

COLLEGE

PHYSICS

EIGHTH EDITION

RAYMOND A. SERWAY

Emeritus, James Madison University

CHRIS VUILLE

Embry-Riddle Aeronautical University

JERRY S. FAUGHN

Emeritus, Eastern Kentucky University

Australia · Brazil · Canada · Mexico · Singapore · Spain · United Kingdom · United States

College Physics, Eighth Edition

Serway/Vuille

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Illustrator: Lachina Publishing Services, Precision Graphics

Cover Designer: Dare Porter/Real Time Design

Cover Image: © Matt Hoover, www. matthoover.com

Compositor: Lachina Publishing Services

Printed in Canada

1 2 3 4 5 6 7 12 11 10 09 08

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Library of Congress Control Number: 2007937232

ISBN-13: 978-0-495-38693-3

ISBN-10: 0-495-38693-6

**Brooks/Cole**

10 Davis Drive

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We dedicate this book

to our colleague Jerry S. Faughn, whose dedication to all aspects of the project and tireless efforts through the years are deeply appreciated.

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ABOUT THE AUTHORS

Raymond A. Serway received his doctorate at Illinois Institute of Technology and 

is Professor Emeritus at James Madison University. In 1990 he received the Madi

son Scholar Award at James Madison University, where he taught for 17 years. Dr.

Serway began his teaching career at Clarkson University, where he conducted

research and taught from 1967 to 1980. He was the recipient of the Distinguished

Teaching Award at Clarkson University in 1977 and of the Alumni Achievement

Award from Utica College in 1985. As Guest Scientist at the IBM Research Labo

ratory in Zurich, Switzerland, he worked with K. Alex Müller, 1987 Nobel Prize

recipient. Dr. Serway also was a visiting scientist at Argonne National Laboratory,

where he collaborated with his mentor and friend, Sam Marshall. In addition to

earlier editions of this textbook, Dr. Serway is the coauthor of *Principles of Physics*,

fourth edition; *Physics for Scientists and Engineers*, seventh edition; *Essentials of College*

*Physics*; and *Modern Physics*, third edition. He also is the coauthor of the high school

textbook *Physics*, published by Holt, Rinehart and Winston. In addition, Dr. Serway

has published more than 40 research papers in the fi eld of condensed matter phys

ics and has given more than 70 presentations at professional meetings. Dr. Serway

and his wife, Elizabeth, enjoy traveling, golf, gardening, singing in a church choir,

and spending time with their four children and eight grandchildren.

Chris Vuille is an associate professor of physics at Embry-Riddle Aeronautical Uni 

versity (ERAU), Daytona Beach, Florida, the world’s premier institution for avia

tion higher education. He received his doctorate in physics from the University of

Florida in 1989 and moved to Daytona after a year at ERAU’s Prescott, Arizona,

campus. Although he has taught courses at all levels, including postgraduate, his

primary interest has been the delivery of introductory physics. He has received

several awards for teaching excellence, including the Senior Class Appreciation

Award (three times). He conducts research in general relativity and quantum

theory, and was a participant in the JOVE program, a special three-year NASA

grant program during which he studied neutron stars. His work has appeared in a

number of scientifi c journals, and he has been a featured science writer in *Analog*

*Science Fiction/Science Fact* magazine. In addition to this textbook, he is coauthor of

*Essentials of College Physics.* Dr. Vuille enjoys tennis, swimming, and playing classi

cal piano, and he is a former chess champion of St. Petersburg and Atlanta. In his

spare time he writes fi ction and goes to the beach. His wife, Dianne Kowing, is an

optometrist for a local Veterans’ Administration clinic. His daughter, Kira Vuille

Kowing, is a meteorology/communications double major at ERAU and a graduate

of her father’s fi rst-year physics course. He has two sons, Christopher, a cellist and

fi sherman, and James, avid reader of Disney comics.

Jerry S. Faughn earned his doctorate at the University of Mississippi. He is Profes 

sor Emeritus and former chair of the Department of Physics and Astronomy at

Eastern Kentucky University. Dr. Faughn has also written a microprocessor inter

facing text for upper-division physics students. He is coauthor of a nonmathemati

cal physics text and a physical science text for general education students, and

(with Dr. Serway) the high-school textbook *Physics*, published by Holt, Reinhart

and Winston. He has taught courses ranging from the lower division to the gradu

ate level, but his primary interest is in students just beginning to learn physics. Dr.

Faughn has a wide variety of hobbies, among which are reading, travel, genealogy,

and old-time radio. His wife, Mary Ann, is an avid gardener, and he contributes to

her efforts by staying out of the way. His daughter, Laura, is in family practice, and

his son, David, is an attorney.

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PREFACE

*College Physics* is written for a one-year course in introductory physics usually taken

by students majoring in biology, the health professions, and other disciplines

including environmental, earth, and social sciences, and technical fi elds such as

architecture. The mathematical techniques used in this book include algebra,

geometry, and trigonometry, but not calculus.

This textbook, which covers the standard topics in classical physics and 20th

century physics, is divided into six parts. Part 1 (Chapters 1–9) deals with New

tonian mechanics and the physics of fl uids; Part 2 (Chapters 10–12) is concerned

with heat and thermodynamics; Part 3 (Chapters 13 and 14) covers wave motion

and sound; Part 4 (Chapters 15–21) develops the concepts of electricity and mag

netism; Part 5 (Chapters 22–25) treats the properties of light and the fi eld of geo

metric and wave optics; and Part 6 (Chapters 26–30) provides an introduction to

special relativity, quantum physics, atomic physics, and nuclear physics.

OBJECTIVES

The main objectives of this introductory textbook are twofold: to provide the stu

dent with a clear and logical presentation of the basic concepts and principles

of physics, and to strengthen an understanding of the concepts and principles

through a broad range of interesting applications to the real world. To meet those

objectives, we have emphasized sound physical arguments and problem-solving

methodology. At the same time, we have attempted to motivate the student through

practical examples that demonstrate the role of physics in other disciplines.

CHANGES TO THE EIGHTH EDITION

A number of changes and improvements have been made to this edition. Based on

comments from users of the seventh edition and reviewers’ suggestions, a major

effort was made to increase the emphasis on conceptual understanding, to add

new end-of-chapter questions and problems that are informed by research, and

to improve the clarity of the presentation. The new pedagogical features added to

this edition are based on current trends in science education. The following repre

sent the major changes in the eighth edition.

Questions and Problems

We have substantially revised the end-of-chapter questions and problems for this

edition. Three new types of questions and problems have been added:

■ **Multiple-Choice Questions** have been introduced with several purposes in

mind. Some require calculations designed to facilitate students’ familiarity with

the equations, the variables used, the concepts the variables represent, and the

relationships between the concepts. The rest are conceptual and are designed

to encourage conceptual thinking. Finally, many students are required to take

multiple-choice tests, so some practice with that form of question is desirable.

Here is an example of a multiple-choice question:

**12.** A truck loaded with sand accelerates along a highway.

The driving force on the truck remains constant. What

happens to the acceleration of the truck as its trailer

leaks sand at a constant rate through a hole in its bot

tom? (a) It decreases at a steady rate. (b) It increases at

a steady rate. (c) It increases and then decreases. (d) It

decreases and then increases. (e) It remains constant.

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x Preface

The instructor may select multiple-choice questions to assign as homework or

use them in the classroom, possibly with “peer instruction” methods or in con

junction with “clicker” systems. More than 350 multiple-choice questions are

included in this edition. Answers to odd-numbered multiple-choice questions

are included in the Answers section at the end of the book, and answers to all

questions are found in the *Instructor’s Solutions Manual* and on the instructor’s

*PowerLecture CD-ROM*.

■ **Enhanced Content problems** require symbolic or conceptual responses from

the student.

A *symbolic Enhanced Content problem* requires the student to obtain an answer

in terms of symbols. In general, some guidance is built into the problem state

ment. The goal is to better train the student to deal with mathematics at a level

appropriate to this course. Most students at this level are uncomfortable with

symbolic equations, which is unfortunate because symbolic equations are the

most effi cient vehicle for presenting relationships between physics concepts.

Once students understand the physical concepts, their ability to solve problems

is greatly enhanced. As soon as the numbers are substituted into an equation,

however, all the concepts and their relationships to one another are lost, melded

together in the student’s calculator. The symbolic Enhanced Content problems

train students to postpone substitution of values, facilitating their ability to

think conceptually using the equations. An example of a symbolic Enhanced

Content problem is provided here:

**14.** ecp An object of mass *m* is dropped from the roof of a

building of height *h*. While the object is falling, a wind

blowing parallel to the face of the building exerts a con

stant horizontal force *F* on the object. (a) How long does

it take the object to strike the ground? Express the time *t*

in terms of *g* and *h*. (b) Find an expression in terms of *m*

and *F* for the acceleration *ax*of the object in the horizon tal direction (taken as the positive *x*-direction). (c) How

far is the object displaced horizontally before hitting the

ground? Answer in terms of *m*, *g*, *F*, and *h*. (d) Find the

magnitude of the object’s acceleration while it is falling,

using the variables *F*, *m*, and *g*.

A *conceptual Enhanced Content problem* encourages the student to think verbally

and conceptually about a given physics problem rather than rely solely on com

putational skills. Research in physics education suggests that standard physics

problems requiring calculations may not be entirely adequate in training stu

dents to think conceptually. Students learn to substitute numbers for symbols

in the equations without fully understanding what they are doing or what the

symbols mean. The conceptual Enhanced Content problem combats this ten

dency by asking for answers that require something other than a number or

a calculation. An example of a conceptual Enhanced Concept problem is pro

vided here:

**4.** ecp A shopper in a supermarket pushes a cart with a force

of 35 N directed at an angle of 25 below the horizontal.

The force is just suffi cient to overcome various frictional

forces, so the cart moves at constant speed. (a) Find the

work done by the shopper as she moves down a 50.0-m

length aisle. (b) What is the net work done on the cart?

Why? (c) The shopper goes down the next aisle, pushing

horizontally and maintaining the same speed as before. If

the work done by frictional forces doesn’t change, would

the shopper’s applied force be larger, smaller, or the same?

What about the work done on the cart by the shopper?

Preface xi

■ **Guided Problems** help students break problems into steps. A physics problem

typically asks for one physical quantity in a given context. Often, however, sev

eral concepts must be used and a number of calculations are required to get

that fi nal answer. Many students are not accustomed to this level of complexity

and often don’t know where to start. A *Guided Problem* breaks a standard prob

lem into smaller steps, enabling students to grasp all the concepts and strate

gies required to arrive at a correct solution. Unlike standard physics problems,

guidance is often built into the problem statement. For example, the problem

might say “Find the speed using conservation of energy” rather than only ask

ing for the speed. In any given chapter there are usually two or three problem

types that are particularly suited to this problem form. The problem must have

a certain level of complexity, with a similar problem-solving strategy involved

each time it appears. Guided Problems are reminiscent of how a student might

interact with a professor in an offi ce visit. These problems help train students

to break down complex problems into a series of simpler problems, an essential

problem-solving skill. An example of a Guided Problem is provided here:

**32.** GP Two blocks of masses *m*1 and *m*2 (*m*1 *m*2) are placed

on a frictionless table in contact with each other. A hori

zontal force of magnitude *F* is applied to the block of mass

*m*1 in Figure P4.32. (a) If *P* is the magnitude of the contact

force between the blocks, draw the free-body diagrams

for each block. (b) What is the net force on the system

consisting of both blocks? (c) What is the net force acting

on *m*1? (d) What is the net force acting on *m*2? (e) Write

the *x*-component of Newton’s second law for each block.

(f) Solve the resulting system of two equations and two

unknowns, expressing the acceleration *a* and contact

force *P* in terms of the masses and force. (g) How would

the answers change if the force had been applied to *m*2

instead? (*Hint*: use symmetry; don’t calculate!) Is the con

tact force larger, smaller, or the same in this case? Why?

**F**

*m*1 *m*2

FIGURE P4.32

In addition to these three new question and problem types, we carefully reviewed all other questions and problems for this revision to improve their vari ety, interest, and pedagogical value while maintaining their clarity and quality. Approximately 30% of the questions and problems in this edition are new.

