of 2.205 lb where the acceleration due to gravity is 32.174 ft/s^2)

Time
1 d = 24 h = 1.44×10^3 min = 8.64×10^4 s

1 yr = 365.24 days = 3.156×10^7 s

Speed
1 mi/h = 1.609 km/h = 1.467 ft/s = 0.4470 m/s

1 km/h = 0.6214 mi/h = 0.2778 m/s = 0.9113 ft/s

Force
1 lb = 4.448 N

1 N = 10^5 dynes = 0.2248 lb

Work and Energy
1 J = 0.7376 ft · lb = 10^7 ergs

1 kcal = 4186 J

1 Btu = 1055 J

1 kWh = 3.600×10^6 J

1 eV = 1.602×10^{-19} J

Power
1 hp = 550 ft · lb/s = 745.7 W

1 W = 0.7376 ft · lb/s

Pressure
1 Pa = 1 N/m^2 = 1.450×10^{-4} lb/in.^{2}

1 lb/in.^{2} = 6.895×10^3 Pa

1 atm = 1.013×10^5 Pa = 1.013 bar = 14.70 lb/in.^{2} = 760 torr

Volume
1 liter = 10^{-3} m^3 = 1000 cm^3 = 0.03531 ft^3

1 ft^3 = 0.02832 m^3 = 7.481 U.S. gallons

1 U.S. gallon = 3.785×10^{-3} m^3 = 0.1337 ft^3

Angle
1 radian = 57.30°

1° = 0.01745 radian

Standard Prefixes Used to Denote Multiples of Ten

Prefix	Symbol	Factor
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}

Basic Mathematical Formulas

Area of a circle = πr^2

Circumference of a circle = $2\pi r$

Surface area of a sphere = $4\pi r^2$

Volume of a sphere = $\frac{4}{3}\pi r^3$

Pythagorean theorem: $h^2 = h_o^2 + h_a^2$

Sine of an angle: $\sin\theta = h_o/h$

Cosine of an angle: $\cos\theta = h_a/h$

Tangent of an angle: $\tan\theta = h_o/h_a$

Law of cosines: $c^2 = a^2 + b^2 - 2ab\cos\gamma$

Law of sines: $a/\sin\alpha = b/\sin\beta = c/\sin\gamma$

Quadratic formula:

If $ax^2 + bx + c = 0$, then, $x = (-b \pm \sqrt{b^2 - 4ac})/(2a)$

Cutnell & Johnson
Physics 10e

David Young
Shane Stadler

Louisiana State University

WILEY

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ABOUT THE NEW AUTHORS

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 almost 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 section sizes, often in excess of 300 students. To engage such a large number of students, he uses *WileyPLUS*, electronic response systems (clickers), tutorial-style recitation sessions, and in-class demonstrations. Professor Young has received multiple awards for outstanding teaching of undergraduates.

When David has free time, he enjoys spending it with his family, playing basketball, and working on his old house.

I would like to thank my wife and best friend Samantha and my children, Sierra, Zach, and Sydney, for their constant love, encouragement, and support. *David Young*

Shane Stadler received his Ph.D. in experimental condensed matter physics from Tulane University in 1998. He went on to accept a National Research Council Postdoctoral Fellowship with the Naval Research Laboratory where he researched artificially structured magnetic materials. He then joined the faculty in the Department of Physics at Southern Illinois University (the home institution of this text's original authors, John Cutnell and Ken Johnson), before joining the faculty of the Department of Physics and Astronomy at Louisiana State University in 2008. His research group studies novel magnetic materials and thin films 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 in fields 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 250, the latter of which sparked his interest to develop methods to address large classes.

In his spare time, Shane writes science fiction novels.

I would like to express my gratitude to my parents, George and Elissa, without whom my career in physics would never have gotten off of the ground. *Shane Stadler*

Dear Students and Instructors,

Believe it or not, we were once students embarking on a year of introductory physics, knowing that it was required for our major, but intimidated by the course content. If we had then what this book offers now, the prospect would seem much less daunting. Below you will find a brief summary of the key resources we think will make a big difference for you in succeeding in this course.

