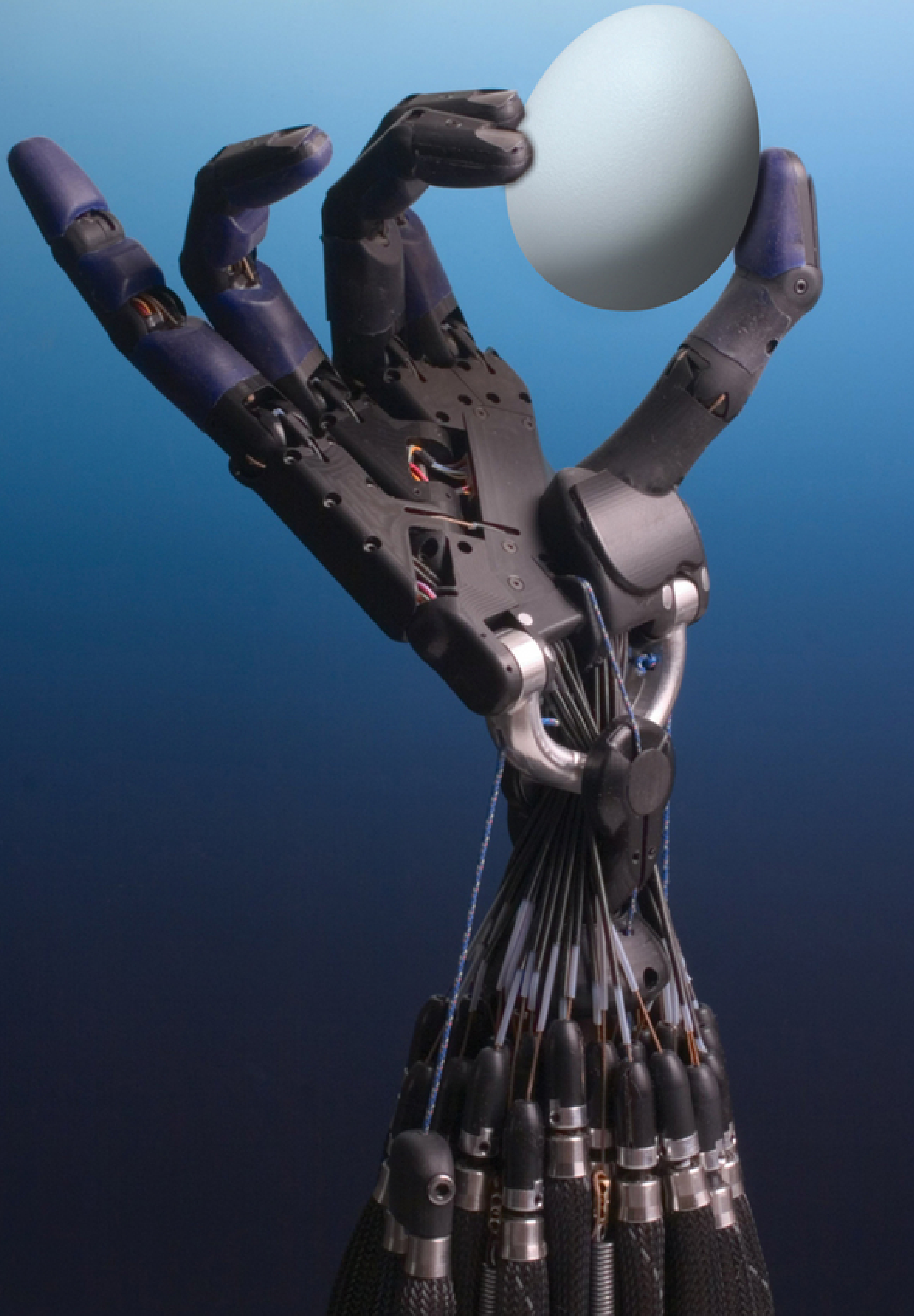

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Physics

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EDITION

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Physics

9 EDITION

John D. Cutnell & Kenneth W. Johnson

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To my wife, Joan Cutnell, a patient friend and my support throughout this project.
To Anne Johnson, my wonderful wife, a caring person, and my best friend.

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The Physics of

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

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Preface

We have written this text for students and teachers who are partners in a one-year course in algebra-based physics. In revising the text, we have focused on two pedagogical issues that underlie all aspects of such a course. One is the synergistic relationship between problem solving and conceptual understanding. The other is the role played by mathematics in physics. We have added new features, refined areas in need of improvement, and simplified the design of the book with a view toward improving clarity. The many insights and suggestions provided by users of the eighth edition, as well as the work of physics-education researchers, have guided us in our efforts.

Goals

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* sections
- *Focus on Concepts* homework material
- *Check Your Understanding* questions
- *Concept Simulations* (an online feature)

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

- *Math Skills*
- Explicit reasoning steps in all examples
- *Reasoning Strategies* for solving certain classes of problems
- *Analyzing Multiple-Concept Problems*
- *Video Help* (an online feature)
- Homework problems with associated Guided Online (GO) Tutorials (an online feature)
- *Interactive LearningWare* (an online feature)
- *Interactive Solutions* (an online feature)

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.

ORGANIZATION AND COVERAGE

The text includes 32 chapters and is organized in a fairly standard fashion according to the following sequence: Mechanics, Thermal Physics, Wave Motion, Electricity and Magnetism, Light and Optics, and Modern Physics. The text is available in a single volume consisting of all 32 chapters. It is also available in two volumes: Volume 1 includes Chapters 1–17 (Mechanics, Thermal Physics, and Wave Motion) and Volume 2 includes Chapters 18–32 (Electricity and Magnetism, Light and Optics, and Modern Physics).

Chapter sections marked with an asterisk (*) can be omitted with little impact on the overall development of the material. For instructors who wish to cover surface tension, we have included a module on the Instructor Companion site accessible through our Web site (**www.wiley.com/college/cutnell**). This module, which includes homework problems, discusses the nature of surface tension, capillary action, and the pressure inside a soap bubble and inside a liquid drop.

The *Concepts at a Glance* flowcharts that appeared in the eighth edition are not in the ninth edition but are available to instructors on the Instructor Companion site accessible through our Web site (**www.wiley.com/college/cutnell**).

FEATURES OF THE NINTH EDITION

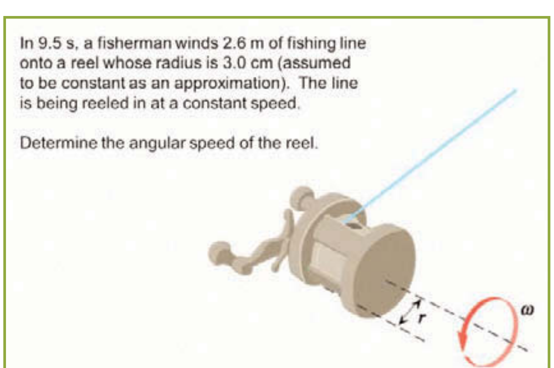
New!

Video Help Solving homework problems can be a daunting experience for students, and to help them we have provided a new feature called *Video Help*. For each of the 270 problems that are marked with the *Video-Help* icon, there is a 3- to 5-minute video. In *WileyPLUS*, instructors can make these videos available for student access with or without a penalty. We have singled out these particular problems since they involve the more challenging task of bringing together two or more physics concepts; *Video Help* is not provided for simpler one-step problems. Each video is:

• professionally produced using PowerPoint (with drawings and/or animations)
• enhanced with a voice overlay
• specifically tailored to a given problem

The video doesn't solve the problem but points the student in the right direction. It does this by using a proven problem-solving technique: (1) visualize the problem, (2) organize the data, and (3) develop a reasoning strategy. Visit **www.wiley.com/college/sc/cutnell** to view some videos.

1. Visualize the Problem



Reading the words that describe a problem is one thing; visualizing the problem is another. Each video has a drawing or an animation that accompanies the words. Most importantly, the drawing or animation often illustrates the pertinent variables (such as the radius r and angular speed ω of the reel here).

Write down each fact and understand it. Give it a brief description, an algebraic symbol, and a numerical value.