Examples

In the last edition all in-text worked examples were reconstituted in a two-column format to better aid student learning and help reinforce physical concepts. For this eighth edition we have reviewed all the worked examples, made improvements, and added a new *Question* at the end of each worked example. The Questions usu

ally require a conceptual response or determination, or estimates requiring knowl edge of the relationships between concepts. The answers for the new Questions can be found at the back of the book. A sample of an in-text worked example fol lows on the next page, with an explanation of each of the example’s main parts:

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The Goal describes the physical concepts being explored within the worked example.

The Solution section uses a two column format that gives the explanation for each step of the

The Problem statement

presents the problem itself.

EXAMPLE 13.7 Measuring the Value of *g* Goal Determine *g* from pendulum motion.

The Strategy section helps students analyze the problem and create a framework for working out the solution.

solution in the left-hand column, while giving each accompanying mathematical step in the right-hand column. This layout facilitates matching the idea with

Problem Using a small pendulum of length 0.171 m, a geophysicist counts 72.0 complete swings in a time of 60.0 s. What is the value of *g* in this location?

Strategy First calculate the period of the pendulum by dividing the total time by the number of complete swings. Solve Equation 13.15 for *g* and substitute values.

its execution and helps students learn how to organize their work. Another benefi t: students can easily use this format as a

Solution

Calculate the period by dividing the total elapsed time by the number of complete oscillations:

*T* 5 time

# of oscillations 5 60.0 s

72.0 5 0.833 s

training tool, covering up the solution on the right and solving the problem using the comments

Solve Equation 13.15 for *g* and substitute values: *T* 5 2p Å*Lg* S *T* 2 5 4p2 *Lg T* 2 5 139.52 10.171 m2

on the left as a guide.

*g* 5 4p2*L*

10.833 s2 2 5 9.73 m/s2

Remarks follow each Solution and highlight some of the underlying concepts and

methodology used in arriving at a correct solution. In addition, the remarks are often used to put the problem into a larger, real-world context.

Remark Measuring such a vibration is a good way of determining the local value of the acceleration of gravity.

QUESTION 13.7

True or False: A simple pendulum of length 0.50 m has a larger frequency of vibration than a simple pendulum of length 1.0 m.

EXERCISE 13.7

What would be the period of the 0.171-m pendulum on the Moon, where the acceleration of gravity is 1.62 m/s2? Answer 2.04 s

Exercise/Answer Every worked example is followed

immediately by an exercise with an answer. These exercises

Question New to this edition, each worked example will feature a conceptual question that promotes student understanding of the underlying concepts contained in the example.

allow students to reinforce their understanding by working a similar or related problem, with the answers giving them instant feedback. At the option of the instructor, the exercises can also be assigned as homework. Students who work through these exercises on a regular basis will fi nd the end-of-chapter problems less intimidating.

Many Worked Examples are also available to be assigned as Active Examples in the Enhanced WebAssign homework management system (visit www.serwayphysics.com for more details).

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Online Homework

It is now easier to assign online homework with Serway and Vuille using the widely

acclaimed program Enhanced WebAssign. All end-of-chapter problems, active fi g

ures, quick quizzes, and most questions and worked examples in this book are avail

able in WebAssign. Most problems include hints and feedback to provide instan

taneous reinforcement or direction for that problem. We have also added math

remediation tools to help students get up to speed in algebra and trigonometry,

animated Active Figure simulations to strengthen students’ visualization skills, and

video to help students better understand the concepts. Visit **www.serwayphysics.**

**com** to view an interactive demo of this innovative online homework solution.

Content Changes

The text has been carefully edited to improve clarity of presentation and preci

sion of language. We hope that the result is a book both accurate and enjoyable to

read. Although the overall content and organization of the textbook are similar to

the seventh edition, a few changes were implemented.

■ Chapter 1, Introduction, has a new biological example involving an estimate.

■ Chapter 2, Motion in One Dimension, has an improved fi rst example. Quick

Quiz 2.1 was given another part so that students would understand the distinc

tion between average speed and average velocity. Quick Quiz 2.2 was completely

rewritten to improve its effectiveness. An extra part was added to Example 2.4,

and an example from the last edition was eliminated because it was not suf

fi ciently illustrative and somewhat redundant. It was replaced with a new sym

bolic example.

■ Chapter 3, Vectors and Two-Dimensional Motion, features a new symbolic exam

ple on the range equation.

■ Chapter 4, The Laws of Motion, contains several improved Quick Quizzes and

a revised and improved example. The fi rst three quick quizzes were combined

into one master quick quiz, requiring the student to answer fi ve related true–

false questions on the concept of a force. Quick Quizzes 4.4 and 4.5 were rewrit

ten, and Example 4.6 was improved.

■ In Chapter 5, Energy, two defi nitions of work and the defi nitions of average

power and instantaneous power were clarifi ed. The Problem-Solving Strategy

on conservation of energy was improved, resulting in positive changes to Exam

ple 5.5. A new part was added to Example 5.14 to enhance student comprehen

sion of instantaneous as opposed to average power.

■ In Chapter 6, Momentum and Collisions, the connection between kinetic

energy and momentum was made explicit early in the chapter and then used in

a Quick Quiz and elsewhere in the problem set.

■ In Chapter 7, Rotational Motion and the Law of Gravity, the defi nitions of the

radian and radian measure were clarifi ed. A new part was added to Example

7.1, dealing with arc length.

■ Chapter 9, Solids and Fluids, features a new discussion of dark matter and dark

energy in Section 9.1, States of Matter. Example 9.2 is a new biological example

about sports injuries.

■ Chapter 12, The Laws of Thermodynamics, has been reorganized slightly, and a

new section (Section 12.3, Thermal Processes) has been added. Another equiv

alent statement of the second law of thermodynamics was included along with

further explanation.

■ Chapter 14, Sound, has a new, more instructive Example 14.1, replacing the pre

vious example.

■ Chapter 15, Electric Forces and Electric Fields, has two worked examples that

were upgraded with new parts.

■ Chapter 16, Electrical Energy and Capacitance, has a new worked example that

illustrates particle dynamics and electric potential. Three other worked exam

ples were upgraded with new parts, and two new quick quizzes were added.

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■ Chapter 17, Current and Resistance, was reorganized slightly, putting the sub

section on power ahead of superconductivity. It also has two new quick quizzes.

■ Chapter 18, Direct-Current Circuits, has both a new and a reorganized quick

quiz.

■ Chapter 19, Magnetism, has a new section on types of magnetic materials as

well as a new quick quiz.

■ Chapter 20, Induced Voltages and Inductance, has new material on *RL* circuits,

along with a new example and quick quiz.

■ Chapter 21, Alternating-Current Circuits and Electromagnetic Waves, has a new

series of four quick quizzes that were added to drill the fundamentals of AC cir

cuits. The problem-solving strategy for *RLC* circuits was completely revised, and

a new physics application on using alternating electric fi elds in cancer treat

ment was added.

■ Chapter 24, Wave Optics, has an improved example and two new quick quizzes.

■ Chapter 26, Relativity, no longer covers relativistic addition of velocities. Three

new quick quizzes were added to the chapter.

■ Chapter 27, Quantum Physics, was rewritten and streamlined. Two superfl u

ous worked examples were eliminated (old Examples 27.1 and 27.2) because

both are discussed adequately in the text. One of two worked examples on the

Heisenberg uncertainty principle was deleted and a new quick quiz was added.

The scanning tunneling microscope application was deleted.

■ Chapter 28, Atomic Physics, was rewritten and streamlined, and the subsection

on spin was transferred to the section on quantum mechanics. The section on

electron clouds was shortened and made into a subsection. The sections on

atomic transitions and lasers were combined into a single, shorter section.

■ Chapter 29, Nuclear Physics, was reduced in size by deleting less essential worked

examples. Old worked examples 29.1 (Sizing a Neutron Star), 29.4 (Radon Gas),

29.6 (The Beta Decay of Carbon-14), and 29.9 (Synthetic Elements) were elimi

nated because they were similar to other examples already in the text. The medi

cal application of radiation was shortened, and a new quick quiz was developed.

■ Chapter 30, Nuclear Energy and Elementary Particles, was rewritten and stream

lined. The section on nuclear reactors was combined with the one on nuclear

fi ssion. The historical section and old Section 30.7 on the meson were elimi

nated, and the beginning of the section on particle physics was eliminated. The

section on strange particles and strangeness was combined with the section on

conservation laws. The sections on quarks and colored quarks were also com

bined into Section 30.8, Quarks and Color.

TEXTBOOK FEATURES

Most instructors would agree that the textbook assigned in a course should be the

student’s primary guide for understanding and learning the subject matter. Fur

ther, the textbook should be easily accessible and written in a style that facilitates

instruction and learning. With that in mind, we have included many pedagogical

features that are intended to enhance the textbook’s usefulness to both students

and instructors. The following features are included.

QUICK QUIZZES All the Quick Quizzes (see example below) are cast in an objec

tive format, including multiple-choice, true–false, matching, and ranking ques

tions. Quick Quizzes provide students with opportunities to test their understand

ing of the physical concepts presented. The questions require students to make

decisions on the basis of sound reasoning, and some have been written to help

students overcome common misconceptions. Answers to all Quick Quiz questions

are found at the end of the textbook, and answers with detailed explanations are

provided in the *Instructor’s Solutions Manual.* Many instructors choose to use Quick

Quiz questions in a “peer instruction” teaching style.

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QUICK QUIZ 4.3 A small sports car collides head-on with a massive truck.

The greater impact force (in magnitude) acts on (a) the car, (b) the truck,

(c) neither, the force is the same on both. Which vehicle undergoes the

greater magnitude acceleration? (d) the car, (e) the truck, (f) the accelera

tions are the same.

PROBLEM-SOLVING STRATEGIES A general problem-solving strategy to be fol

lowed by the student is outlined at the end of Chapter 1. This strategy provides stu

dents with a structured process for solving problems. In most chapters more spe

cifi c strategies and suggestions (see example below) are included for solving the

types of problems featured in both the worked examples and the end-of-chapter

problems. This feature helps students identify the essential steps in solving prob

lems and increases their skills as problem solvers.

PROBLEM-SOLVING STRATEGY

NEWTON’S SECOND LAW

Problems involving Newton’s second law can be very complex. The following

protocol breaks the solution process down into smaller, intermediate goals:

1. **Read** the problem carefully at least once.

2. **Draw** a picture of the system, identify the object of primary interest, and

indicate forces with arrows.

3. **Label** each force in the picture in a way that will bring to mind what physi

cal quantity the label stands for (e.g., *T* for tension).

4. **Draw** a free-body diagram of the object of interest, based on the labeled

picture. If additional objects are involved, draw separate free-body diagrams

for them. Choose convenient coordinates for each object.

5. **Apply Newton’s second law**. The *x*- and *y*-components of Newton’s second

law should be taken from the vector equation and written individually. This

usuallyresults in two equations and two unknowns.

6. **Solve** for the desired unknown quantity, and substitute the numbers.

BIOMEDICAL APPLICATIONS For biology and pre-med students, icons point

the way to various practical and interesting applications of physical principles to

biology and medicine. Whenever possible, more problems that are relevant to

these disciplines are included.

MCAT SKILL BUILDER STUDY GUIDE The eighth edition of *College Physics* con

tains a special skill-building appendix (Appendix E) to help premed students pre

pare for the MCAT exam. The appendix contains examples written by the text

authors that help students build conceptual and quantitative skills. These skill

building examples are followed by MCAT-style questions written by test prep

experts to make sure students are ready to ace the exam.

MCAT TEST PREPARATION GUIDE Located after the “To the Student” section

in the front of the book, this guide outlines 12 concept-based study courses for

the physics part of the MCAT exam. Students can use the guide to prepare for the

MCAT exam, class tests, or homework assignments.

APPLYING PHYSICS The Applying Physics features provide students with an

additional means of reviewing concepts presented in that section. Some Applying

Physics examples demonstrate the connection between the concepts presented in

that chapter and other scientifi c disciplines. These examples also serve as models

for students when assigned the task of responding to the Conceptual Questions

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TIP 4.3 Newton’s Second Law Is a *Vector* Equation

In applying Newton’s second law, add all of the forces on the object as vectors and then fi nd the resultant vector acceleration by dividing by *m*. Don’t fi nd the individual magnitudes of the forces and add them like scalars.