One of the great strengths of this text is the synergistic relationship it develops between problem solving and conceptual understanding. Teaching concepts and problem solving together encourages students to understand both the qualitative and quantitative aspects of what they are learning: the why as well as the how. We have added a new type of problem-solving support called *Chalkboard Videos* which consist of short (2 – 3 min) videos demonstrating step-by-step practical solutions to typical homework problems. The *Concepts and Calculations* section at the end of each chapter in the ninth edition has been moved to the end-of-chapter problems and integrated with the new video solutions, thereby streamlining the text and enhancing their pedagogical impact. We have added new Guided Online (GO) Tutorial problems to each chapter. The GO tutorials use a guided, 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 FBDs 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, providing students with a personal, adaptive learning experience so they can build their proficiency on concepts and use their study time effectively.

Over the last 15 years nothing has had a more significant impact on the way students learn than the World Wide Web. Students essentially have 24/7 access to countless sources of digital multimedia. They complete homework assignments online with their PCs, tablets, and smart phones. Online homework systems are no longer "in the future," but are now the norm. Physics is no exception. Unfortunately, having all of this information readily available comes at a price. Students have fundamentally changed the way in which they approach their homework assignments. Instead of struggling through the entire solution to a problem from scratch, where much of the learning process takes place, they default to online resources where they can pay for access to written solutions to the end-of-chapter problems. Alternatively, many students find solutions by simply searching the questions on Google or Yahoo Answers. As a result, a student's online-homework grade has become a rather poor measure of their knowledge of the course material. What's even worse is the false sense of security the students feel as a result of their inflated homework grades. They feel confident and prepared for exams because they have 95-100% on their homework. Unfortunately, a poor performance on the first exam is often the initial indicator of their level of misunderstanding.

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

- The multi-step problems created in *WileyPLUS* are designed to provide targeted, intelligent feedback when a student misses a question.
- The new free-body diagram vector drawing tools provide students with an easy way to enter answers requiring vector drawing, and also provide enhanced feedback.
- The new *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.

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: youngstadler@gmail.com

Brief Contents

Contents

A list of The Physics of applications can be found on the showcase site: **www.wiley.com/college/sc/cutnell**

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:

- *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
- *Interactive LearningWare* (in *WileyPLUS*)
- *Interactive Solutions* (in *WileyPLUS*)
- *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**.

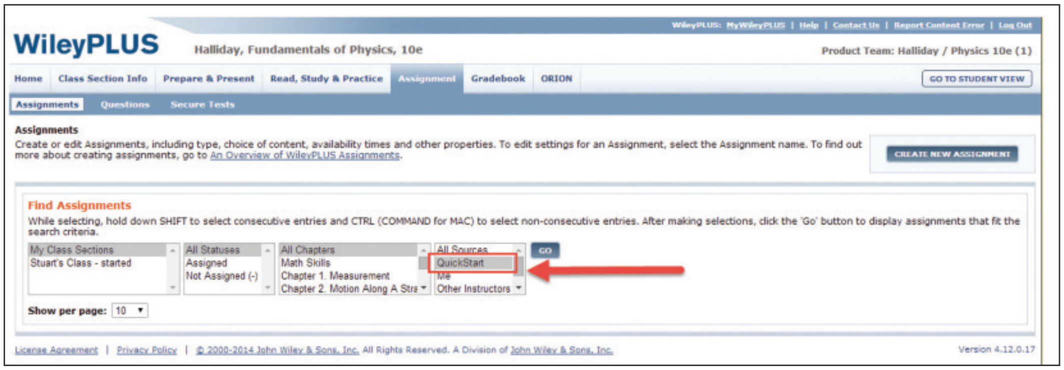
With *WileyPLUS*, our efficacy research shows that students improve their outcomes by as much as one letter grade. *WileyPLUS* helps students take more initiative, so you'll have greater impact on their achievement in the classroom and beyond.

- **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.