2. Organize the Data

Description	Symbol	Value	Comments
Elapsed time	t	9.5 s	
Length of fishing line	x	2.6 m	This line is wrapped around the reel.
Radius of the reel	r	0.030 m	1 m = 100 cm
Unknown Variable			
Angular speed of reel	ω	?	This is constant.

Algebraic symbols are especially important, because the laws of physics are written in terms of them. Therefore, a solution to a problem is written first in terms of algebraic symbols. Then, numerical values for the symbols are substituted into the algebraic solution to reach a numerical answer.

Identify the quantity you're trying to find. Give it a description and an algebraic symbol. You can't answer a question if you don't understand what you're looking for.

The purpose of the reasoning strategy is to facilitate creating a model of the problem in terms of the algebraic symbols identified in the data table.

3. Develop a Reasoning Strategy

Modeling the Problem

STEP 1

The angular speed of the reel is related to the tangential speed v_T of the fishing line by Equation 8.9.

$$v_T = r\omega \qquad (8.9)$$

$$\omega = \frac{v_T}{r} \qquad (1)$$

Since each Video Help problem deals with two or more physics concepts, several steps must be taken in order to reach a solution. Video Help guides the student through the first step of this process (and sometimes the second step if there are three or more steps).

New! ***Math Skills*** The mathematical backgrounds that students bring to the classroom vary enormously, and these backgrounds play a major role in the students' success in physics. To address the issue of limited skills in mathematics, we have added a new feature called *Math Skills*. The feature consists of 58 sidebars that appear throughout the text.

The sidebars are designed to provide additional help with mathematics for students who need it, yet be unobtrusive for students who do not. They appear sometimes in connection with a mathematical step in a calculational example and sometimes in connection with the text discussion of a concept. Where necessary, drawings are included.

Some mathematical issues occur repeatedly during the typical physics course. This is particularly true of trigonometry. For instance, it plays an important role in situations involving vectors but also is used regularly in the determination of lever arms. In such situations, when the related sidebar offers a review of a mathematical technique that has been discussed in a previous sidebar, it is repeated in an altered form that is tailored to the specific issue at hand.

Here is a partial list of the sidebar topics:

- algebra
- geometry
- trigonometry
- vectors and vector components
- simultaneous equations
- coordinate systems and their role in the interpretation of results
- absolute values
- radians versus degrees
- significant figures
- powers of ten
- common logarithms and natural logarithms

An example of Math Skills dealing with trigonometry and vector components

Example 14 Towing a Supertanker

A supertanker of mass $m = 1.50 \times 10^8$ kg is being towed by two tugboats, as in Figure 4.30*a*. The tensions in the towing cables apply the forces $\vec{\mathbf{T}}_1$ and $\vec{\mathbf{T}}_2$ at equal angles of 30.0° with respect to the tanker's axis. In addition, the tanker's engines produce a forward drive force $\vec{\mathbf{D}}$, whose magnitude is $D = 75.0 \times 10^3$ N. Moreover, the water applies an opposing force $\vec{\mathbf{R}}$, whose magnitude is $R = 40.0 \times 10^3$ N. The tanker moves forward with an acceleration that points along the tanker's axis and has a magnitude of 2.00×10^{-3} m/s². Find the magnitudes of the tensions $\vec{\mathbf{T}}_1$ and $\vec{\mathbf{T}}_2$.

Reasoning The unknown forces $\vec{\mathbf{T}}_1$ and $\vec{\mathbf{T}}_2$ contribute to the net force that accelerates the tanker. To determine $\vec{\mathbf{T}}_1$ and $\vec{\mathbf{T}}_2$, therefore, we analyze the net force, which we will do using components. The various force components can be found by referring to the free-body diagram for the tanker in Figure 4.30*b*, where the ship's axis is chosen as the *x* axis. We will then use Newton's second law in its component form, $\Sigma F_x = ma_x$ and $\Sigma F_y = ma_y$, to obtain the magnitudes of $\vec{\mathbf{T}}_1$ and $\vec{\mathbf{T}}_2$.

MATH SKILLS The sine and cosine functions are defined in Equations 1.1 and 1.2 as $\sin\theta = \frac{h_o}{h}$ and $\cos\theta = \frac{h_a}{h}$, where h_o is the length of the side of a right triangle that is opposite the angle θ, h_a is the length of the side adjacent to the angle θ, and h is the length of the hypotenuse (see Figure 4.31*a*). When using the sine and cosine functions to determine the scalar components of a vector, we begin by identifying the angle θ. Figure 4.31*b* indicates that $\theta = 30.0°$ for the vector $\vec{\mathbf{T}}_1$. The components of $\vec{\mathbf{T}}_1$ are T_{1x} and T_{1y}. Comparing the shaded triangles in Figure 4.31, we can see that $h_o = T_{1y}$, $h_a = T_{1x}$, and $h = T_1$. Therefore, we have

$$\cos 30.0° = \frac{h_a}{h} = \frac{T_{1x}}{T_1} \quad \text{or} \quad T_{1x} = T_1 \cos 30.0°$$

$$\sin 30.0° = \frac{h_o}{h} = \frac{T_{1y}}{T_1} \quad \text{or} \quad T_{1y} = T_1 \sin 30.0°$$

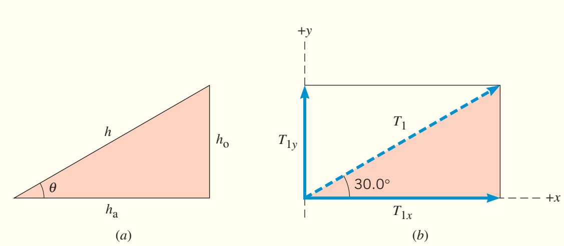


Figure 4.31 Math Skills drawing.

Solution The individual force components are summarized as follows:

Force	*x* Component	*y* Component
$\vec{\mathbf{T}}_1$	$+T_1 \cos 30.0°$	$+T_1 \sin 30.0°$
$\vec{\mathbf{T}}_2$	$+T_2 \cos 30.0°$	$-T_2 \sin 30.0°$
$\vec{\mathbf{D}}$	$+D$	0
$\vec{\mathbf{R}}$	$-R$	0

Since the acceleration points along the *x* axis, there is no *y* component of the acceleration ($a_y = 0$ m/s²). Consequently, the sum of the *y* components of the forces must be zero:

$$\Sigma F_y = +T_1 \sin 30.0° - T_2 \sin 30.0° = 0$$

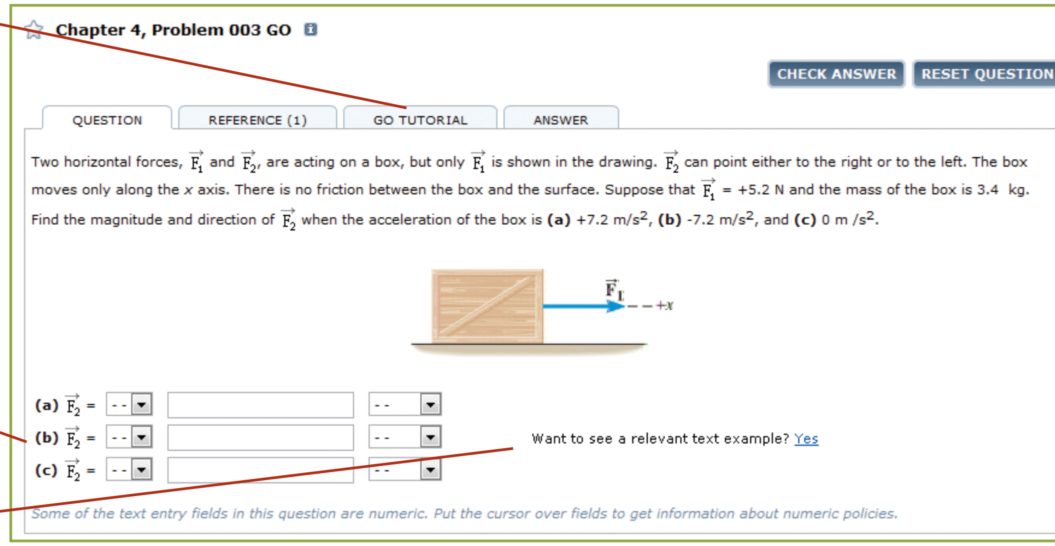
This result shows that the magnitudes of the tensions in the cables are equal, $T_1 = T_2$. Since the ship accelerates

New! ***Expanded GO 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 517 GO problems, an increase of about 45% over the number present in the eighth 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.