Newton’s third law R

APPLICATION

Diet Versus Exercise in

Weight-loss Programs

presented at the end of each chapter. For examples of Applying Physics boxes, see Applying Physics 9.5 (Home Plumbing) on page 299 and Applying Physics 13.1 (Bungee Jumping) on page 435.

TIPS Placed in the margins of the text, Tips address common student miscon ceptions and situations in which students often follow unproductive paths (see example at the left). More than ninety-fi ve Tips are provided in this edition to help students avoid common mistakes and misunderstandings.

MARGINAL NOTES Comments and notes appearing in the margin (see example at the left) can be used to locate important statements, equations, and concepts in the text.

APPLICATIONS Although physics is relevant to so much in our modern lives, it may not be obvious to students in an introductory course. Application margin notes (see example at the left) make the relevance of physics to everyday life more obvious by pointing out specifi c applications in the text. Some of these applica

tions pertain to the life sciences and are marked with a icon.

MULTIPLE-CHOICE QUESTIONS New to this edition are end-of-chapter multiple choice questions. The instructor may select items to assign as homework or use them in the classroom, possibly with “peer instruction” methods or with “clicker” systems. More than 350 multiple-choice questions are included in this edition. Answers to odd-numbered multiple-choice questions are included in the answer section at the end of the book, and answers to all questions are found in the *Instructor’s Solutions Manual.*

CONCEPTUAL QUESTIONS At the end of each chapter there are 10–15 con ceptual questions. The Applying Physics examples presented in the text serve as models for students when conceptual questions are assigned and show how the concepts can be applied to understanding the physical world. The conceptual questions provide the student with a means of self-testing the concepts presented in the chapter. Some conceptual questions are appropriate for initiating classroom discussions. Answers to odd-numbered conceptual questions are included in the Answers section at the end of the book, and answers to all questions are found in the *Instructor’s Solutions Manual.*

PROBLEMS An extensive set of problems is included at the end of each chapter (in all, almost 2 000 problems are provided in this edition). Answers to odd- numbered problems are given at the end of the book. For the convenience of both the stu dent and instructor, about two-thirds of the problems are keyed to specifi c sections of the chapter. The remaining problems, labeled “Additional Problems,” are not keyed to specifi c sections. The three levels of problems are graded according to their diffi culty. Straightforward problems are numbered in black, intermediate

level problems are numbered in **blue**, and the most challenging problems are numbered in **magenta**. The icon identifi es problems dealing with applications to the life sciences and medicine. Solutions to approximately 12 problems in each chapter are in the *Student Solutions Manual/Study Guide.*

STYLE To facilitate rapid comprehension, we have attempted to write the book in a style that is clear, logical, relaxed, and engaging. The somewhat informal and relaxed writing style is designed to connect better with students and enhance their reading enjoyment. New terms are carefully defi ned, and we have tried to avoid the use of jargon.

INTRODUCTIONS All chapters begin with a brief preview that includes a discus sion of the chapter’s objectives and content.

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UNITS The international system of units (SI) is used throughout the text. The

U.S. customary system of units is used only to a limited extent in the chapters on

mechanics and thermodynamics.

PEDAGOGICAL USE OF COLOR Readers should consult the **pedagogical color**

**chart** (inside the front cover) for a listing of the color-coded symbols used in the

text diagrams. This system is followed consistently throughout the text.

IMPORTANT STATEMENTS AND EQUATIONS Most important statements and

defi nitions are set in **boldface** type or are highlighted with a background screen

for added emphasis and ease of review. Similarly, important equations are high

lighted with a tan background screen to facilitate location.

ILLUSTRATIONS AND TABLES The readability and effectiveness of the text mate

rial, worked examples, and end-of-chapter conceptual questions and problems are

enhanced by the large number of fi gures, diagrams, photographs, and tables. Full

color adds clarity to the artwork and makes illustrations as realistic as possible.

Three-dimensional effects are rendered with the use of shaded and lightened

areas where appropriate. Vectors are color coded, and curves in graphs are drawn

in color. Color photographs have been carefully selected, and their accompanying

captions have been written to serve as an added instructional tool. A complete

description of the pedagogical use of color appears on the inside front cover.

SUMMARY The end-of-chapter Summary is organized by individual section

headings for ease of reference.

SIGNIFICANT FIGURES Signifi cant fi gures in both worked examples and end

of-chapter problems have been handled with care. Most numerical examples and

problems are worked out to either two or three signifi cant fi gures, depending on

the accuracy of the data provided. Intermediate results presented in the examples

are rounded to the proper number of signifi cant fi gures, and only those digits are

carried forward.

APPENDICES AND ENDPAPERS Several appendices are provided at the end of

the textbook. Most of the appendix material represents a review of mathematical

concepts and techniques used in the text, including scientifi c notation, algebra,

geometry, trigonometry, differential calculus, and integral calculus. Reference

to these appendices is made as needed throughout the text. Most of the math

ematical review sections include worked examples and exercises with answers. In

addition to the mathematical review, some appendices contain useful tables that

supplement textual information. For easy reference, the front endpapers contain a

chart explaining the use of color throughout the book and a list of frequently used

conversion factors.

ACTIVE FIGURES Many diagrams from the text have been animated to become

Active Figures (identifi ed in the fi gure legend), part of the *Enhanced WebAssign*

online homework system. By viewing animations of phenomena and processes that

cannot be fully represented on a static page, students greatly increase their con

ceptual understanding. In addition to viewing animations of the fi gures, students

can see the outcome of changing variables to see the effects, conduct suggested

explorations of the principles involved in the fi gure, and take and receive feedback

on quizzes related to the fi gure. All Active Figures are included on the instructor’s

*PowerLecture CD-ROM* for in-class lecture presentation.

TEACHING OPTIONS

This book contains more than enough material for a one-year course in introduc

tory physics, which serves two purposes. First, it gives the instructor more fl exibility

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in choosing topics for a specifi c course. Second, the book becomes more useful

as a resource for students. On average, it should be possible to cover about one

chapter each week for a class that meets three hours per week. Those sections,

examples, and end-of-chapter problems dealing with applications of physics to life

sciences are identifi ed with the DNA icon . We offer the following suggestions for

shorter courses for those instructors who choose to move at a slower pace through

the year.

***Option A:*** If you choose to place more emphasis on contemporary topics in phys

ics, you could omit all or parts of Chapter 8 (Rotational Equilibrium and Rota

tional Dynamics), Chapter 21 (Alternating-Current Circuits and Electromag

netic Waves), and Chapter 25 (Optical Instruments).

***Option B:*** If you choose to place more emphasis on classical physics, you could omit

all or parts of Part 6 of the textbook, which deals with special relativity and

other topics in 20th-century physics.

The *Instructor’s Solutions Manual* offers additional suggestions for specifi c sec

tions and topics that may be omitted without loss of continuity if time presses.

COURSE SOLUTIONS THAT FIT YOUR TEACHING

GOALS AND YOUR STUDENTS’ LEARNING NEEDS

Recent advances in educational technology have made homework management

systems and audience response systems powerful and affordable tools to enhance

the way you teach your course. Whether you offer a more traditional text-based

course, are interested in using or are currently using an online homework man

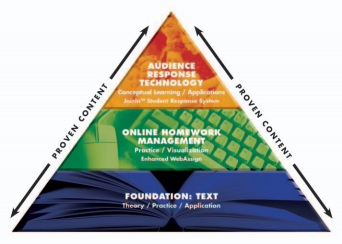
agement system such as WebAssign, or are ready to turn your lecture into an inter

active learning environment with an audience response system, you can be con

fi dent that the text’s proven content provides the foundation for each and every

component of our technology and ancillary package.

VISUALIZE WHERE YOU WANT TO TAKE YOUR COURSE



WE PROVIDE YOU WITH THE FOUNDATION TO GET THERE

Serway/Vuille, College Physics, 8e

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Homework Management Systems

ENHANCED WEBASSIGN Enhanced WebAssign is the perfect solution to your

homework management needs. Designed by physicists for physicists, this system is

a reliable and user-friendly teaching companion. Enhanced WebAssign is available

for *College Physics*, giving you the freedom to assign

• every end-of-chapter Problem, Multiple-Choice Question, and Conceptual 

Question, enhanced with hints and feedback

• most worked examples, enhanced with hints and feedback, to help strengthen

students’ problem-solving skills

• every Quick Quiz, giving your students ample opportunity to test their concep

tual understanding

• animated Active Figures, enhanced with hints and feedback, to help students

develop their visualization skills

• a math review to help students brush up on key quantitative concepts

Please visit **www.serwayphysics.com t**o view an interactive demonstration of

Enhanced WebAssign.

The text is also supported by the following Homework Management Systems.

Contact your local sales representative for more information.

CAPA: A Computer-Assisted Personalized Approach and LON-CAPA,

http://www.lon-capa.org/

The University of Texas Homework Service

Audience Response Systems 

AUDIENCE RESPONSE SYSTEM CONTENT Regardless of the response system

you are using, we provide the tested content to support it. Our ready-to-go content

includes all the questions from the Quick Quizzes, all the end-of-chapter Multiple

Choice Questions, test questions, and a selection of end-of-chapter questions to

provide helpful conceptual checkpoints to drop into your lecture. Our Active Fig

ure animations have also been enhanced with multiple-choice questions to help

test students’ observational skills.

We also feature the Assessing to Learn in the Classroom content from the Uni

versity of Massachusetts. This collection of 250 advanced conceptual questions has

been tested in the classroom for more than ten years and takes peer learning to

a new level. Contact your local sales representative to learn more about our audi

ence response software and hardware.

Visit **www.serwayphysics.com** to download samples of our audience response

system content.

Lecture Presentation Resources

The following resources provide support for your presentations in lecture.

*POWERLECTURE CD-ROM* An easy-to-use multimedia lecture tool, the *Power*

*Lecture CD-ROM* allows you to quickly assemble art, animations, digital video, and

database fi les with notes to create fl uid lectures. The two-volume set (Volume 1:

Chapters 1–14; Volume 2: Chapters 15–30) includes prebuilt PowerPoint® lectures,

a database of animations, video clips, and digital art from the text as well as edit

able electronic fi les of the *Instructor’s Solutions Manual.* Also included is the easy-to

use test generator *ExamView*, which features all the questions from the printed *Test*

*Bank* in an editable format.

TRANSPARENCY ACETATES Each volume contains approximately 100 transpar

ency acetates featuring art from the text. Volume 1 contains Chapters 1 through

14, and Volume 2 contains Chapters 15 through 30.

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Assessment and Course Preparation Resources:

A number of the resources listed below will help assist with your assessment and

preparation processes, and are available to qualifi ed adopters. Please contact your

local Cengage • Brooks/Cole sales representative for details. Ancillaries offered

in two volumes are split as follows: Volume 1 contains Chapters 1 through 14, and

Volume 2 contains Chapters 15 through 30.

*INSTRUCTOR’S SOLUTIONS MANUAL* by Charles Teague and Jerry S. Faughn.

Available in two volumes, the *Instructor’s Solutions Manual* consists of complete solu

tions to all the problems, multiple-choice questions, and conceptual questions in

the text, and full answers with explanations to the Quick Quizzes. An editable

version of the complete instructor’s solutions is also available electronically on the

*PowerLecture CD-ROM*.

PRINTED TEST BANK by Ed Oberhofer. This test bank contains approximately

1 750 multiple-choice problems and questions. Answers are provided in a sepa

rate key. The test bank is provided in print form (in two volumes) for the instruc

tor who does not have access to a computer, and instructors may duplicate pages

for distribution to students. These questions are also available on the *PowerLecture*

*CD-ROM* as either editable Word® fi les (with complete answers and solutions) or

via the *ExamView* test software.

WEBCT AND BLACKBOARD CONTENT For users of either course management

system, we provide our test bank questions in proper WebCT and Blackboard con

tent format for easy upload into your online course.

INSTRUCTOR’S COMPANION WEB SITE Consult the instructor’s Web site at **www.**

**serwayphysics.com** for additional Quick Quiz questions, a problem correlation

guide, images from the text, and sample PowerPoint® lectures. Instructors adopt

ing the eighth edition of *College Physics* may download these materials after secur

ing the appropriate password from their local Brooks/Cole sales representative.