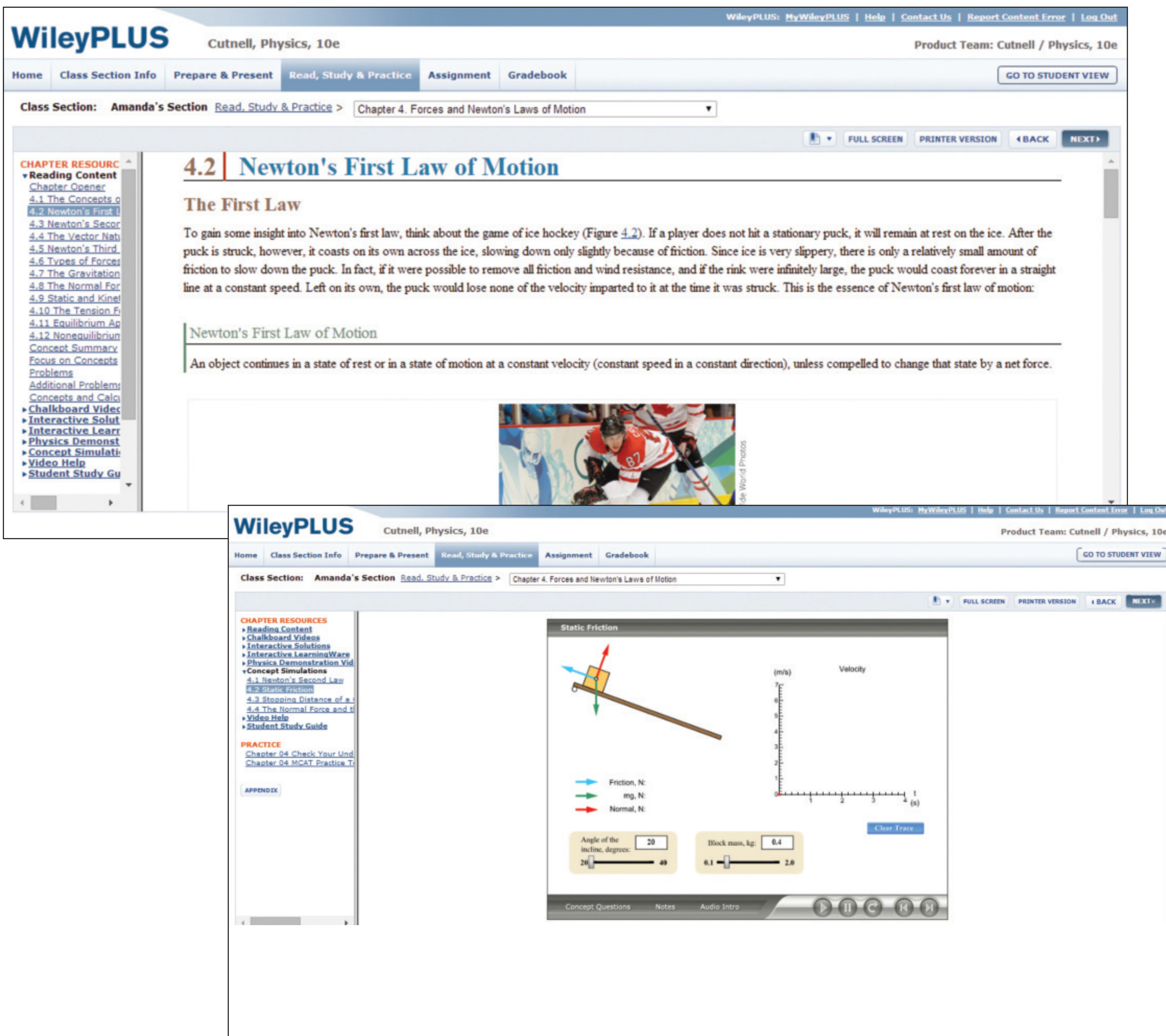
With *WileyPLUS*, instructors receive:

- **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.