Access to the GO tutorial.

Answer input, including direction and units.

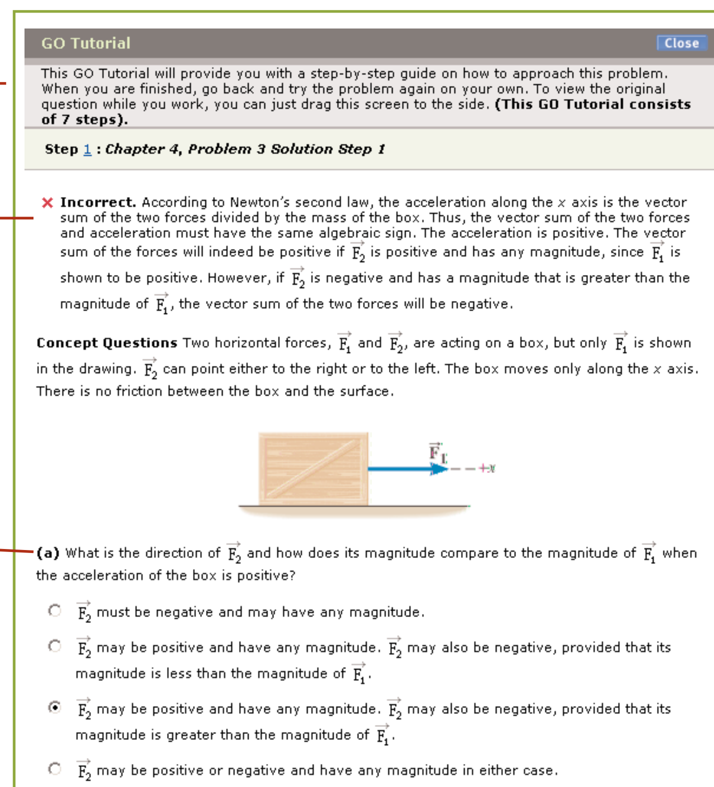
Access to a relevant text example.



The GO tutorial.

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

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



Analyzing Multiple-Concept Problems One of the main goals of physics instruction is to help students develop the ability to solve problems that are more thought-provoking than the typical simple one-step problems. In these more sophisticated or "multiple-concept" problems, students must combine two or more physics concepts before reaching a solution. This is a challenge because they must first identify the physics concepts involved in the simple one-step associate with each concept an appropriate mathematical equation, and finally assemble the equations to produce a unified algebraic solution. In order to reduce a complex problem into a sum of simpler parts, each Multiple-Concept example consists of four sections: Reasoning, Knowns and Unknowns, Modeling the Problem, and Solution:

Analyzing Multiple-Concept Problems

Example 4 The Physics of **an Ion Propulsion Drive**

The space probe *Deep Space 1* was launched October 24, 1998, and it used a type of engine called an ion propulsion drive. An ion propulsion drive generates only a weak force (or thrust), but can do so for long periods of time using only small amounts of fuel. Suppose the probe, which has a mass of 474 kg, is traveling at an initial speed of 275 m/s. No forces act on it except the 5.60×10^{-2}-N thrust of its engine. This external force $\vec{F}$ is directed parallel to the displacement $\vec{s}$, which has a magnitude of 2.42×10^9 m (see Figure 6.6). Determine the final speed of the probe, assuming that its mass remains nearly constant.

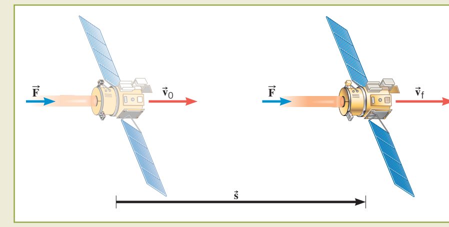


Figure 6.6 An ion propulsion drive generates a single force $\vec{F}$ that points in the same direction as the displacement $\vec{s}$. The force performs positive work, causing the space probe to gain kinetic energy.

This section discusses the strategy that will be used to solve the problem, and it presents an overview of the physics concepts employed in the solution.

Reasoning If we can determine the final kinetic energy of the space probe, we can determine its final speed, since kinetic energy is related to mass and speed according to Equation 6.2 and the mass of the probe is known. We will use the work–energy theorem ($W = \text{KE}_f - \text{KE}_0$), along with the definition of work, to find the final kinetic energy.

Each known variable is given a verbal description, an algebraic symbol, and a numerical value. Assigning algebraic symbols is important because the solution is constructed using these symbols. Both explicit data and implicit data are identified because students often focus only on explicitly stated numerical values and overlook data that are present implicitly in the verbal statement of the problem.

Knowns and Unknowns The following list summarizes the data for this problem:

Description	Symbol	Value	Comment
Explicit Data			
Mass	m	474 kg	
Initial speed	v_0	275 m/s	
Magnitude of force	F	5.60×10^{-2} N	
Magnitude of displacement	s	2.42×10^9 m	
Implicit Data			
Angle between force $\vec{F}$ and displacement $\vec{s}$	θ	0°	The force is parallel to the displacement.
Unknown Variable			
Final speed	v_f	?	

In the left column are the individual steps used in solving the problem. As each step in the left column is presented, the mathematical result of that step is incorporated in the right column into the results from the previous steps, so students can see readily how the individual mathematical equations fit together to produce the desired result.

Modeling the Problem

STEP 1 Kinetic Energy An object of mass m and speed v has a kinetic energy KE given by Equation 6.2 as $\text{KE} = \frac{1}{2}mv^2$. Using the subscript f to denote the final kinetic energy and the final speed of the probe, we have that

$$\text{KE}_f = \tfrac{1}{2}mv_f^2$$

Solving for v_f gives Equation 1 at the right. The mass m is known but the final kinetic energy KE_f is not, so we will turn to Step 2 to evaluate it.

$$v_f = \sqrt{\frac{2(\text{KE}_f)}{m}} \quad (1)$$

?

STEP 2 The Work–Energy Theorem The work–energy theorem relates the final kinetic energy KE_f of the probe to its initial kinetic energy KE_0 and the work W done by the force of the engine. According to Equation 6.3, this theorem is $W = \text{KE}_f - \text{KE}_0$. Solving for KE_f shows that

$$\text{KE}_f = \text{KE}_0 + W$$

The initial kinetic energy can be expressed as $\text{KE}_0 = \frac{1}{2}mv_0^2$, so the expression for the final kinetic energy becomes

$$\boxed{\text{KE}_f = \tfrac{1}{2}mv_0^2 + W}$$

This result can be substituted into Equation 1, as indicated at the right. Note from the data table that we know the mass m and the initial speed v_0. The work W is not known and will be evaluated in Step 3.

$$v_f = \sqrt{\frac{2(\text{KE}_f)}{m}} \quad (1)$$

$$\boxed{\text{KE}_f = \tfrac{1}{2}mv_0^2 + W} \quad (2)$$

?

STEP 3 Work The work W is that done by the net external force acting on the space probe. Since there is only the one force $\vec{F}$ acting on the probe, it is the net force. The work done by this force is given by Equation 6.1 as

$$\boxed{W = (F\cos\theta)s}$$

where F is the magnitude of the force, θ is the angle between the force and the displacement, and s is the magnitude of the displacement. All the variables on the right side of this equation are known, so we can substitute it into Equation 2, as shown in the right column.

$$v_f = \sqrt{\frac{2(\text{KE}_f)}{m}} \quad (1)$$

$$\boxed{\text{KE}_f = \tfrac{1}{2}mv_0^2 + W} \quad (2)$$

$$\boxed{W = (F\cos\theta)s}$$

This part of the example takes the algebraic equations developed in the modeling section and assembles them into an algebraic solution. Then, the data from the Knowns and Unknowns section are inserted to produce a numerical solution.