Student Resources

Brooks/Cole offers several items to supplement and enhance the classroom expe

rience. These ancillaries allow instructors to customize the textbook to their stu

dents’ needs and to their own style of instruction. One or more of the following

ancillaries may be shrink-wrapped with the text at a reduced price:

*STUDENT SOLUTIONS MANUAL/STUDY GUIDE* by John R. Gordon, Charles

Teague, and Raymond A. Serway. Now offered in two volumes, the *Student Solutions*

*Manual/Study Guide* features detailed solutions to approximately 12 problems per

chapter. Boxed numbers identify those problems in the textbook for which com

plete solutions are found in the manual. The manual also features a skills section,

important notes from key sections of the text, and a list of important equations

and concepts. Volume 1 contains Chapters 1 through 14, and Volume 2 contains

Chapters 15 through 30.

*PHYSICS LABORATORY MANUAL*, 3rd edition, by David Loyd. The *Physics Labora*

*tory Manual* supplements the learning of basic physical principles while introduc

ing laboratory procedures and equipment. Each chapter of the manual includes

a prelaboratory assignment, objectives, an equipment list, the theory behind the

experiment, experimental procedures, graphs, and questions. A laboratory report

is provided for each experiment so that the student can record data, calculations,

and experimental results. To develop their ability to judge the validity of their

results, students are encouraged to apply statistical analysis to their data. A com

plete instructor’s manual is also available to facilitate use of this manual.

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ACKNOWLEDGMENTS

In preparing the eighth edition of this textbook, we have been guided by the

expertise of many people who have reviewed manuscript or provided prerevision

suggestions. We wish to acknowledge the following reviewers and express our sin

cere appreciation for their helpful suggestions, criticism, and encouragement.

**Eighth edition reviewers:**

Gary Blanpied, *University of South Carolina*

Gardner Friedlander, *University School of Milwaukee*

Dolores Gende, *Parish Episcopal School* Grant W. Hart, *Brigham Young University*

Joey Huston, *Michigan State University* Mark James, *Northern Arizona University* Teruki Kamon, *Texas A & M University*

Mark Lucas, *Ohio University*

Mark E. Mattson, *James Madison University*

J. Patrick Polley, *Beloit College* Eugene Surdutovich, *Wayne State University*

Marshall Thomsen, *Eastern Michigan University*

David P. Young, *Louisiana State University*

*College Physics*, eighth edition, was carefully checked for accuracy by Philip W. Adams, *Louisiana State University*; Grant W. Hart, *Brigham Young University*; Thomas K. Hemmick, *Stony Brook University*; Ed Oberhofer, *Lake Sumter Community College*; M. Anthony Reynolds, *Embry-Riddle Aeronautical University*; Eugene Surdutovich,

*Wayne State University*; and David P. Young, *Louisi ana State University*. Although responsibility for any remaining errors rests with us, we thank them for their dedi cation and vigilance.

Prior to our work on this revision, we conducted a survey of professors to gauge how they used student assessment in their classroom. We were overwhelmed not only by the number of professors who wanted to take part in the survey, but also by their insightful comments. Their feedback and suggestions helped shape the revi

sion of the end-of-chapter questions and problems in this edition, and so we would like to thank the survey participants:

Elise Adamson, *Wayland Baptist University*; Rhett Allain, *Southeastern Louisiana University*; Michael Anderson, *University of California, San Diego*; James Andrews, *Youngstown State University*; Bradley Anta naitis, *Lafayette College*; Robert Astalos, *Adams State College*; Charles Atchley, *Sauk Valley Community Col lege*; Kandiah Balachandran, *Kalamazoo Valley Community College*; Colley Baldwin, *St. John’s University*; Mahmoud Basharat, *Houston Community College Northeast*; Celso Batalha, *Evergreen Valley College*; Nata lie Batalha, *San Jose State University*; Charles Benesh, *Wesleyan College*; Raymond Benge, *Tarrant County College Northeast*; Lee Benjamin, *Marywood University*; Edgar Bering, *University of Houston*; Ron Bin gaman, *Indiana University East*; Jennifer Birriel, *Morehead State University*; Earl Blodgett, *University of Wisconsin–River Falls*; Anthony Blose, *University of North Alabama*; Jeff Bodart, *Chipola College*; Ken Bol land, *The Ohio State University*; Roscoe Bowen, *Campbellsville University*; Shane Brower, *Grove City College*; Charles Burkhardt, *St. Louis Community College*; Richard Cardenas, *St. Mary’s University*; Kelly Casey, *Yakima Valley Community College*; Cliff Castle, *Jefferson College*; Marco Cavaglia, *University of Mississippi*; Eugene Chaffi n, *Bob Jones University*; Chang Chang, *Drexel University*; Jing Chang, *Culver-Stockton Col lege*; Hirendra Chatterjee, *Camden County College*; Soumitra Chattopadhyay, *Georgia Highlands College*; Anastasia Chopelas, *University of Washington*; Krishna Chowdary, *Bucknell University*; Kelvin Chu, *Uni versity of Vermont*; Alice D. Churukian, *Concordia College*; David Cinabro, *Wayne State University*; Gary Copeland, *Old Dominion University*; Sean Cordry, *Northwestern College of Iowa*; Victor Coronel, *SUNY Rockland Community College*; Douglas Corteville, *Iowa Western Community College*; Randy Criss, *Saint Leo University*; John Crutchfi eld, *Rockingham Community College*; Danielle Dalafave, *College of New Jersey*; Law rence Day, *Utica College*; Joe DeLeone, *Corning Community College*; Tony DeLia, *North Florida Community College*; Duygu Demirlioglu, *Holy Names University*; Sandra Desmarais, *Daytona Beach Community College*; Gregory Dolise, *Harrisburg Area Community College*; Duane Doyle, *Arkansas State University–Newport*; James Dull, *Albertson College of Idaho*; Tim Duman, *University of Indianapolis*; Arthur Eggers, *Community College of Southern Nevada*; Robert Egler, *North Carolina State University*; Steve Ellis, *University of Kentucky*; Terry Ellis, *Jacksonville University*; Ted Eltzroth, *Elgin Community College*; Martin Epstein, *California State University, Los Angeles*; Florence Etop, *Virginia State University*; Mike Eydenberg, *New Mexico State Univer sity at Alamogordo*; Davene Eyres, *North Seattle Community College*; Brett Fadem, *Muhlenberg College*; Greg Falabella, *Wagner College*; Michael Faleski, *Delta College*; Jacqueline Faridani, *Shippensburg University*; Abu Fasihuddin, *University of Connecticut*; Scott Fedorchak, *Campbell University*; Frank Ferrone, *Drexel*

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*University*; Harland Fish, *Kalamazoo Valley Community College*; Kent Fisher, *Columbus State Community Col*

*lege*; Allen Flora, *Hood College*; James Friedrichsen, *Austin Community College*; Cynthia Galovich, *Univer*

*sity of Northern Colorado*; Ticu Gamalie, *Arkansas State University–LRAFB*; Andy Gavrin, *Indiana Univer*

*sity Purdue University Indianapolis*; Michael Giangrande, *Oakland Community College*; Wells Gordon, *Ohio*

*Valley University*; Charles Grabowski, *Carroll Community College*; Robert Gramer, *Lake City Community Col*

*lege*; Janusz Grebowicz, *University of Houston–Downtown*; Morris Greenwood, *San Jacinto College Central*;

David Groh, *Gannon University*; Fred Grosse, *Susquehanna University*; Harvey Haag, *Penn State DuBois*;

Piotr Habdas, *Saint Joseph’s University*; Robert Hagood, *Washtenaw Community College*; Heath Hatch, *Uni*

*versity of Massachusetts Amherst*; Dennis Hawk, *Navarro College*; George Hazelton, *Chowan University*;

Qifang He, *Arkansas State University at Beebe*; Randall Headrick, *University of Vermont*; Todd Holden,

*Brooklyn College*; Susanne Holmes-Koetter; Doug Ingram, *Texas Christian University*; Dwain Ingram,

*Texas State Technical College*; Rex Isham, *Sam Houston State University*; Herbert Jaeger, *Miami University*;

Mohsen Janatpour, *College of San Mateo*; Peter Jeschofnig, *Colorado Mountain College*; Lana Jordan, *Mer*

*ced College*; Teruki Kamon, *Texas A & M University*; Charles Kao, *Columbus State University*; David

Kardelis, *College of Eastern Utah*; Edward Kearns, *Boston University*; Robert Keefer, *Lake Sumter Commu*

*nity College*; Mamadou Keita, *Sheridan College, Gillette Campus*; Luke Keller, *Ithaca College*; Andrew Kerr,

*University of Findlay*; Kinney Kim, *North Carolina Central University*; Kevin Kimberlin, *Bradley University*;

George Knott, *Cosumnes River College*; Corinne Krauss, *Dickinson State University*; Christopher Kulp,

*Eastern Kentucky University*; A. Anil Kumar, *Prairie View A & M University*; Josephine Lamela, *Middlesex*

*County College*; Eric Lane, *University of Tennessee*; Gregory Lapicki, *East Carolina University*; Byron Leles,

*Snead State Community College*; David Lieberman, *Queensborough Community College*; Marilyn Listvan,

*Normandale Community College*; Rafael Lopez-Mobilia, *University of Texas at San Antonio*; Jose Lozano,

*Bradley University*; Mark Lucas, *Ohio University*; Ntungwa Maasha, *Coastal Georgia Community College*;

Keith MacAdam, *University of Kentucky*; Kevin Mackay, *Grove City College*; Steve Maier, *Northwestern Okla*

*homa State University*; Helen Major, *Lincoln University*; Igor Makasyuk, *San Francisco State University*; Gary

Malek, *Johnson County Community College*; Frank Mann, *Emmanuel College*; Ronald Marks, *North Green*

*ville University*; Perry Mason, *Lubbock Christian University*; Mark Mattson, *James Madison University*; John

McClain, *Panola College*; James McDonald, *University of Hartford*; Linda McDonald, *North Park University*;

Ralph V. McGrew, *Broome Community College*; Janet McLarty-Schroeder, *Cerritos College*; Rahul Mehta,

*University of Central Arkansas*; Mike Mikhaiel, *Passaic County Community College*; Laney Mills, *College of*

*Charleston*; John Milton, *DePaul University*; Stephen Minnick, *Kent State University, Tuscarawas Campus*;

Dominick Misciascio, *Mercer County Community College*; Arthur Mittler, *University of Massachusetts Lowell*;

Glenn Modrak, *Broome Community College*; Toby Moleski, *Muskegon Community College*; G. David Moore,

*Reinhardt College*; Hassan Moore, *Johnson C. Smith University*; David Moran, *Breyer State University*; Laurie

Morgus, *Drew University*; David Murdock, *Tennessee Technological University*; Dennis Nemeschansky, *Uni*

*versity of Southern California*; Bob Nerbun, *University of South Carolina Sumter*; Lorin Neufeld, *Fresno*

*Pacifi c University*; K. W. Nicholson, *Central Alabama Community College*; Charles Nickles, *University of Mas*

*sachusetts Dartmouth*; Paul Nienaber, *Saint Mary’s University of Minnesota*; Ralph Oberly, *Marshall Univer*

*sity*; Terry F. O’Dwyer, *Nassau Community College*; Don Olive, *Gardner-Webb University*; Jacqueline

Omland, *Northern State University*; Paige Ouzts, *Lander University*; Vaheribhai Patel, *Tomball College*;

Bijoy Patnaik, *Halifax Community College*; Philip Patterson, *Southern Polytechnic State University*; James

Pazun, *Pfeiffer University*; Chuck Pearson, *Shorter College*; Todd Pedlar, *Luther College*; Anthony Peer, *Del*

*aware Technical & Community College*; Frederick Phelps, *Central Michigan University*; Robert Philbin, *Trin*

*idad State Junior College*; Joshua Phiri, *Florence- Darlington Technical College*; Cu Phung, *Methodist College*;

Alberto Pinkas, *New Jersey City University*; Ali Piran, *Stephen F. Austin State University*; Marie Plumb, *James*

*town Community College*; Dwight Portman, *Miami University Middletown*; Rose Rakers, *Trinity Christian*

*College*; Periasamy Ramalingam, *Albany State University*; Marilyn Rands, *Lawrence Technological Univer*