With *WileyPLUS*, students receive:

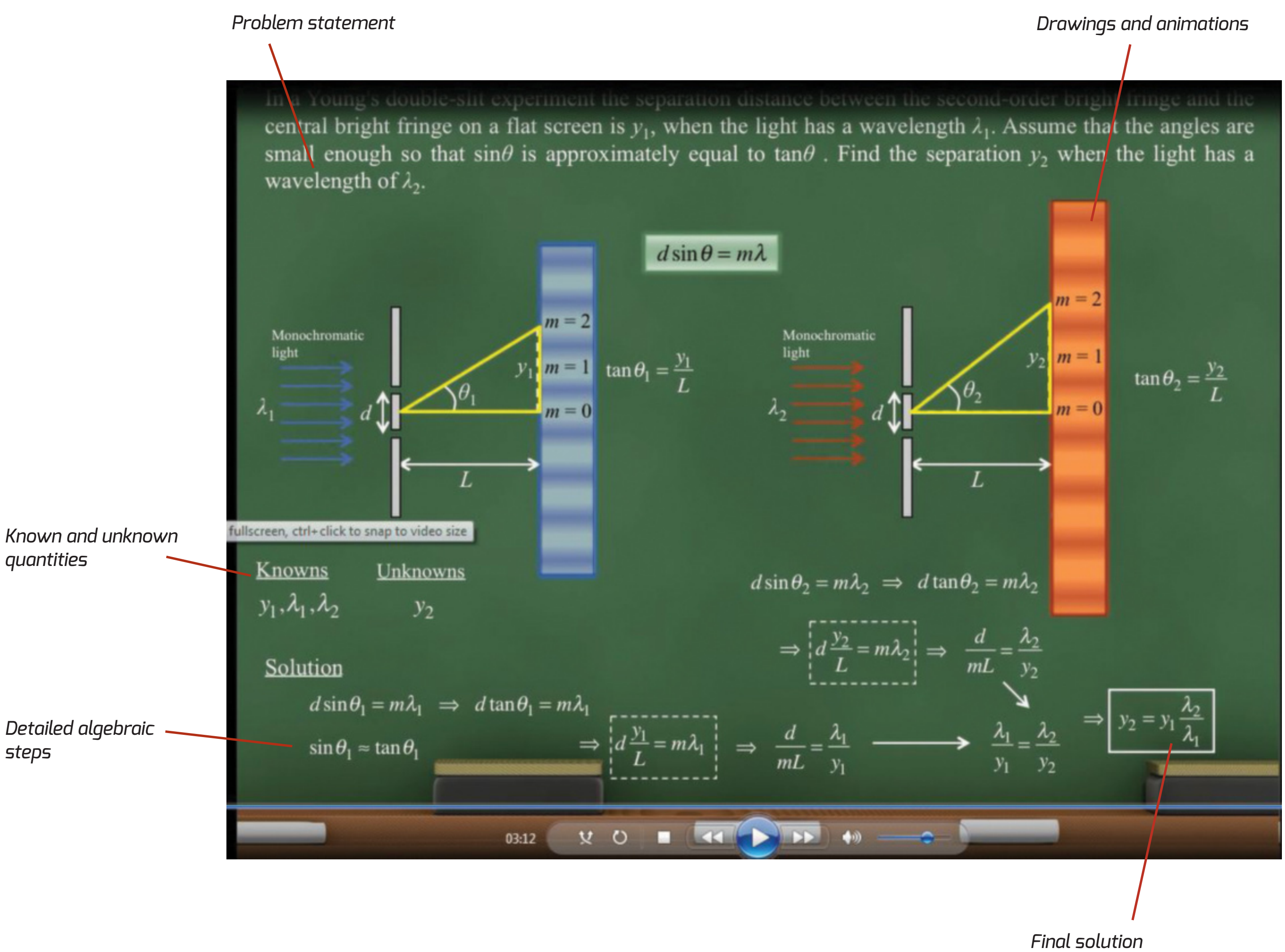
- The complete digital textbook, saving students up to 60% off the cost of a printed text
- Question assistance, including links to relevant sections in the online digital textbook
- Immediate feedback and proof of progress, 24/7
- Integrated, multimedia resources—including animations, simulations, video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