Solution Algebraically combining the results of the three steps, we have

STEP 1 STEP 2 STEP 3

$$v_f = \sqrt{\frac{2(\text{KE}_f)}{m}} = \sqrt{\frac{2(\frac{1}{2}mv_0^2 + W)}{m}} = \sqrt{\frac{2[\frac{1}{2}mv_0^2 + (F\cos\theta)s]}{m}}$$

The final speed of the space probe is

$$v_f = \sqrt{\frac{2[\frac{1}{2}mv_0^2 + (F\cos\theta)s]}{m}}$$

$$= \sqrt{\frac{2[\frac{1}{2}(474\text{ kg})(275\text{ m/s})^2 + (5.60 \times 10^{-2}\text{ N})(\cos 0°)(2.42 \times 10^9\text{ m})]}{474\text{ kg}}} = \boxed{805\text{ m/s}}$$

At the end of each Multiple-Concept example, one or more related homework problems are identified, which contain concepts similar to those in the example.

Related Homework: *Problem 22* ■

Concepts & Calculations To emphasize the role of conceptual understanding in solving problems, every chapter includes a *Concepts & Calculations* section. These sections are organized around a special type of example, each of which begins with several conceptual questions that are answered before the quantitative problem is worked out. The purpose of the questions is to focus attention on the concepts with which the problem deals. These examples also provide mini-reviews of material studied earlier in the chapter and in previous chapters.

Concepts & Calculations Example 19

The Buoyant Force

A father (weight $W = 830$ N) and his daughter (weight $W = 340$ N) are spending the day at the lake. They are each sitting on a beach ball that is just submerged beneath the water (see Figure 11.41). Ignoring the weight of the air within the balls and the volumes of their legs that are under water, find the radius of each ball.

Concept Questions and Answers Each beach ball is in equilibrium, being stationary and having no acceleration. Thus, the net force acting on each ball is zero. What balances the downward-acting weight in each case?

> *Answer* The downward-acting weight is balanced by the upward-acting buoyant force F_B that the water applies to the ball.

In which case is the buoyant force greater?

> *Answer* The buoyant force acting on the father's beach ball is greater, since it must balance his greater weight.

In the situation described, what determines the magnitude of the buoyant force?

> *Answer* According to Archimedes' principle, the magnitude of the buoyant force equals the weight of the fluid that the ball displaces. Since the ball is completely submerged, it displaces a volume of water that equals the ball's volume. The weight of this volume of water is the magnitude of the buoyant force.

Which beach ball has the larger radius?

> *Answer* The father's ball has the larger volume and the larger radius. This follows because a larger buoyant force acts on that ball. For the buoyant force to be larger, that ball must displace a greater volume of water, according to Archimedes' principle. Therefore, the volume of that ball is larger, since the balls are completely submerged.

Solution Since the balls are in equilibrium, the net force acting on each of them must be zero. Therefore, taking upward to be the positive direction, we have

$$\underbrace{\Sigma F}_{\text{Net force}} = F_B - W = 0$$

Archimedes' principle specifies that the magnitude of the buoyant force is the weight of the water displaced by the ball. Using the definition of density given in Equation 11.1, the mass of the displaced water is $m = \rho V$, where $\rho = 1.00 \times 10^3\ \text{kg/m}^3$ is the density of water (see Table 11.1) and V is the volume displaced. Since all of the ball is submerged, $V = \frac{4}{3}\pi r^3$, assuming that the ball remains spherical. The weight of the displaced water is $mg = \rho(\frac{4}{3}\pi r^3)g$. With this value for the buoyant force, the force equation becomes

$$F_B - W = \rho(\tfrac{4}{3}\pi r^3)g - W = 0$$

Solving for the radius r, we find that

$$\textit{Father}\quad r = \sqrt[3]{\frac{3W}{4\pi\rho g}} = \sqrt[3]{\frac{3(830\ \text{N})}{4\pi(1.00 \times 10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)}} = \boxed{0.27\ \text{m}}$$

$$\textit{Daughter}\quad r = \sqrt[3]{\frac{3W}{4\pi\rho g}} = \sqrt[3]{\frac{3(340\ \text{N})}{4\pi(1.00 \times 10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)}} = \boxed{0.20\ \text{m}}$$

As expected, the radius of the father's beach ball is greater.

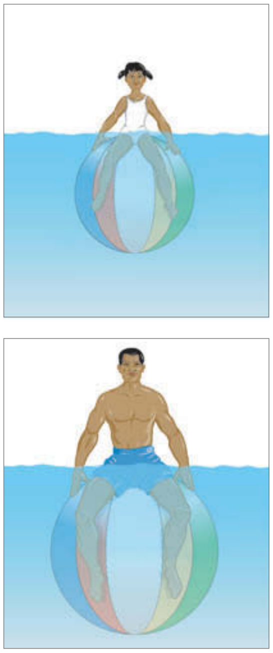


Figure 11.41 The two bathers are sitting on different-sized beach balls that are just submerged beneath the water.

Focus on Concepts This feature is located at the end of every chapter. It consists primarily of multiple-choice questions that deal with important concepts. Some problems are also included that are designed to avoid mathematical complexity in order to probe basic conceptual understanding. All of the questions and problems are available for assignment via an online homework management program such as *WileyPLUS* or WebAssign. Extensive feedback is provided for both right and wrong answers to the multiple-choice questions. In *WileyPLUS*, the ordering of the answers for the multiple-choice questions and the data for the problems are randomized on a student-by-student basis.

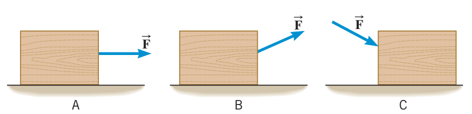
Focus on Concepts

WILEY PLUS

Note to Instructors: The numbering of the questions shown here reflects the fact that they are only a representative subset of the total number that are available online. However, all of the questions are available for assignment via an online homework management program such as WileyPLUS *or WebAssign.*

16. Three identical blocks are being pulled or pushed across a horizontal surface by a force $\vec{\mathbf{F}}$, as shown in the drawings. The force $\vec{\mathbf{F}}$ in each case has the same magnitude. Rank the kinetic frictional forces that act on the blocks in ascending order (smallest first).

(a) B, C, A **(b)** C, A, B **(c)** B, A, C **(d)** C, B, A **(e)** A, C, B



Conceptual Examples Conceptual examples appear in every chapter. They are intended as explicit models of how to use physics principles to analyze a situation before attempting to solve a problem numerically that deals with that situation. The *Focus on Concepts* questions provide the homework counterpart to the conceptual examples. Since the majority of the *Focus on Concepts* questions utilize a multiple-choice format, most of the conceptual examples also appear in that format. A small number, however, deal with important issues in a way that is not compatible with a multiple-choice presentation.

Feedback for correct and incorrect answers.

Most examples are structured so that they lead naturally to homework problems found at the ends of the chapters. These problems contain explicit cross references to the conceptual example.

Conceptual Example 7 Deceleration Versus Negative Acceleration

A car is traveling along a straight road and is decelerating. Which one of the following statements correctly describes the car's acceleration? **(a)** It must be positive. **(b)** It must be negative. **(c)** It could be positive or negative.

Reasoning The term "decelerating" means that the acceleration vector points opposite to the velocity vector and indicates that the car is slowing down. One possibility is that the velocity vector of the car points to the right, in the positive direction, as Figure 2.10*a* shows. The term "decelerating" implies, then, that the acceleration vector of the car points to the left, which is the negative direction. Another possibility is that the car is traveling to the left, as in Figure 2.10*b*. Now, since the velocity vector points to the left, the acceleration vector would point opposite, or to the right, which is the positive direction.

Answers (a) and (b) are incorrect. The term "decelerating" means only that the acceleration vector points opposite to the velocity vector. It is not specified whether the velocity vector of the car points in the positive or negative direction. Therefore, it is not possible to know whether the acceleration is positive or negative.

Answer (c) is correct. As shown in Figure 2.10, the acceleration vector of the car could point in the positive or the negative direction, so that the acceleration could be either positive or negative, depending on the direction in which the car is moving.