*sity*; Tom Richardson, *Marian College*; Herbert Ringel, *Borough of Manhattan Community College*; Salva

tore Rodano, *Harford Community College*; John Rollino, *Rutgers University– Newark*; Fernando Romero

Borja, *Houston Community College–Central*; Michael Rulison, *Oglethorpe University*; Marylyn Russ,

*Marygrove College*; Craig Rutan, *Santiago Canyon College*; Jyotsna Sau, *Delaware Technical & Community*

*College*; Charles Sawicki, *North Dakota State University*; Daniel Schoun, *Kettering College of Medical Arts*;

Andria Schwortz, *Quinsigamond Community College*; David Seely, *Albion College*; Ross Setze, *Pearl River*

*Community College*; Bart Sheinberg; Peter Sheldon, *Randolph-Macon Woman’s College*; Wen Shen, *Commu*

*nity College of Southern Nevada*; Anwar Shiekh, *Dine College*; Marllin Simon, *Auburn University*; Don

Sparks, *Pierce College*; Philip Spickler, *Bridgewater College*; Fletcher Srygley, *Lipscomb University*; Scott

Steckenrider, *Illinois College*; Donna Stokes, *University of Houston*; Laurence Stone, *Dakota County Techni*

*cal College*; Yang Sun, *University of Notre Dame*; Gregory Suran, *Raritan Valley Community College*; Vahe

Tatoian, *Mt. San Antonio College*; Alem Teklu, *College of Charleston*; Paul Testa, *Tompkins Cortland Com*

*munity College*; Michael Thackston, *Southern Polytechnic State University*; Melody Thomas, *Northwest Arkan*

*sas Community College*; Cheng Ting, *Houston Community College–Southeast*; Donn Townsend, *Penn State*

*Shenango*; Herman Trivilino; Gajendra Tulsian, *Daytona Beach Community College*; Rein Uritam, *Boston*

*College*; Daniel Van Wingerden, *Eastern Michigan University*; Ashok Vaseashta, *Marshall University*; Rob

ert Vaughn, *Graceland University*; Robert Warasila, *Suffolk County Community College*; Robert Webb, *Texas*

*A & M University*; Zodiac Webster, *Columbus State University*; Brian Weiner, *Penn State DuBois*; Jack Wells,

*Thomas More College*; Ronnie Whitener, *Tri-County Community College*; Tom Wilbur, *Anne Arundel Com*

*munity College*; Sam Wiley, *California State University, Dominguez Hills*; Judith Williams, *William Penn Uni*

*versity*; Mark Williams; Don Williamson, *Chadron State College*; Neal Wilsey, *College of Southern Maryland*;

Preface xxiii

Lowell Wood, *University of Houston*; Jainshi Wu; Pei Xiong-Skiba, *Austin Peay State University*; Ming Yin,

*Benedict College*; David Young, *Louisiana State University*; Douglas Young, *Mercer University*; T. Waldek

Zerda, *Texas Christian University*; Peizhen Zhao, *Edison Community College*; Steven Zides, *Wofford College*;

and Ulrich Zurcher, *Cleveland State University.*

Finally, we would like to thank the following people for their suggestions and

assistance during the preparation of earlier editions of this textbook:

Gary B. Adams, *Arizona State University*; Marilyn Akins, *Broome Community College*; Ricardo Alarcon,

*Arizona State University*; Albert Altman, *University of Lowell*; John Anderson, *University of Pittsburgh*; Law

rence Anderson-Huang, *University of Toledo*; Subhash Antani, *Edgewood College*; Neil W. Ashcroft, *Cornell*

*University*; Charles R. Bacon, *Ferris State University*; Dilip Balamore, *Nassau Community College*; Ralph

Barnett, *Florissant Valley Community College*; Lois Barrett, *Western Washington University*; Natalie Batalha,

*San Jose State University*; Paul D. Beale, *University of Colorado at Boulder*; Paul Bender, *Washington State*

*University*; David H. Bennum, *University of Nevada at Reno*; Ken Bolland, *The Ohio State University*; Jeffery

Braun, *University of Evansville*; John Brennan, *University of Central Florida*; Michael Bretz, *University of*

*Michigan, Ann Arbor*; Michael E. Browne, *University of Idaho*; Joseph Cantazarite, *Cypress College*; Ronald

W. Canterna, *University of Wyoming*; Clinton M. Case, *Western Nevada Community College*; Neal M. Cason,

*University of Notre Dame*; Kapila Clara Castoldi, *Oakland University*; Roger W. Clapp, *University of South*

*Florida*; Giuseppe Colaccico, *University of South Florida*; Lattie F. Collins, *East Tennessee State University*;

Lawrence B. Colman, *University of California, Davis*; Andrew Cornelius, *University of Nevada, Las Vegas*;

Jorge Cossio, *Miami Dade Community College*; Terry T. Crow, *Mississippi State College*; Yesim Darici, *Flor*

*ida International University*; Stephen D. Davis, *University of Arkansas at Little Rock*; John DeFord, *University*

*of Utah*; Chris J. DeMarco, *Jackson Community College*; Michael Dennin, *University of California, Irvine*;

N. John DiNardo, *Drexel University*; Steve Ellis, *University of Kentucky*; Robert J. Endorf, *University of*

*Cincinnati*; Steve Ellis, *University of Kentucky*; Hasan Fakhruddin, *Ball State University/Indiana Academy*;

Paul Feldker, *Florissant Valley Community College*; Leonard X. Finegold, *Drexel University*; Emily Flynn;

Lewis Ford, *Texas A & M University*; Tom French, *Montgomery County Community College*; Albert Thomas

Frommhold, Jr*.*, *Auburn University*; Lothar Frommhold, *University of Texas at Austin*; Eric Ganz, *Uni*

*versity of Minnesota*; Teymoor Gedayloo, *California Polytechnic State University*; Simon George, *California*

*State University, Long Beach*; James R. Goff, *Pima Community College*; Yadin Y. Goldschmidt, *University*

*of Pittsburgh*; John R. Gordon, *James Madison University*; George W. Greenlees, *University of Minnesota*;

Wlodzi mierz Guryn, *Brookhaven National Laboratory*; Steve Hagen, *University of Florida*; Raymond Hall,

*California State University, Fresno*; Patrick Hamill, *San Jose State University*; Joel Handley; James Harmon,

*Oklahoma State University*; Grant W. Hart, *Brigham Young University*; James E. Heath, *Austin Community*

*College*; Grady Hendricks, *Blinn College*; Christopher Herbert, *New Jersey City University*; Rhett Her

man, *Radford University*; John Ho, *State University of New York at Buffalo*; Aleksey Holloway, *University*

*of Nebraska at Omaha*; Murshed Hossain, *Rowan University*; Robert C. Hudson, *Roanoke College*; Joey

Huston, *Michigan State University*; Fred Inman, *Mankato State University*; Mark James, *Northern Arizona*

*University*; Ronald E. Jodoin, *Rochester Institute of Technology*; Randall Jones, *Loyola College in Maryland*;

Drasko Jovanovic, *Fermilab*; George W. Kattawar, *Texas A & M University*; Joseph Keane, *St. Thomas*

*Aquinas College*; Frank Kolp, *Trenton State University*; Dorina Kosztin, *University of Missouri–Columbia*;

Joan P. S. Kowalski, *George Mason University*; Ivan Kramer, *University of Maryland, Baltimore County*; Sol

Krasner, *University of Chicago*; Karl F. Kuhn, *Eastern Kentucky University*; David Lamp, *Texas Tech Uni*

*versity*; Harvey S. Leff, *California State Polytechnic University*; Joel Levine, *Orange Coast College*; Michael

Lieber, *University of Arkansas*; Martha Lietz, *Niles West High School*; James Linbald, *Saddleback Community*

*College*; Edwin Lo; Bill Lochslet, *Pennsylvania State University*; Rafael Lopez-Mobilia, *University of Texas*

*at San Antonio*; Michael LoPresto, *Henry Ford Community College*; Bo Lou, *Ferris State University*; Jeffrey V.

Mallow, *Loyola University of Chicago*; David Markowitz, *University of Connecticut*; Joe McCauley, Jr., *Univer*

*sity of Houston*; Steven McCauley, *California State Polytechnic University, Pomona*; Ralph V. McGrew, *Broome*

*Community College*; Bill F. Melton, *University of North Carolina at Charlotte*; John A. Milsom, *University of*

*Arizona*; Monty Mola, *Humboldt State University*; H. Kent Moore, *James Madison University*; John Morack,

*University of Alaska, Fairbanks*; Steven Morris, *Los Angeles Harbor College*; Charles W. Myles, *Texas Tech*

*University*; Carl R. Nave, *Georgia State University*; Martin Nikolo, *Saint Louis University*; Blaine Norum,

*University of Virginia*; M. E. Oakes, *University of Texas at Austin*; Lewis J. Oakland, *University of Minnesota*;

Ed Oberhofer, *Lake Sumter Community College*; Lewis O’Kelly, *Memphis State University*; David G. Onn,

*University of Delaware*; J. Scott Payson, *Wayne State University*; Chris Pearson, *University of Michigan–Flint*;

Alexey A. Petrov, *Wayne State University*; T. A. K. Pillai, *University of Wisconsin, La Crosse*; Lawrence S.

Pinsky, *University of Houston*; William D. Ploughe, *The Ohio State University*; Patrick Polley, *Beloit College*;

Brooke M. Pridmore, *Clayton State University*; Joseph Priest, *Miami University*; James Purcell, *Georgia*

*State University*; W. Steve Quon, *Ventura College*; Michael Ram, *State University of New York at Buffalo*; Kurt

Reibel, *The Ohio State University*; M. Anthony Reynolds, *Embry-Riddle Aeronautical University*; Barry Rob

ertson, *Queen’s University*; Virginia Roundy, *California State University, Fullerton*; Larry Rowan, *University*

*of North Carolina, Chapel Hill*; Dubravka Rupnik, *Louisiana State University*; William R. Savage, *University*

*of Iowa*; Reinhard A. Schumacher, *Carnegie Mellon University*; Surajit Sen, *State University of New York at*

*Buffalo*; John Simon, *University of Toledo*; Marllin L. Simon, *Auburn University*; Matthew Sirocky; Don

ald D. Snyder, *Indiana University at Southbend*; George Strobel, *University of Georgia*; Carey E. Stron

ach, *Virginia State University*; Thomas W. Taylor, *Cleveland State University*; Perry A. Tompkins, *Samford*

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*University*; L. L. Van Zandt, *Purdue University*; Howard G. Voss, *Arizona State University*; James Wanliss,

*Embry-Riddle Aeronautical University*; Larry Weaver, *Kansas State University*; Donald H. White, *Western*

*Oregon State College*; Bernard Whiting, *University of Florida*; George A. Williams, *University of Utah*; Jerry

H. Wilson, *Metropolitan State College*; Robert M. Wood, *University of Georgia*; and Clyde A. Zaidins, *Uni*

*versity of Colorado at Denver.*

Gerd Kortemeyer and Randall Jones contributed several end-of-chapter problems,

especially those of interest to the life sciences. Edward F. Redish of the University

of Maryland graciously allowed us to list some of his problems from the Activity

Based Physics Project.

We are extremely grateful to the publishing team at the Brooks/Cole Publishing

Company for their expertise and outstanding work in all aspects of this project. In

particular, we thank Ed Dodd, who tirelessly coordinated and directed our efforts

in preparing the manuscript in its various stages, and Sylvia Krick, who transmit

ted all the print ancillaries. Jane Sanders Miller, the photo researcher, did a great

job fi nding photos of physical phenomena, Sam Subity coordinated the media pro

gram for the text, and Rob Hugel helped translate our rough sketches into accu

rate, compelling art. Katherine Wilson of Lachina Publishing Services managed

the diffi cult task of keeping production moving and on schedule. Mark Santee,

Teri Hyde, and Chris Hall also made numerous valuable contributions. Mark, the

book’s marketing manager, was a tireless advocate for the text. Teri coordinated

the entire production and manufacturing of the text, in all its various incarna

tions, from start to fi nish. Chris provided just the right amount of guidance and

vision throughout the project. We also thank David Harris, a great team builder

and motivator with loads of enthusiasm and an infectious sense of humor. Finally,

we are deeply indebted to our wives and children for their love, support, and long

term sacrifi ces.