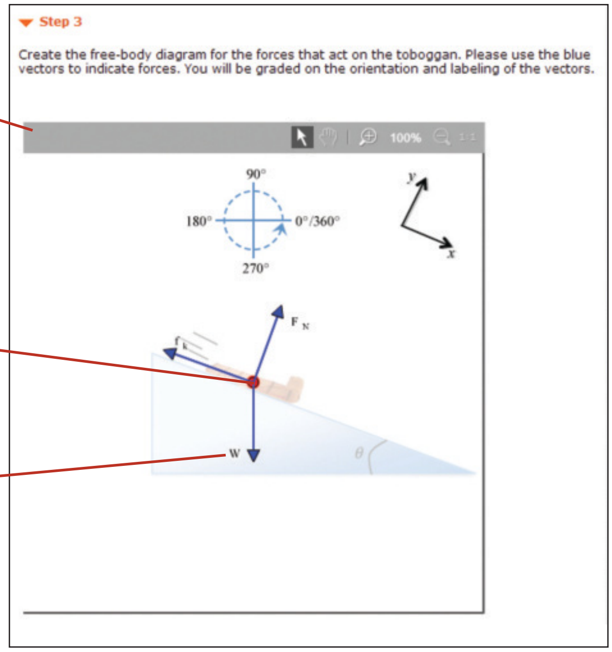
New to WileyPLUS for the Tenth Edition

***NEW** Chalkboard Videos* Solving homework problems can be a daunting experience for students, and to help them with this task the authors have enhanced the *Video Help* feature of the text. The new edition now contains two different kinds of online video help. The original *Video Help* provides a hint to certain end-of-chapter problems through a formal and rigorous approach, which is particularly useful for a student's early development of their problem-solving skills. The new *Chalkboard Videos*, created by authors David Young and Shane Stadler, are shorter (2 – 3 minutes) and guide the student step-by-step through a more practical solution, similar to what a student might see during office hours with his or her professor. There are 160 new *Chalkboard Videos* in the tenth edition, each marked with this icon: . These author-created videos maintain the trademark continuity between text and media resources, making the presentation of material in all resources consistent for students. Each video is:

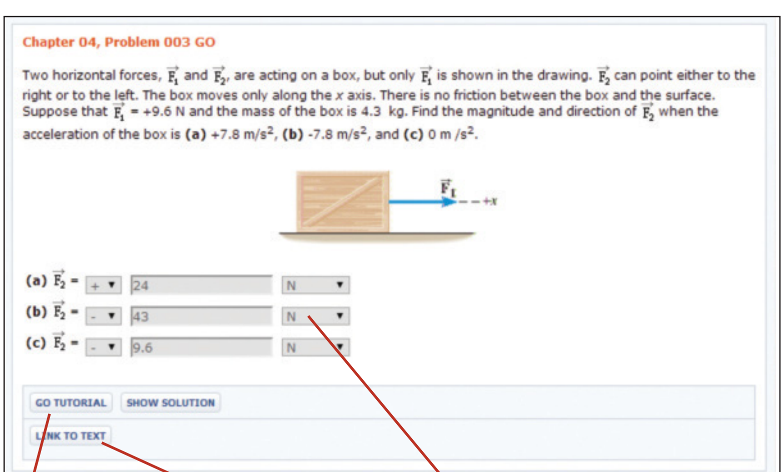
- professionally produced by the authors using PowerPoint (with drawings and/or animations)
- enhanced with a voice overlay that reiterates important concepts and identifies potential pitfalls
- specifically tailored to a given problem
- introduced by identifying the known and unknown quantities in each problem
- solved, showing the algebra step-by-step, with the final solution presented in terms of the unknown variable(s), and, in some cases, with numerical values