Related Homework: *Problems 14, 73*

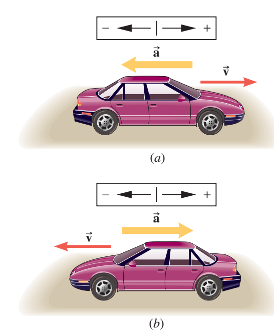


Figure 2.10 When a car decelerates along a straight road, the acceleration vector points opposite to the velocity vector, as Conceptual Example 7 discusses.

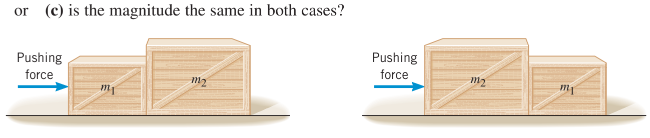
Check Your Understanding

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

23. A circus performer hangs stationary from a rope. She then begins to climb upward by pulling herself up, hand over hand. When she starts climbing, is the tension in the rope **(a)** less than, **(b)** equal to, or **(c)** greater than it is when she hangs stationary?

24. A freight train is accelerating on a level track. Other things being equal, would the tension in the coupling between the engine and the first car change if some of the cargo in the last car were transferred to any one of the other cars?

25. Two boxes have masses m_1 and m_2, and m_2 is greater than m_1. The boxes are being pushed across a frictionless horizontal surface. As the drawing shows, there are two possible arrangements, and the pushing force is the same in each. In which arrangement, **(a)** or **(b)**, does the force that the left box applies to the right box have a greater magnitude, or **(c)** is the magnitude the same in both cases?



Check Your Understanding This feature appears at the ends of selected sections in every chapter and consists of questions in either a multiple-choice or a free-response format. The questions (answers are at the back of the book) are designed to enable students to see if they have understood the concepts discussed in the section. Teachers who use a classroom response system will also find the questions helpful to use as "clicker" questions.

Explicit Reasoning Steps Since reasoning is the cornerstone of problem solving, we have stated the reasoning in all examples. In this step, we explain what motivates our procedure for solving the problem before any algebraic or numerical work is done. In the *Concepts & Calculations* examples, the reasoning is presented in a question-and-answer format.

Example 6 Ice Skaters

Starting from rest, two skaters push off against each other on smooth level ice, where friction is negligible. As Figure 7.9*a* shows, one is a woman ($m_1 = 54$ kg), and one is a man ($m_2 = 88$ kg). Part *b* of the drawing shows that the woman moves away with a velocity of $v_{f1} = +2.5$ m/s. Find the "recoil" velocity v_{f2} of the man.

Reasoning For a system consisting of the two skaters on level ice, the sum of the external forces is zero. This is because the weight of each skater is balanced by a corresponding normal force and friction is negligible. The skaters, then, constitute an isolated system, and the principle of conservation of linear momentum applies. We expect the man to have a smaller recoil speed for the following reason: The internal forces that the man and woman exert on each other during pushoff have equal magnitudes but opposite directions, according to Newton's action–reaction law. The man, having the larger mass, experiences a smaller acceleration according to Newton's second law. Hence, he acquires a smaller recoil speed.

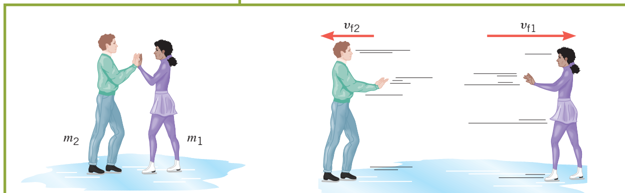
Solution The total momentum of the skaters before they push on each other is zero, since they are at rest. Momentum conservation requires that the total momentum remains zero after the skaters have separated, as in Figure 7.9b:

$$\underbrace{m_1 v_{f1} + m_2 v_{f2}}_{\text{Total momentum after pushing}} = \underbrace{0}_{\text{Total momentum before pushing}}$$

Solving for the recoil velocity of the man gives

$$v_{f2} = \frac{-m_1 v_{f1}}{m_2} = \frac{-(54\text{ kg})(+2.5\text{ m/s})}{88\text{ kg}} = \boxed{-1.5\text{ m/s}}$$

The minus sign indicates that the man moves to the left in the drawing. After the skaters separate, the total momentum of the system remains zero, because momentum is a vector quantity, and the momenta of the man and the woman have equal magnitudes but opposite directions.



(*a*) Before pushoff

(*b*) After pushoff

Figure 7.9 (*a*) In the absence of friction, two skaters pushing on each other constitute an isolated system. (*b*) As the skaters move away, the total linear momentum of the system remains zero, which is what it was initially.

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

Reasoning Strategy Applying the Principle of Conservation of Linear Momentum

1. Decide which objects are included in the system.
2. Relative to the system that you have chosen, identify the internal forces and the external forces.
3. Verify that the system is isolated. In other words, verify that the sum of the external forces applied to the system is zero. Only if this sum is zero can the conservation principle be applied. If the sum of the average external forces is not zero, consider a different system for analysis.
4. Set the total final momentum of the isolated system equal to the total initial momentum. Remember that linear momentum is a vector. If necessary, apply the conservation principle separately to the various vector components.

The Physics of The text contains 262 real-world applications 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, and those that deal with biological or medical material are further marked with an icon in the shape of a caduceus. A list of the applications can be found after the Table of Contents.

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

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

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

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

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

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

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

Problem-Solving Insights To reinforce the problem-solving techniques illustrated in the worked-out examples, we have included short statements in the margins or in the text, identified by the label *Problem-Solving Insight*. These statements help students to develop good problem-solving skills by providing the kind of advice that an instructor might give when explaining a calculation in detail.

Example 7 The Physics of **a Hydraulic Car Lift**

In the hydraulic car lift shown in Figure 11.14*b*, the input piston on the left has a radius of $r_1 = 0.0120$ m and a negligible weight. The output plunger on the right has a radius of $r_2 = 0.150$ m. The combined weight of the car and the plunger is 20 500 N. Since the output force has a magnitude of $F_2 = 20\,500$ N, it supports the car. Suppose that the bottom surfaces of the piston and plunger are at the same level, so that $h = 0$ m in Figure 11.14*b*. What is the magnitude F_1 of the input force needed so that $F_2 = 20\,500$ N?

Reasoning When the bottom surfaces of the piston and plunger are at the same level, as in Figure 11.14*a*, Equation 11.5 applies, and we can use it to determine F_1.

■ **Problem-Solving Insight.** Note that the relation $F_1 = F_2(A_1/A_2)$, which results from Pascal's principle, applies only when the points 1 and 2 lie at the same depth ($h = 0$ m) in the fluid.

Solution According to Equation 11.5, we have

$$F_2 = F_1\left(\frac{A_2}{A_1}\right) \quad \text{or} \quad F_1 = F_2\left(\frac{A_1}{A_2}\right)$$

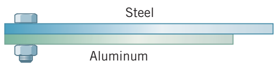
Using $A = \pi r^2$ for the circular areas of the piston and plunger, we find that

$$F_1 = F_2\left(\frac{A_1}{A_2}\right) = F_2\left(\frac{\pi r_1^2}{\pi r_2^2}\right) = (20\,500\text{ N})\frac{(0.0120\text{ m})^2}{(0.150\text{ m})^2} = \boxed{131\text{ N}}$$

Homework Material The homework material consisits of the *Focus on Concepts* questions and the *Problems* found at the end of each chapter. Approximately 250 new problems have been added to this edition. The problems are ranked according to difficulty, with the most difficult marked with a double asterisk (**) and those of intermediate difficulty marked with a single asterisk (*). The easiest problems are unmarked.

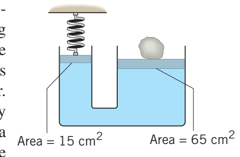
Most of the homework material is available for assignment via an online homework management program such as* WileyPLUS *or* WebAssign*. In* WileyPLUS*, the problems marked with the Video-Help icon are accompanied by a 3- to 5-minute video that provides enhanced interactivity.

* **22.** As the drawing shows, two thin strips of metal are bolted together at one end; both have the same temperature. One is steel, and the other is aluminum. The steel strip is 0.10% longer than the aluminum strip. By how much should the temperature of the strips be increased, so that the strips have the same length?