**Raymond A. Serway**

St. Petersburg, Florida

**Chris Vuille**

Daytona Beach, Florida

ENGAGING APPLICATIONS

Although physics is relevant to so much in our modern lives, it may not be obvious to students in an introductory course. In this eighth edition of *College Physics*, we continue a design feature begun in the seventh edition. This feature makes the relevance of physics to everyday life more obvious by pointing out specifi c applications in the form of a marginal note. Some of these applications pertain to the life sciences and are marked with the DNA icon . The list below is not intended to be a complete listing of all the applications of the principles of physics found in this textbook. Many other applications are to be found within the text and especially in the worked examples, conceptual questions, and end-of-chapter problems.

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TO THE STUDENT

As a student, it’s important that you understand how to use this book most effec

tively and how best to go about learning physics. Scanning through the pref

ace will acquaint you with the various features available, both in the book and

online. Awareness of your educational resources and how to use them is essential.

Although physics is challenging, it can be mastered with the correct approach.

HOW TO STUDY

Students often ask how best to study physics and prepare for examinations. There

is no simple answer to this question, but we’d like to offer some suggestions based

on our own experiences in learning and teaching over the years.

First and foremost, maintain a positive attitude toward the subject matter. Like

learning a language, physics takes time. Those who keep applying themselves on a

*daily basis* can expect to reach understanding and succeed in the course. Keep in

mind that physics is the most fundamental of all natural sciences. Other science

courses that follow will use the same physical principles, so it is important that you

understand and are able to apply the various concepts and theories discussed in

the text. They’re relevant!

CONCEPTS AND PRINCIPLES

Students often try to do their homework without fi rst studying the basic concepts.

It is essential that you understand the basic concepts and principles *before* attempt

ing to solve assigned problems. You can best accomplish this goal by carefully

reading the textbook *before* you attend your lecture on the covered material. When

reading the text, you should jot down those points that are not clear to you. Also

be sure to make a diligent attempt at answering the questions in the Quick Quizzes

as you come to them in your reading. We have worked hard to prepare questions

that help you judge for yourself how well you understand the material. Pay care

ful attention to the many Tips throughout the text. They will help you avoid mis

conceptions, mistakes, and misunderstandings as well as maximize the effi ciency

of your time by minimizing adventures along fruitless paths. During class, take

careful notes and ask questions about those ideas that are unclear to you. Keep

in mind that few people are able to absorb the full meaning of scientifi c material

after only one reading. Your lectures and laboratory work supplement your text

book and should clarify some of the more diffi cult material. You should minimize

rote memorization of material. Successful memorization of passages from the text,

equations, and derivations does not necessarily indicate that you understand the

fundamental principles.

Your understanding will be enhanced through a combination of effi cient study

habits, discussions with other students and with instructors, and your ability to

solve the problems presented in the textbook. Ask questions whenever you think

clarifi cation of a concept is necessary.

STUDY SCHEDULE

It is important for you to set up a regular study schedule, preferably a daily one.

Make sure you read the syllabus for the course and adhere to the schedule set

by your instructor. As a general rule, you should devote about two hours of study

time for every one hour you are in class. If you are having trouble with the course,

seek the advice of the instructor or other students who have taken the course. You

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may fi nd it necessary to seek further instruction from experienced students. Very

often, instructors offer review sessions in addition to regular class periods. It is

important that you avoid the practice of delaying study until a day or two before an

exam. One hour of study a day for 14 days is far more effective than 14 hours the

day before the exam. “Cramming” usually produces disastrous results, especially

in science. Rather than undertake an all-night study session immediately before an

exam, briefl y review the basic concepts and equations and get a good night’s rest.

If you think you need additional help in understanding the concepts, in preparing

for exams, or in problem solving, we suggest you acquire a copy of the *Student Solu*

*tions Manual/Study Guide* that accompanies this textbook; this manual should be

available at your college bookstore.

USE THE FEATURES

You should make full use of the various features of the text discussed in the pref

ace. For example, marginal notes are useful for locating and describing important

equations and concepts, and **boldfaced** type indicates important statements and

defi nitions. Many useful tables are contained in the appendices, but most tables

are incorporated in the text where they are most often referenced. Appendix A is a

convenient review of mathematical techniques.

Answers to all Quick Quizzes and Example Questions, as well as odd-numbered

multiple-choice questions, conceptual questions, and problems, are given at the

end of the textbook. Answers to selected end-of-chapter problems are provided

in the *Student Solutions Manual/Study Guide.* Problem-Solving Strategies included

in selected chapters throughout the text give you additional information about

how you should solve problems. The contents provides an overview of the entire

text, and the index enables you to locate specifi c material quickly. Footnotes some

times are used to supplement the text or to cite other references on the subject

discussed.

After reading a chapter, you should be able to defi ne any new quantities intro

duced in that chapter and to discuss the principles and assumptions used to arrive

at certain key relations. The chapter summaries and the review sections of the

*Student Solutions Manual/Study Guide* should help you in this regard. In some cases,

it may be necessary for you to refer to the index of the text to locate certain topics.

You should be able to correctly associate with each physical quantity the symbol

used to represent that quantity and the unit in which the quantity is specifi ed.

Further, you should be able to express each important relation in a concise and

accurate prose statement.

PROBLEM SOLVING

R. P. Feynman, Nobel laureate in physics, once said, “You do not know anything

until you have practiced.” In keeping with this statement, we strongly advise that

you develop the skills necessary to solve a wide range of problems. Your ability to

solve problems will be one of the main tests of your knowledge of physics, so you

should try to solve as many problems as possible. It is essential that you under

stand basic concepts and principles before attempting to solve problems. It is good

practice to try to fi nd alternate solutions to the same problem. For example, you

can solve problems in mechanics using Newton’s laws, but very often an alternate

method that draws on energy considerations is more direct. You should not deceive

yourself into thinking you understand a problem merely because you have seen it

solved in class. You must be able to solve the problem and similar problems on

your own. We have cast the examples in this book in a special, two-column format

to help you in this regard. After studying an example, see if you can cover up the

right-hand side and do it yourself, using only the written descriptions on the left as

hints. Once you succeed at that, try solving the example completely on your own.

Finally, answer the question and solve the exercise. Once you have accomplished

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all these steps, you will have a good mastery of the problem, its concepts, and

mathematical technique. After studying all the Example Problems in this way, you

are ready to tackle the problems at the end of the chapter. Of these, the Guided

Problems provide another aid to learning how to solve some of the more complex

problems.

The approach to solving problems should be carefully planned. A systematic

plan is especially important when a problem involves several concepts. First, read

the problem several times until you are confi dent you understand what is being

asked. Look for any key words that will help you interpret the problem and per

haps allow you to make certain assumptions. Your ability to interpret a question

properly is an integral part of problem solving. Second, you should acquire the

habit of writing down the information given in a problem and those quantities

that need to be found; for example, you might construct a table listing both the

quantities given and the quantities to be found. This procedure is sometimes used

in the worked examples of the textbook. After you have decided on the method

you think is appropriate for a given problem, proceed with your solution. Finally,

check your results to see if they are reasonable and consistent with your initial

understanding of the problem. General problem-solving strategies of this type are

included in the text and are highlighted with a surrounding box. If you follow the

steps of this procedure, you will fi nd it easier to come up with a solution and will

also gain more from your efforts.

Often, students fail to recognize the limitations of certain equations or physical

laws in a particular situation. It is very important that you understand and remem

ber the assumptions underlying a particular theory or formalism. For example,

certain equations in kinematics apply only to a particle moving with constant

acceleration. These equations are not valid for describing motion whose accelera

tion is not constant, such as the motion of an object connected to a spring or the

motion of an object through a fl uid.

EXPERIMENTS

Because physics is a science based on experimental observations, we recommend

that you supplement the text by performing various types of “hands-on” experi

ments, either at home or in the laboratory. For example, the common Slinky™ toy

is excellent for studying traveling waves, a ball swinging on the end of a long string

can be used to investigate pendulum motion, various masses attached to the end

of a vertical spring or rubber band can be used to determine their elastic nature,

an old pair of Polaroid sunglasses and some discarded lenses and a magnifying

glass are the components of various experiments in optics, and the approximate

measure of the free-fall acceleration can be determined simply by measuring with

a stopwatch the time it takes for a ball to drop from a known height. The list of

such experiments is endless. When physical models are not available, be imagina

tive and try to develop models of your own.

An Invitation to Physics

It is our hope that you too will fi nd physics an exciting and enjoyable experience

and that you will profi t from this experience, regardless of your chosen profession.

Welcome to the exciting world of physics!

*To see the World in a Grain of Sand*

*And a Heaven in a Wild Flower*,

*Hold infi nity in the palm of your hand*

*And Eternity in an hour.*

**—William Blake, “Auguries of Innocence”**

Welcome to your MCAT Test Preparation Guide

The MCAT Test Preparation Guide makes your copy of *College Physics,* eighth edition, the most comprehensive MCAT study tool and classroom resource in introductory physics. The grid, which begins below and continues on the next two pages, outlines 12 concept-based study courses for the physics part of your MCAT exam. Use it to prepare for the MCAT, class tests, and your homework assignments.

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*Vectors*

Skill Objectives: To calculate distance, angles between vectors, and magnitudes.

Review Plan:

Distance and Angles:

Chapter 1, Sections 1.7, 1.8

Active Figure 1.6

Chapter Problems 35, 41, 44

Using Vectors:

Chapter 3, Sections 3.1, 3.2

Quick Quizzes 3.1, 3.2

Examples 3.1–3.3

Active Figure 3.3

Chapter Problems 8, 13

*Motion*

Skill Objectives: To understand motion in two dimensions and to calculate speed and velocity, centripetal acceleration, and acceleration in free-fall problems.

Review Plan:

Motion in One Dimension:

Chapter 2, Sections 2.1–2.6

Quick Quizzes 2.1–2.8

Examples 2.1–2.10

Active Figure 2.15

Chapter Problems 3, 10, 23, 31, 50, 59

Motion in Two Dimensions:

Chapter 3, Sections 3.3, 3.4

Quick Quizzes 3.4–3.7

Examples 3.3–3.7

Active Figures 3.14, 3.15

Chapter Problems 27, 33

Centripetal Acceleration:

Chapter 7, Section 7.4

Quick Quizzes 7.6, 7.7

Example 7.6

*Force*

Skill Objectives: To know and understand Newton’s laws and to calculate resultant forces and weight.

Review Plan:

Newton’s Laws:

Chapter 4, Sections 4.1–4.4

Quick Quizzes 4.1, 4.3

Examples 4.1–4.4

Active Figure 4.6

Chapter Problems 5, 7, 11

Resultant Forces:

Chapter 4, Section 4.5

Quick Quizzes 4.4, 4.5

Examples 4.7, 4.9, 4.10

Chapter Problems 19, 27, 37

*Equilibrium*

Skill Objectives: To calculate momentum and impulse, center of gravity, and torque.

Review Plan:

Momentum:

Chapter 6, Sections 6.1–6.3

Quick Quizzes 6.2–6.6

Examples 6.1–6.4, 6.6

Active Figures 6.7, 6.10, 6.13

Chapter Problems 20, 23

Torque:

Chapter 8, Sections 8.1–8.4

Examples 8.1–8.7

Chapter Problems 5, 9

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*Work*

Skill Objectives: To calculate friction, work, kinetic energy, potential energy, and power.

Review Plan:

Friction:

Chapter 4, Section 4.6

Quick Quizzes 4.6–4.8

Active Figure 4.19

Work:

Chapter 5, Section 5.1

Quick Quiz 5.1

Example 5.1

Active Figure 5.5

Chapter Problem 17

Energy:

Chapter 5, Sections 5.2, 5.3

Examples 5.4, 5.5

Quick Quizzes 5.2, 5.3

Power:

Chapter 5, Section 5.6

Examples 5.12, 5.13

*Waves*

Skill Objectives: To understand interference of waves and to calculate basic properties of waves, properties of springs, and properties of pendulums.