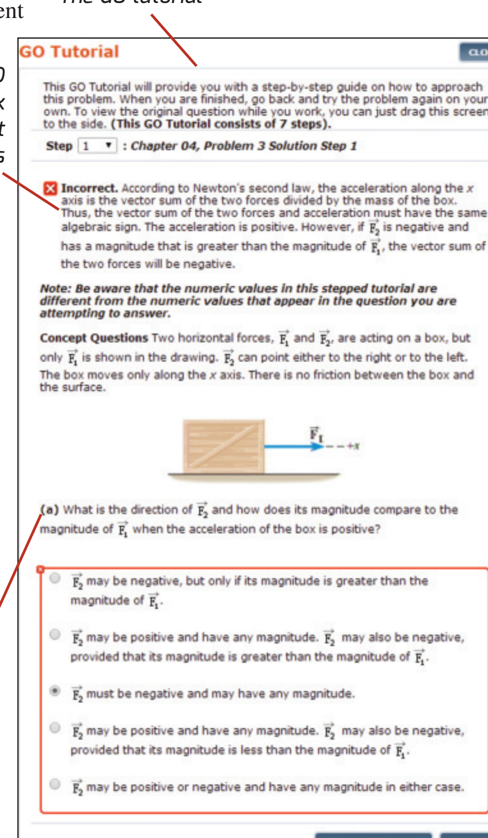


***NEW** Free-Body Diagram (FBD) Tools* For many problems involving multiple forces, an interactive free-body diagram tool in *WileyPLUS* is used to construct the diagram. It is essential for students to practice drawing FBDs, as that is the critical first step in solving many equilibrium and non-equilibrium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

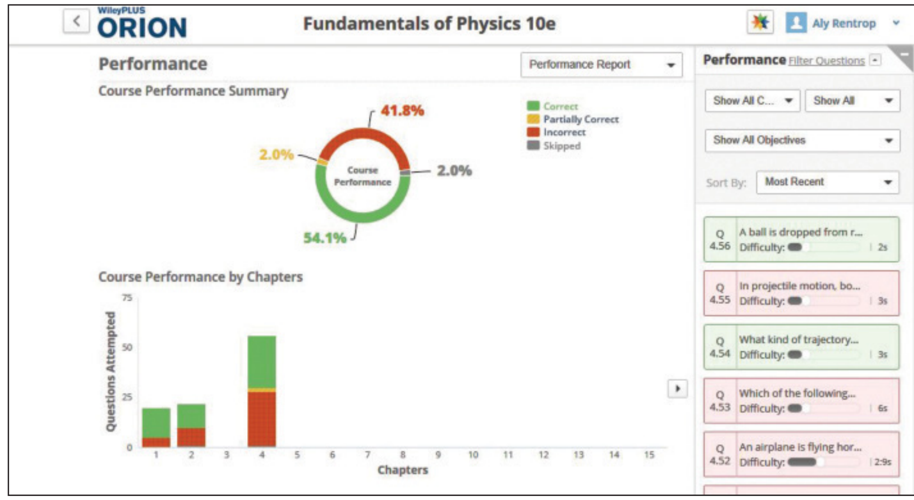


***New and Expanded** GO Tutorial Problems* Some of the homework problems found in the collection at the end of each chapter are marked with a special GO icon. All of these problems are available for assignment via an online homework management program such as *WileyPLUS* or WebAssign. There are now 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.





ORION



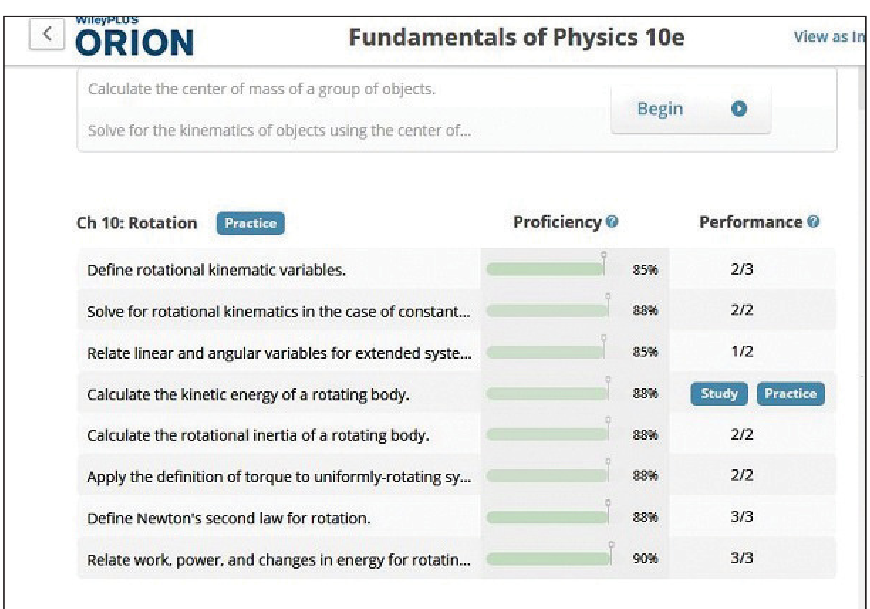
WileyPLUS with ORION provides students with a personal, adaptive learning experience so they can build their proficiency on concepts and use their study time effectively.