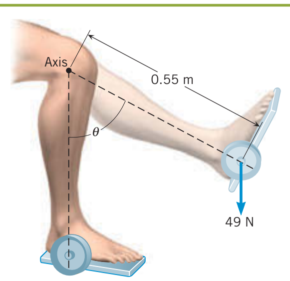
In* WileyPLUS*, the problems marked with the icon are presented in a guided tutorial format that provides enhanced interactivity. The number of such problems in this edition has been increased by about 45%.

* **38.** The drawing shows a hydraulic chamber with a spring (spring constant = 1600 N/m) attached to the input piston and a rock of mass 40.0 kg resting on the output plunger. The piston and plunger are nearly at the same height, and each has a negligible mass. By how much is the spring compressed from its unstrained position?



In all of the homework material, we have used a variety of real-world situations with realistic data. Those problems marked with a caduceus deal with biological or medical situations, and a special effort has been made to increase the amount of this type of homework material.

69. The drawing shows a lower leg being exercised. It has a 49-N weight attached to the foot and is extended at an angle θ with respect to the vertical. Consider a rotational axis at the knee. **(a)** When $\theta = 90.0°$, find the magnitude of the torque that the weight creates. **(b)** At what angle θ does the magnitude of the torque equal 15 N·m?



***Instructors often want to assign homework without identifying a particular section from the text. Such a group of problems is provided under the heading* Additional Problems.**

Additional Problems

85. An aluminum baseball bat has a length of 0.86 m at a temperature of 17 °C. When the temperature of the bat is raised, the bat lengthens by 0.000 16 m. Determine the final temperature of the bat.

86. A person eats a container of strawberry yogurt. The Nutritional Facts label states that it contains 240 Calories (1 Calorie = 4186 J). What mass of perspiration would one have to lose to get rid of this energy? At body temperature, the latent heat of vaporization of water is 2.42×10^6 J/kg.

***Problems whose solutions appear in the Student Solutions Manual are identified with the label* ssm.**

* **9. ssm** In 0.750 s, a 7.00-kg block is pulled through a distance of 4.00 m on a frictionless horizontal surface, starting from rest. The block has a constant acceleration and is pulled by means of a horizontal spring that is attached to the block. The spring constant of the spring is 415 N/m. By how much does the spring stretch?

***Problems for which multimedia help is available online at the Student and Instructor Companion sites accessible through www.wiley.com/college/cutnell are identified with the label* mmh.**

59. mmh The carbon monoxide molecule (CO) consists of a carbon atom and an oxygen atom separated by a distance of 1.13×10^{-10} m. The mass m_C of the carbon atom is 0.750 times the mass m_O of the oxygen atom, or $m_C = 0.750\, m_O$. Determine the location of the center of mass of this molecule relative to the carbon atom.

Multimedia Help A variety of multimedia help is available to students online at **www.wiley.com/college/cutnell** for those homework problems marked with the label **mmh**. The following list summarizes the various kinds of help that this label indicates.

- **Interactive Learningware**. This type of help consists of interactive calculational examples. Each example is presented in a five-step format designed to improve students' problem-solving skills. The format is similar to that used in the text for the examples in the *Analyzing Multiple-Concept Problems* feature.
- **Interactive Solutions.** These solutions to online problems are allied with particular homework problems in the text. Each solution is worked out by the student in an interactive manner and is designed to serve as a model for the associated homework problem.
- **Concept Simulations.** In these simulations, various parameters are under user control. Therefore, students can use the simulations to experiment with and learn more about concepts such as relative velocity, collisions, and ray tracing. Many of the simulations are directly related to homework material.

Concept Summaries Chapter-ending summaries present an abridged but complete version of the material organized section by section and include important equations. The summaries have been redesigned in a more open format.

Concept Summary

9.1 The Action of Forces and Torques on Rigid Objects The line of action of a force is an extended line that is drawn colinear with the force. The lever arm ℓ is the distance between the line of action and the axis of rotation, measured on a line that is perpendicular to both.

The torque of a force has a magnitude that is given by the magnitude F of the force times the lever arm ℓ. The magnitude of the torque τ is given by Equation 9.1, and τ is positive when the force tends to produce a counterclockwise rotation about the axis, and negative when the force tends to produce a clockwise rotation.

$$\text{Magnitude of torque} = F\ell \quad (9.1)$$

9.2 Rigid Objects in Equilibrium A rigid body is in equilibrium if it has zero translational acceleration and zero angular acceleration. In equilibrium, the net external force and the net external torque acting on the body are zero, according to Equations 4.9a, 4.9b, and 9.2.

$$\Sigma F_x = 0 \quad \text{and} \quad \Sigma F_y = 0 \quad (4.9a \text{ and } 4.9b)$$

$$\Sigma\tau = 0 \quad (9.2)$$

9.3 Center of Gravity The center of gravity of a rigid object is the point where its entire weight can be considered to act when calculating the torque due to the weight. For a symmetrical body with uniformly distributed weight, the center of gravity is at the geometrical center of the body. When a number of objects whose weights are $W_1, W_2, \ldots$ are distributed along the x axis at locations $x_1, x_2, \ldots$, the center of gravity x_{cg} is given by Equation 9.3. The center of gravity is identical to the center of mass, provided the acceleration due to gravity does not vary over the physical extent of the objects.

$$x_{cg} = \frac{W_1x_1 + W_2x_2 + \cdots}{W_1 + W_2 + \cdots} \quad (9.3)$$

9.4 Newton's Second Law for Rotational Motion About a Fixed Axis The moment of inertia I of a body composed of N particles is given by Equation 9.6, where m is the mass of a particle and r is the perpendicular distance of the particle from the axis of rotation.

For a rigid body rotating about a fixed axis, Newton's second law for rotational motion is stated as in Equation 9.7, where $\Sigma\tau$ is the net external torque applied to the body, I is the moment of inertia of the body, and α is its angular acceleration.

$$I = m_1r_1^2 + m_2r_2^2 + \cdots + m_Nr_N^2 = \Sigma mr^2 \quad (9.6)$$

$$\Sigma\tau = I\alpha \quad (\alpha \text{ in rad/s}^2) \quad (9.7)$$

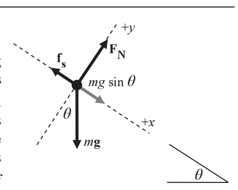
9.5 Rotational Work and Energy The rotational work W_R done by a constant torque τ in turning a rigid body through an angle θ is specified by Equation 9.8.

The rotational kinetic energy KE_R of a rigid object rotating with an angular speed ω about a fixed

$$W_R = \tau\theta \quad (\theta \text{ in radians}) \quad (9.8)$$

Chapter 4 Problems 1

57. SSM ***REASONING*** The worker is standing still. Therefore, he is in equilibrium, and the net force acting on him is zero. The static frictional force $\mathbf{f}_s$ that prevents him from slipping points upward along the roof, an angle of θ degrees above the horizontal; we choose this as the $-x$ direction (see the free-body diagram). The normal force $\mathbf{F}_N$ is perpendicular to the roof and thus has no x component. But the gravitational force $m\mathbf{g}$ of the earth on the worker points straight down, and thus has a component parallel to the roof. We will use this free-body diagram and find the worker's mass m by applying Newton's second law with the acceleration equal to zero.



Free-body diagram of the worker

SOLUTION The static frictional force $\mathbf{f}_s$ points in the $-x$ direction, and the x component of the worker's weight $m\mathbf{g}$ points in the $+x$ direction. Because there are no other forces with x components, and the worker's acceleration is zero, these two forces must balance each other. The x component of the worker's weight is $mg \sin\theta$, therefore $f_s = mg \sin\theta$. Solving this relation for the worker's mass, we obtain

$$m = \frac{f_s}{g\sin\theta} = \frac{390\ \text{N}}{(9.80\ \text{m/s}^2)(\sin 36^\circ)} = \boxed{68\ \text{kg}}$$

Solutions The solutions to all of the end-of-chapter problems are available to instructors, and approximately one-half of the solutions to the odd-numbered problems are available to students. In general, the solutions are divided into two parts: *Reasoning* and *Solution*. The *Reasoning* section, like that in the text examples, presents an overview of the physics principles used in solving the problem. The *Solution* section takes the physics principles outlined in the *Reasoning* section and assembles them in a step-by-step manner into an algebraic solution for the problem. The data are then inserted to produce a numerical answer. Where appropriate, drawings—such as free-body diagrams—are included to aid the student in visualizing the situation. Proper procedures for significant figures are adhered to throughout all solutions.