Review Plan:

Wave Properties:

Chapters 13, Sections 13.1–13.4, 13.7–13.11 Quick Quizzes 13.1–13.6

Examples 13.1, 13.6, 13.8–13.10

Active Figures 13.1, 13.8, 13.12, 13.13, 13.24, 13.26, 13.32, 13.33, 13.34, 13.35 Chapter Problems 11, 17, 25, 33, 45, 55, 61

Pendulum:

Chapter 13, Section 13.5

Quick Quizzes 13.7–13.9

Example 13.7

Active Figures 13.15, 13.16

Chapter Problem 39

*Matter*

Skill Objectives: To calculate pressure, density, specifi c gravity, and fl ow rates.

Review Plan:

Properties:

Chapter 9, Sections 9.1–9.3

Quick Quiz 9.1

Examples 9.1, 9.3, 9.4

Active Figure 9.3

Chapter Problem 7

Pressure:

Chapter 9, Sections 9.3–9.6

Quick Quizzes 9.2–9.6

Examples 9.4–9.9

Active Figures 9.19, 9.20

Chapter Problems 25, 43

Flow Rates:

Chapter 9, Sections 9.7, 9.8

Quick Quiz 9.7

Examples 9.11–9.14

Chapter Problem 46

*Sound*

Skill Objectives: To understand interference of waves and to calculate properties of waves, the speed of sound, Doppler shifts, and intensity.

Review Plan:

Sound Properties:

Chapter 14, Sections 14.1–14.4, 14.6 Quick Quizzes 14.1, 14.2

Examples 14.1, 14.2, 14.4, 14.5

Active Figures 14.6, 14.11

Chapter Problems 7, 27

Interference/Beats:

Chapter 14, Sections 14.7, 14.8, 14.11 Quick Quiz 14.7

Examples 14.6, 14.11

Active Figures 14.18, 14.25

Chapter Problems 37, 41, 57

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*Light*

Skill Objectives: To understand mirrors and lenses, to calculate the angles of refl ection, to use the index of refraction, and to fi nd focal lengths.

Review Plan:

Refl ection and Refraction:

Chapter 22, Sections 22.1–22.4

Quick Quizzes 22.2–22.4

Examples 22.1–22.4

Active Figures 22.4, 22.6, 22.7

Chapter Problems 11, 17, 19, 25

Mirrors and Lenses:

Chapter 23, Sections 23.1–23.6

Quick Quizzes 23.1, 23.2, 23.4–23.6 Examples 23.7, 23.8, 23.9

Active Figures 23.2, 23.16, 23.25

Chapter Problems 25, 31, 35, 39

*Electrostatics*

Skill Objectives: To understand and calculate the electric fi eld, the electrostatic force, and the electric potential.

Review Plan:

Coulomb’s Law:

Chapter 15, Sections 15.1–15.3

Quick Quiz 15.2

Examples 15.1–15.3

Active Figure 15.6

Chapter Problems 11

Electric Field:

Chapter 15, Sections 15.4, 15.5

Quick Quizzes 15.3–15.6

Examples 15.4, 15.5

Active Figures 15.11, 15.16

Chapter Problems 19, 23, 27

Potential:

Chapter 16, Sections 16.1–16.3

Quick Quizzes 16.1, 16.3–16.7

Examples 16.1, 16.4

Active Figure 16.7

Chapter Problems 7, 15

*Circuits*

Skill Objectives: To understand and calculate current, resistance, voltage, power, and energy and to use circuit analysis.

Review Plan:

Ohm’s Law:

Chapter 17, Sections 17.1–17.4

Quick Quizzes 17.1, 17.3, 17.5

Example 17.1

Chapter Problem 15

Power and Energy:

Chapter 17, Section 17.6

Quick Quizzes 17.7–17.9

Example 17.5

Active Figure 17.9

Chapter Problem 38

Circuits:

Chapter 18, Sections 18.2, 18.3

Quick Quizzes 18.3, 18.5, 18.6

Examples 18.1–18.3

Active Figures 18.2, 18.6

*Atoms*

Skill Objectives: To calculate half-life and to understand decay processes and nuclear reactions.

Review Plan:

Atoms:

Chapter 29, Sections 29.1, 29.2

Radioactive Decay:

Chapter 29, Sections 29.3–29.5

Examples 29.2, 29.5

Active Figures 29.6, 29.7

Chapter Problems 15, 19, 25, 31

Nuclear Reactions:

Chapter 29, Section 29.6

Quick Quiz 29.4

Example 29.6

Chapter Problems 35, 39

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INTRODUCTION

The goal of physics is to provide an understanding of the physical world by developing theo ries based on experiments. A physical theory is essentially a guess, usually expressed math ematically, about how a given physical system works. The theory makes certain predictions about the physical system which can then be checked by observations and experiments. If the predictions turn out to correspond closely to what is actually observed, then the theory stands, although it remains provisional. No theory to date has given a complete description of all physical phenomena, even within a given subdiscipline of physics. Every theory is a work in progress.

The basic laws of physics involve such physical quantities as force, velocity, volume, and acceleration, all of which can be described in terms of more fundamental quantities. In mechanics, the three most fundamental quantities are length (L), mass (M), and time (T); all other physical quantities can be constructed from these three.

1.1 STANDARDS OF LENGTH, MASS, AND TIME To communicate the result of a measurement of a certain physical quantity, a *unit* for the quantity must be defi ned. If our fundamental unit of length is defi ned to be 1.0 meter, for example, and someone familiar with our system of measure ment reports that a wall is 2.0 meters high, we know that the height of the wall is twice the fundamental unit of length. Likewise, if our fundamental unit of mass is defi ned as 1.0 kilogram and we are told that a person has a mass of 75 kilograms, then that person has a mass 75 times as great as the fundamental unit of mass.

In 1960 an international committee agreed on a standard system of units for the fundamental quantities of science, called **SI** (Système International). Its units of length, mass, and time are the meter, kilogram, and second, respectively.

Length

In 1799 the legal standard of length in France became the meter, defi ned as one ten-millionth of the distance from the equator to the North Pole. Until 1960,

1

Stonehenge, in southern England, was built thousands of years ago to help keep track of the seasons. At dawn on the summer solstice the sun can be seen through these giant stone slabs.

1.1 Standards of Length, Mass, and Time

1.2 The Building Blocks of Matter

1.3 Dimensional Analysis

1.4 Uncertainty in

Measurement and

Signifi cant Figures

1.5 Conversion of Units

1.6 Estimates and Order-of Magnitude Calculations

1.7 Coordinate Systems

1.8 Trigonometry

1.9 Problem-Solving Strategy

1

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the offi cial length of the meter was the distance between two lines on a specifi c

bar of platinum-iridium alloy stored under controlled conditions. This standard

was abandoned for several reasons, the principal one being that measurements

of the separation between the lines are not precise enough. In 1960 the meter

was defi ned as 1 650 763.73 wavelengths of orange-red light emitted from a kryp

Defi nition of the meter R

Defi nition of the kilogram R

TIP 1.1 No Commas in Numbers with Many Digits

In science, numbers with more than three digits are written in groups of three digits separated by spaces rather than commas; so that 10 000 is the same as the common American notation 10,000. Similarly, p 3.14159265 is written as 3.141 592 65.

Defi nition of the second R

FIGURE 1.1 (a) The National Stand ard Kilogram No. 20, an accurate copy of the International Standard Kilogram kept at Sèvres, France, is housed under a double bell jar in a vault at the National Institute of Standards and Technology. (b) The nation’s primary time standard is a cesium fountain atomic clock devel oped at the National Institute of Standards and Technology laborato ries in Boulder, Colorado. This clock will neither gain nor lose a second in 20 million years.

ton-86 lamp. In October 1983 this defi nition was abandoned also, and **the meter was redefi ned as the distance traveled by light in vacuum during a time interval of 1/299 792 458 second**. This latest defi nition establishes the speed of light at 299 792 458 meters per second.

Mass

**The SI unit of mass, the kilogram, is defi ned as the mass of a specifi c platinum iridium alloy cylinder kept at the International Bureau of Weights and Measures at Sèvres, France** (similar to that shown in Fig. 1.1a). As we’ll see in Chapter 4, mass is a quantity used to measure the resistance to a change in the motion of an object. It’s more diffi cult to cause a change in the motion of an object with a large mass than an object with a small mass.

Time

Before 1960, the time standard was defi ned in terms of the average length of a solar day in the year 1900. (A solar day is the time between successive appearances of the Sun at the highest point it reaches in the sky each day.) The basic unit of time, the second, was defi ned to be (1/60)(1/60)(1/24) 1/86 400 of the average solar day. In 1967 the second was redefi ned to take advantage of the high preci

sion attainable with an atomic clock, which uses the characteristic frequency of the light emitted from the cesium-133 atom as its “reference clock.” **The second is now defi ned as 9 192 631 700 times the period of oscillation of radiation from the cesium atom.** The newest type of cesium atomic clock is shown in Figure 1.1b.

Approximate Values for Length, Mass, and Time Intervals Approximate values of some lengths, masses, and time intervals are presented in Tables 1.1, 1.2, and 1.3, respectively. Note the wide ranges of values. Study these tables to get a feel for a kilogram of mass (this book has a mass of about 2 kilograms), a time interval of 1010 seconds (one century is about 3 109 seconds), or two meters of length (the approximate height of a forward on a basketball



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TABLE 1.1

**Approximate Values of Some Measured Lengths**

1.1 Standards of Length, Mass, and Time 3

TABLE 1.2

**Approximate Values of Some**

**Length (m)**

Distance from Earth to most remote known quasar 1 1026 Distance from Earth to most remote known normal galaxies 4 1025 Distance from Earth to nearest large galaxy (M31, the Andromeda galaxy) 2 1022 Distance from Earth to nearest star (Proxima Centauri) 4 1016 One light year 9 1015 Mean orbit radius of Earth about Sun 2 1011 Mean distance from Earth to Moon 4 108

Mean radius of Earth 6 106 Typical altitude of satellite orbiting Earth 2 105 Length of football fi eld 9 101 Length of housefl y 5 10 3

Size of smallest dust particles 1 10 4 Size of cells in most living organisms 1 10 5 Diameter of hydrogen atom 1 10 10 Diameter of atomic nucleus 1 10 14 Diameter of proton 1 10 15

team). Appendix A reviews the notation for powers of 10, such as the expression of the number 50 000 in the form 5 104.

Systems of units commonly used in physics are the Système International, in which the units of length, mass, and time are the meter (m), kilogram (kg), and second (s); the cgs, or Gaussian, system, in which the units of length, mass, and time are the centimeter (cm), gram (g), and second; and the U.S. customary sys

tem, in which the units of length, mass, and time are the foot (ft), slug, and sec ond. SI units are almost universally accepted in science and industry, and will be used throughout the book. Limited use will be made of Gaussian and U.S. custom ary units.

Some of the most frequently used “metric” (SI and cgs) prefi xes representing powers of 10 and their abbreviations are listed in Table 1.4. For example, 10 3 m is

TABLE 1.3

**Approximate Values of Some Time Intervals**

**Time Interval (s)**

Age of Universe 5 1017 Age of Earth 1 1017 Average age of college student 6 108

One year 3 107

One day 9 104  Time between normal heartbeats 8 10 1 Perioda of audible sound waves 1 10 3 Perioda of typical radio waves 1 10 6 Perioda of vibration of atom in solid 1 10 13

Perioda of visible light waves 2 10 15 Duration of nuclear collision 1 10 22 Time required for light to travel across a proton 3 10 24

aA *period* is defi ned as the time required for one complete vibration.

**Masses**

**Mass (kg)**

Observable Universe 1 1052 Milky Way galaxy 7 1041 Sun 2 1030 Earth 6 1024 Moon 7 1022 Shark 1 102

Human 7 101 Frog 1 10 1 Mosquito 1 10 5 Bacterium 1 10 15 Hydrogen atom 2 10 27 Electron 9 10 31

TABLE 1.4

**Some Prefi xes for Powers of Ten Used with “Metric” (SI and cgs) Units**

**Power Prefi x Abbreviation** 10 18 atto- a 10 15 femto- f 10 12 pico- p 10 9 nano- n 10 6 micro- m 10 3 milli- m 10 2 centi- c 10 1 deci- d 101 deka- da 103 kilo- k 106 mega- M 109 giga- G 1012 tera- T 1015 peta- P 1018 exa- E

4 Chapter 1 Introduction

equivalent to 1 millimeter (mm), and 103 m is 1 kilometer (km). Likewise, 1 kg is

equal to 103 g, and 1 megavolt (MV) is 106 volts (V).