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

As new authors, we embarked on this project with little knowledge of the world of textbook writing, and even less of the world of publishing. It has been a fascinating experience to learn what the process involves and, even more so, the number of talented people who are essential in order to complete such an enormous and multifaceted project. As these people are experts, we, as new authors, are not, and we are grateful for the guidance and patience they all have afforded us.

We are especially grateful to Stuart Johnson, our Executive Editor, who was there from the very beginning. His guidance and candidness was much appreciated and was a major factor in our signing onto this project in the first place. We hope that retirement treats him well, and that his hammering arm stays healthy.

The shock of losing an experienced and talented person like Stuart Johnson could only be tempered by finding another talented person to step in, and that person is our new Executive Editor, Jessica Fiorillo. Jessica has done a wonderful job guiding us through the final stages of the project and making some final improvements while bringing in an energy and enthusiasm that are infectious.

We are thankful to our Production Editor, Elizabeth Swain, for her patience and for keeping us on track. We can hardly imagine how much work goes into her job.

We are grateful to those who have tended to the fine details and polished the book to a mirror finish. This includes Copy Editor, Helen Walden, Proofreader, Lilian Brady, Photo Editor, Lisa Gee, and Designer, Madelyn Lesure.

We have had the great pleasure to work with Geraldine Osnato, the Product Designer responsible for extending the textbook into the digital world. As technical textbooks are in the midst of a paradigm shift toward digital content, Geraldine's expertise has been crucial in the development of this book.

One of the many facets of the book is the extensive supplemental package, including solutions manuals. We are grateful to Alyson Rentrop, Associate Editor, for the flawless assembly of these important components.

We are grateful to Amanda Rillo, Editorial Assistant, for her help in facilitating the flow of the manuscript through its various production stages.

We are thankful to Kristine Ruff, Senior Marketing Manager, for developing an effective marketing campaign, and for forcing us out of our shells on many occasions to play our part—we realize and appreciate the coaxing that took.

Thank you to 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 allows you to bring our work to the attention of physics teachers in a way that is widely respected and indispensable to the book's success.

We are particularly indebted to Dayna Leaman, Senior Sales Representative. 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 you. Thank you.

A project of this size would have no chance of succeeding without someone overseeing the big picture. We would like to acknowledge our Publisher, Petra Recter, for her contributions, guidance, support, and organization of this project at all levels.

Finally, we would like to thank the original authors, John Cutnell and Kenneth Johnson. We are privileged to inherit such a fine book—one that reflects thirty years of hard work on your part. Our intent is to preserve the essence of your masterpiece while making improvements that track with the times.

We would also like to acknowledge the contributions made to our *WileyPLUS* course by David Marx (Illinois State University), Richard Holland (Southeastern Illinois College), George Caplan (Wellesley College), and Derrick Hilger (Duquesne University).

Many physicists and their students have generously shared their ideas with us about good pedagogy and helped us 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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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, Higher Education Division, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, or contact us at **www.wiley.com/college/cutnell**

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.

Chapter | 1

1 | 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, 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.

Courtesy NIST Archives

Figure 1.1 The standard platinum–iridium meter bar.

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)

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.

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.

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 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}.