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**

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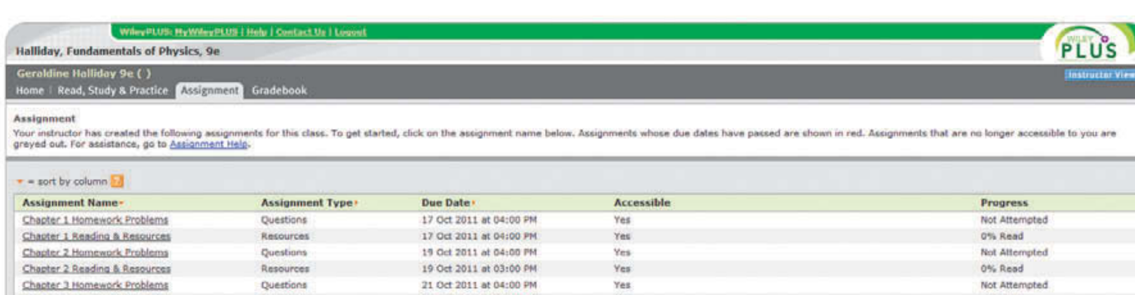

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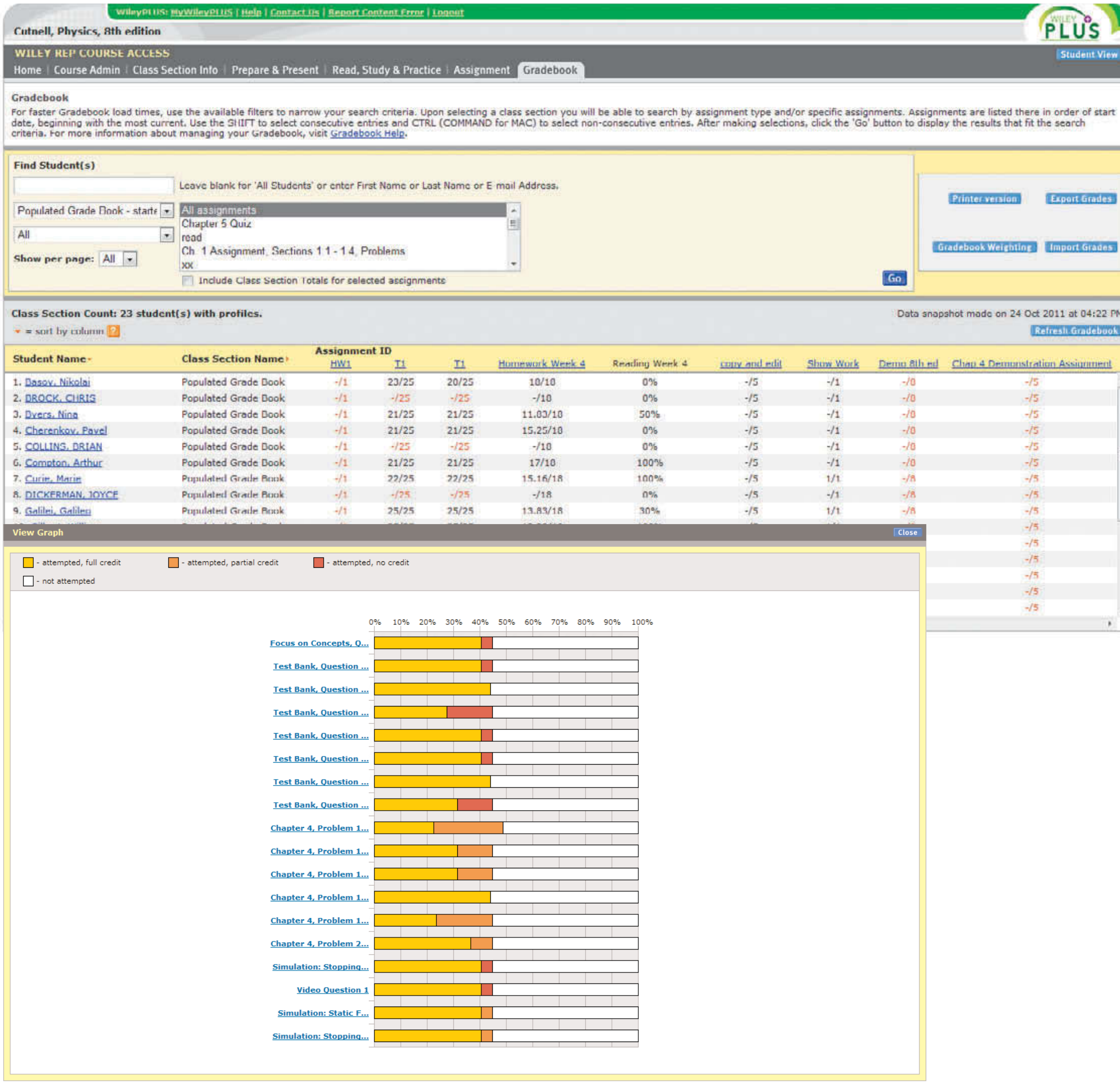

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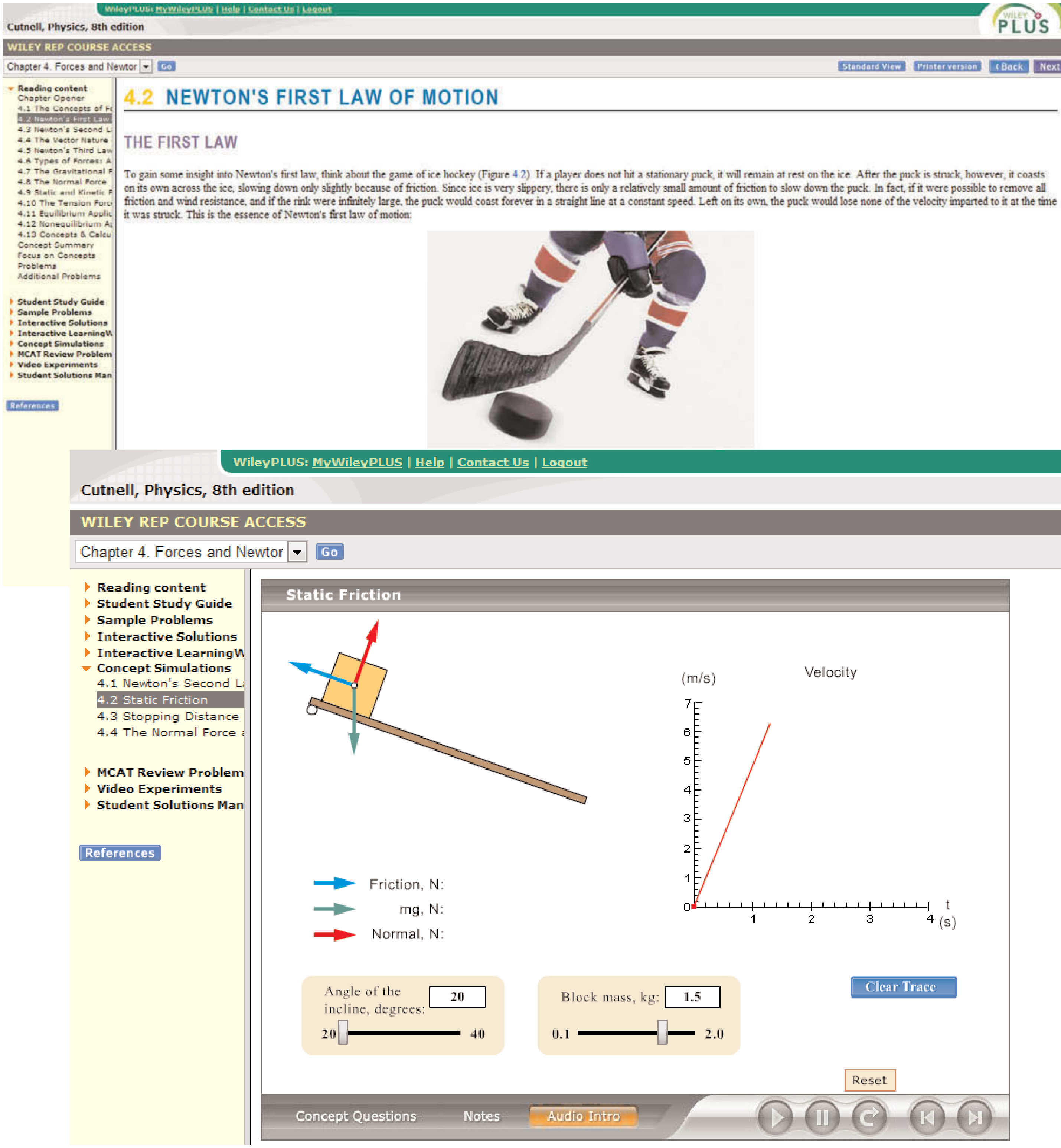

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- Concept Simulations (indicated in the text with an **mmh** icon)
- Interactive LearningWare examples (indicated in the text with an **mmh** icon)
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In baseball, only a team with a good catcher makes the play-offs. We are indeed fortunate to have an all-star catcher, our proofreader, Georgia Mederer. She handled all of our bad pitches—inconsistencies in language and style, grammatical mistakes, ill-chosen mathematical symbols, and a handful of eye-popping typographical math errors.

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CHAPTER 1

The animation techniques and special effects used in the film *Avatar* rely on computers and mathematical concepts such as trigonometry and vectors. Such mathematical concepts will also be useful throughout this book in our discussion of physics. (© 20th Century Fox Licensing/Merch/Everett Collection, Inc.)

Introduction and Mathematical Concepts

1.1 The Nature of Physics

The science of physics has developed out of the efforts of men and women to explain our physical environment. These efforts have been so successful that the laws of physics now encompass a remarkable variety of phenomena, including planetary orbits, radio and TV waves, magnetism, and lasers, to name just a few.

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.

Figure 1.1 The standard platinum–iridium meter bar. (Courtesy Bureau International des Poids et Mesures, France)

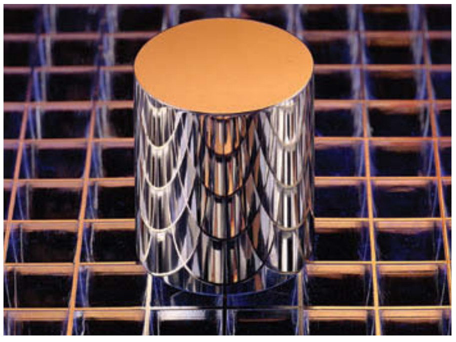

Figure 1.2 The standard platinum–iridium kilogram is kept at the International Bureau of Weights and Measures in Sèvres, France. This copy of it was assigned to the United States in 1889 and is housed at the National Institute of Standards and Technology. (Copyright Robert Rathe, National Institute of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

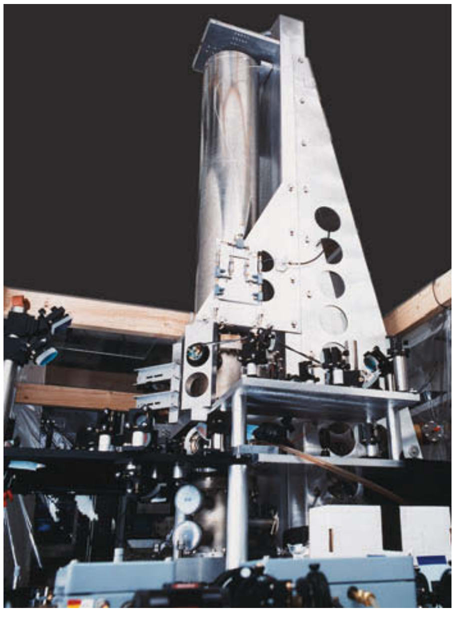

Figure 1.3 This atomic clock, the NIST-F1, keeps time with an uncertainty of about one second in sixty million years. (© Geoffrey Wheeler)

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.

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}.

*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.

Figure 1.4 Angel Falls in Venezuela is the highest waterfall in the world. (© Andoni Canela/age fotostock)

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:

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

Table 1.2 Standard Prefixes Used to Denote Multiples of Ten

Prefix	Symbol	Factor[a]
tera	T	10^{12}
giga[b]	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.
[b]Pronounced jig′a.

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

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

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

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

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?

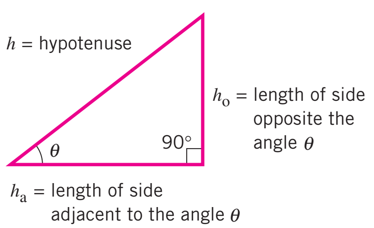

Figure 1.5 A right triangle.

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 Figure 1.5.

Definition of Sin θ, Cos θ, and Tan θ

$$\sin\theta = \frac{h_o}{h} \tag{1.1}$$

$$\cos\theta = \frac{h_a}{h} \tag{1.2}$$

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

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.

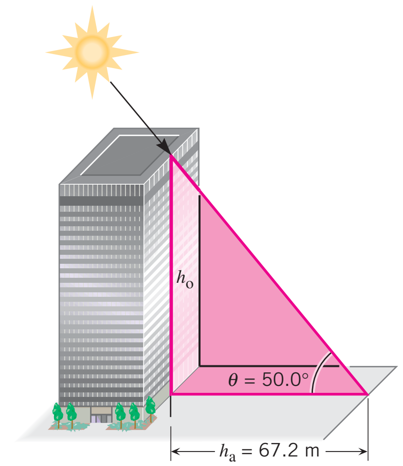

Figure 1.6 From a value for the angle θ and the length h_a of the shadow, the height h_o of the building can be found using trigonometry.

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.

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?

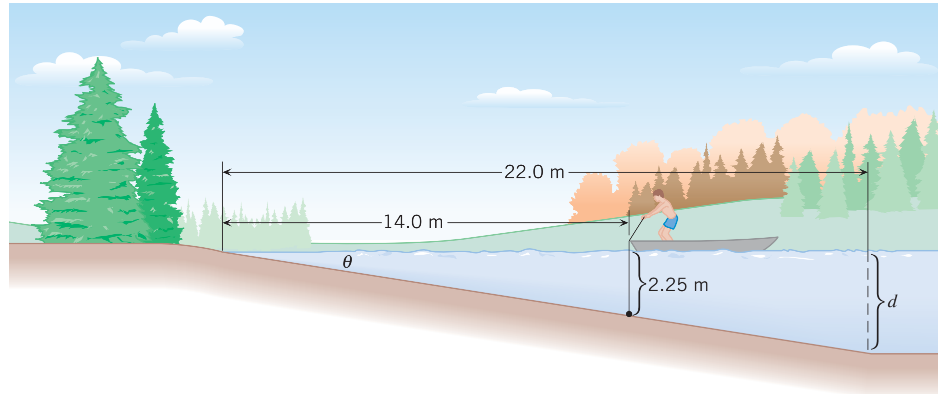

Figure 1.7 If the distance from the shore and the depth of the water at any one point are known, the angle θ can be found with the aid of trigonometry. Knowing the value of θ is useful, because then the depth d at another point can be determined.

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

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

(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

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

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.

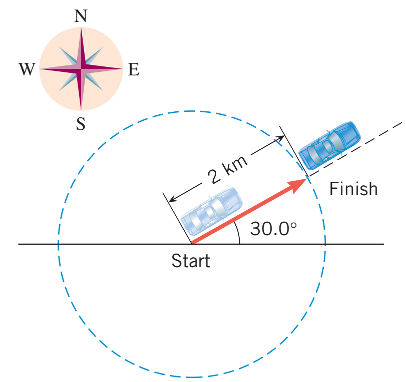

Figure 1.8 A vector quantity has a magnitude and a direction. The colored arrow in this drawing represents a displacement vector.

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.

The velocity of this cyclist is an example of a vector quantity, because it has a magnitude (his speed) and a direction. The cyclist is seven-time Tour-de-France winner Lance Armstrong. (© Steven E. Sutton/Duomo/Corbis)

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.

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