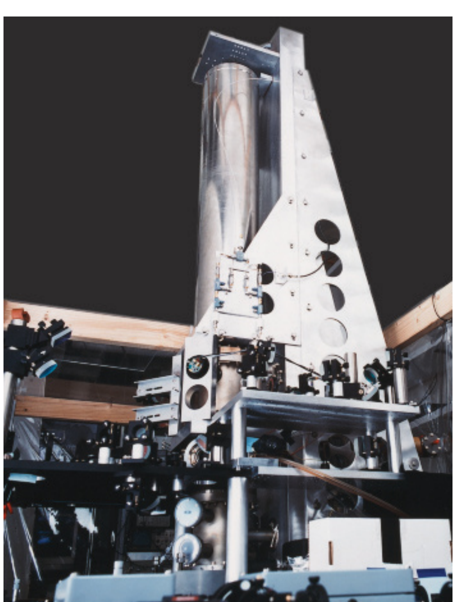

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Figure 1.3 This atomic clock, the NIST-F1, keeps time with an uncertainty of about one second in sixty million years.

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

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.

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:

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

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

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.

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

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

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

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

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

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

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

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

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

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

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?

1.4 | Trigonometry

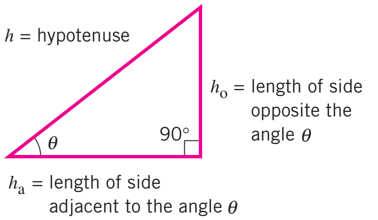

Figure 1.5 A right triangle.

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 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.

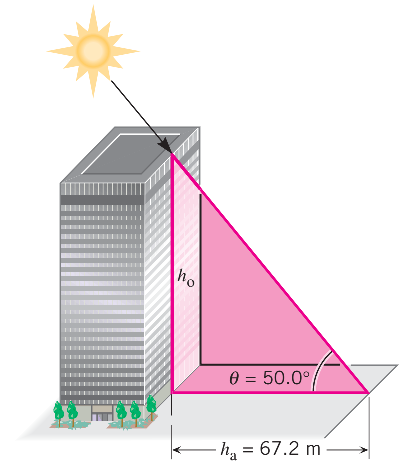

Figure 1.6 From a value for the angle θ and the length h_a of the shadow, the height h_o of the building can be found using trigonometry.

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. 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.***

Problem-Solving Insight

Often the values for two sides of the right triangle in 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?

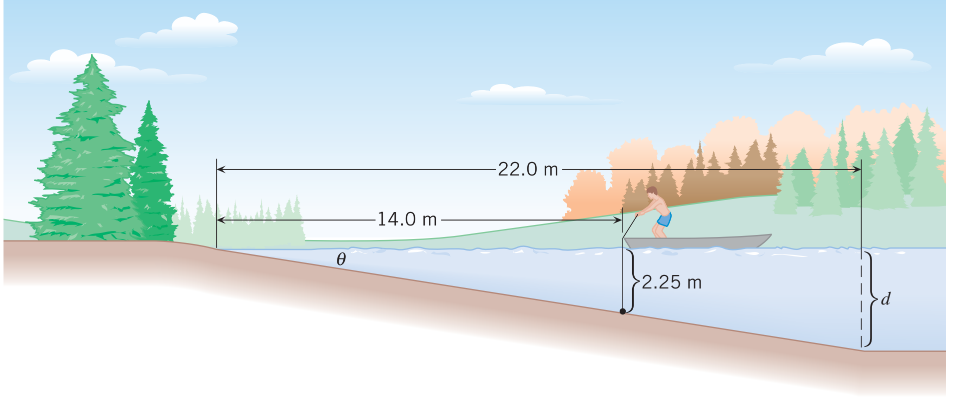

Figure 1.7 If the distance from the shore and the depth of the water at any one point are known, the angle θ can be found with the aid of trigonometry. Knowing the value of θ is useful, because then the depth d at another point can be determined.

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.

The right triangle in 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.***

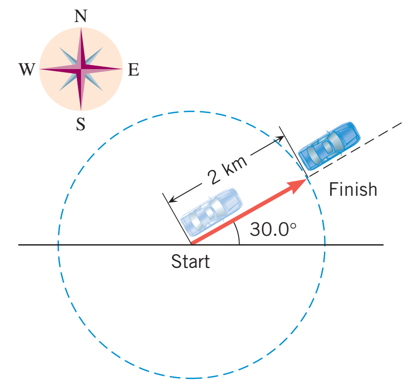

Figure 1.8 A vector quantity has a magnitude and a direction. The colored arrow in this drawing represents a displacement vector.

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.

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.