1.2 THE BUILDING BLOCKS OF MATTER

A 1-kg ( 2-lb) cube of solid gold has a length of about 3.73 cm ( 1.5 in.) on a

side. If the cube is cut in half, the two resulting pieces retain their chemical iden

tity as solid gold. But what happens if the pieces of the cube are cut again and

again, indefi nitely? The Greek philosophers Leucippus and Democritus couldn’t

accept the idea that such cutting could go on forever. They speculated that the

process ultimately would end when it produced a particle that could no longer

be cut. In Greek, *atomos* means “not sliceable.” From this term comes our English

word *atom*, once believed to be the smallest particle of matter but since found to be

a composite of more elementary particles.

The atom can be naively visualized as a miniature Solar System, with a dense,

positively charged nucleus occupying the position of the Sun and negatively

charged electrons orbiting like planets. This model of the atom, fi rst developed

by the great Danish physicist Niels Bohr nearly a century ago, led to the under

standing of certain properties of the simpler atoms such as hydrogen but failed to

Gold cube

Nucleus



Neutron

Gold

Gold atoms

explain many fi ne details of atomic structure.

Notice the size of a hydrogen atom, listed in Table 1.1, and the size of a pro ton—the nucleus of a hydrogen atom—one hundred thousand times smaller. If the proton were the size of a Ping Pong ball, the electron would be a tiny speck about the size of a bacterium, orbiting the proton a kilometer away! Other atoms are similarly constructed. So there is a surprising amount of empty space in ordi nary matter.

After the discovery of the nucleus in the early 1900s, questions arose concerning its structure. The exact composition of the nucleus hasn’t been defi ned completely even today, but by the early 1930s scientists determined that two basic entities— protons and neutrons—occupy the nucleus. The *proton* is nature’s fundamental carrier of positive charge, equal in magnitude but opposite in sign to the charge on the electron. The number of protons in a nucleus determines what the element is. For instance, a nucleus containing only one proton is the nucleus of an atom of hydrogen, regardless of how many neutrons may be present. Extra neutrons cor

respond to different isotopes of hydrogen— deuterium and tritium—which react chemically in exactly the same way as hydrogen, but are more massive. An atom having two protons in its nucleus, similarly, is always helium, although again, dif

nucleus

Proton

u u

d

fering numbers of neutrons are possible.

The existence of *neutrons* was verifi ed conclusively in 1932. A neutron has no charge and has a mass about equal to that of a proton. One of its primary purposes is to act as a “glue” to hold the nucleus together. If neutrons were not present, the repulsive electrical force between the positively charged protons would cause the nucleus to fl y apart.

The division doesn’t stop here; it turns out that protons, neutrons, and a zoo of other exotic particles are now thought to be composed of six particles called **quarks** (rhymes with “forks,” though some rhyme it with “sharks”). These particles have been given the names *up, down, strange, charm, bottom*, and *top*. The up, charm,

Quark composition of a proton

FIGURE 1.2 Levels of organization in matter. Ordinary matter consists of atoms, and at the center of each atom is a compact nucleus consisting of protons and neutrons. Protons and neutrons are composed of quarks. The quark composition of a proton is shown.

and top quarks each carry a charge equal to 23 that of the proton, whereas the down, strange, and bottom quarks each carry a charge equal to 13 the proton charge. The proton consists of two up quarks and one down quark (see Fig. 1.2), giving the correct charge for the proton, 1. The neutron is composed of two down quarks and one up quark and has a net charge of zero.

The up and down quarks are suffi cient to describe all normal matter, so the exis tence of the other four quarks, indirectly observed in high-energy experiments, is something of a mystery. It’s also possible that quarks themselves have internal

1.3 Dimensional Analysis 5

structure. Many physicists believe that the most fundamental particles may be tiny

loops of vibrating string.

1.3 DIMENSIONAL ANALYSIS

In physics the word *dimension* denotes the physical nature of a quantity. The dis

tance between two points, for example, can be measured in feet, meters, or fur

longs, which are different ways of expressing the dimension of *length*.

The symbols used in this section to specify the dimensions of length, mass,

and time are L, M, and T, respectively. Brackets [ ] will often be used to denote the

dimensions of a physical quantity. In this notation, for example, the dimensions of

velocity *v* are written [*v*] L/T, and the dimensions of area *A* are [*A*] L2. The

dimensions of area, volume, velocity, and acceleration are listed in Table 1.5, along

with their units in the three common systems. The dimensions of other quantities,

such as force and energy, will be described later as they are introduced.

In physics it’s often necessary either to derive a mathematical expression or

equation or to check its correctness. A useful procedure for doing this is called

**dimensional analysis**, which makes use of the fact that **dimensions can be treated**

**as algebraic quantities**. Such quantities can be added or subtracted only if they

have the same dimensions. It follows that the terms on the opposite sides of an

equation must have the same dimensions. If they don’t, the equation is wrong. If

they do, the equation is probably correct, except for a possible constant factor.

To illustrate this procedure, suppose we wish to derive a formula for the distance

*x* traveled by a car in a time *t* if the car starts from rest and moves with constant

acceleration *a*. The quantity *x* has the dimension length: [*x*] L. Time *t*, of course,

has dimension [*t*] T. Acceleration is the change in velocity *v* with time. Because

*v* has dimensions of length per unit time, or [*v*] L/T, acceleration must have

dimensions [*a*] L/T2. We organize this information in the form of an equation:

3*a*4 5 3*v*4

T 5 LT2 5 3*x*4

3*t*45 L/T

3*t*42

Looking at the left- and right-hand sides of this equation, we might now guess that *a* 5 *x*

*t*2 S *x* 5 *at* 2

This expression is not quite correct, however, because there’s a constant of pro portionality—a simple numerical factor—that can’t be determined solely through dimensional analysis. As will be seen in Chapter 2, it turns out that the correct expression is *x* 5 12*at* 2 .

When we work algebraically with physical quantities, dimensional analysis allows us to check for errors in calculation, which often show up as discrepancies in units. If, for example, the left-hand side of an equation is in meters and the right-hand side is in meters per second, we know immediately that we’ve made an error.

TABLE 1.5

**Dimensions and Some Units of Area, Volume, Velocity, and Acceleration System Area (L**2**) Volume (L**3**) Velocity (L/T) Acceleration (L/T**2**)** SI m2 m3 m/s m/s2 cgs cm2 cm3 cm/s cm/s2 U.S. customary ft2 ft3 ft/s ft/s2

6 Chapter 1 Introduction

EXAMPLE 1.1 Analysis of an Equation

Goal Check an equation using dimensional analysis.

Problem Show that the expression *v*  *v*0  *at* is dimensionally correct, where *v* and *v*0 represent velocities, *a* is acceleration, and *t* is a time interval.

Strategy Analyze each term, fi nding its dimensions, and then check to see if all the terms agree with each other.

Solution

Find dimensions for *v* and *v*0. 3*v*4 5 3*v*0 4 5 LT Find the dimensions of *at*. 3*at*4 5 LT2 1T2 5 LT

Remarks All the terms agree, so the equation is dimensionally correct.

QUESTION 1.1

True or False. An equation that is dimensionally correct is always physically correct, up to a constant of proportionality.

EXERCISE 1.1

Determine whether the equation *x*  *vt*2 is dimensionally correct. If not, provide a correct expression, up to an over all constant of proportionality.

Answer Incorrect. The expression *x*  *vt* is dimensionally correct.

EXAMPLE 1.2 Find an Equation

Goal Derive an equation by using dimensional analysis.

Problem Find a relationship between a constant acceleration *a*, speed *v*, and distance *r* from the origin for a par ticle traveling in a circle.

Strategy Start with the term having the most dimensionality, *a*. Find its dimensions, and then rewrite those dimen sions in terms of the dimensions of *v* and *r*. The dimensions of time will have to be eliminated with *v*, because that’s the only quantity in which the dimension of time appears.

Solution

Write down the dimensions of *a*: 3*a*4 5 LT2

Solve the dimensions of speed for T: 3*v*4 5 LTS T 5 L3*v*4

1L/3*v*4 2 2 5 3*v*42

Substitute the expression for T into the equation for [*a*]: 3*a*4 5 LT2 5 L L

Substitute L [*r*], and guess at the equation: 3*a*4 5 3*v*42 3*r*4 S *a* 5 *v* 2*r*

Remarks This is the correct equation for centripetal acceleration—acceleration towards the center of motion—to be discussed in Chapter 7. In this case it isn’t necessary to introduce a numerical factor. Such a factor is often dis played explicitly as a constant *k* in front of the right-hand side—for example, *a*  *kv*2/*r*. As it turns out, *k*  1 gives the correct expression.

1.4 Uncertainty in Measurement and Signifi cant Figures 7

QUESTION 1.2

True or False: Replacing *v* by *r*/*t* in the fi nal answer also gives a dimensionally correct equation.

EXERCISE 1.2

In physics, energy *E* carries dimensions of mass times length squared divided by time squared. Use dimensional analysis to derive a relationship for energy in terms of mass *m* and speed *v*, up to a constant of proportionality. Set the speed equal to *c*, the speed of light, and the constant of proportionality equal to 1 to get the most famous equa tion in physics.

Answer *E*  *kmv* 2 S *E*  *mc* 2 when *k*  1 and *v*  *c*.

1.4 UNCERTAINTY IN MEASUREMENT

AND SIGNIFICANT FIGURES

Physics is a science in which mathematical laws are tested by experiment. No physi

cal quantity can be determined with complete accuracy because our senses are

physically limited, even when extended with microscopes, cyclotrons, and other

gadgets.

Knowing the experimental uncertainties in any measurement is very important.

Without this information, little can be said about the fi nal measurement. Using

a crude scale, for example, we might fi nd that a gold nugget has a mass of 3 kilo

grams. A prospective client interested in purchasing the nugget would naturally

want to know about the accuracy of the measurement, to ensure paying a fair

price. He wouldn’t be happy to fi nd that the measurement was good only to within

a kilogram, because he might pay for three kilograms and get only two. Of course,

he might get four kilograms for the price of three, but most people would be hesi

tant to gamble that an error would turn out in their favor.

Accuracy of measurement depends on the sensitivity of the apparatus, the skill

of the person carrying out the measurement, and the number of times the mea

surement is repeated. There are many ways of handling uncertainties, and here

we’ll develop a basic and reliable method of keeping track of them in the measure

ment itself and in subsequent calculations.

Suppose that in a laboratory experiment we measure the area of a rectangular

plate with a meter stick. Let’s assume that the accuracy to which we can measure a

particular dimension of the plate is 0.1 cm. If the length of the plate is measured

to be 16.3 cm, we can claim only that it lies somewhere between 16.2 cm and 16.4

cm. In this case, we say that the measured value has three signifi cant fi gures. Like

wise, if the plate’s width is measured to be 4.5 cm, the actual value lies between

4.4 cm and 4.6 cm. This measured value has only two signifi cant fi gures. We could

write the measured values as 16.3 0.1 cm and 4.5 0.1 cm. In general, **a signifi -**

**cant fi gure is a reliably known digit** (other than a zero used to locate a decimal

point).

Suppose we would like to fi nd the area of the plate by mul tiplying the two mea

sured values together. The fi nal value can range between (16.3 0.1 cm)(4.5

0.1 cm) (16.2 cm)(4.4 cm) 71.28 cm2 and (16.3 0.1 cm)(4.5 0.1 cm)

(16.4 cm)(4.6 cm) 75.44 cm2. Claiming to know anything about the hundredths

place, or even the tenths place, doesn’t make any sense, because it’s clear we

can’t even be certain of the units place, whether it’s the 1 in 71, the 5 in 75, or

somewhere in between. The tenths and the hundredths places are clearly not sig

nifi cant. We have some information about the units place, so that number is sig

nifi cant. Multiplying the numbers at the middle of the uncertainty ranges gives

(16.3 cm)(4.5 cm) 73.35 cm2, which is also in the middle of the area’s uncer

tainty range. Because the hundredths and tenths are not signifi cant, we drop them

and take the answer to be 73 cm2, with an uncertainty of 2 cm2. Note that the

answer has two signifi cant fi gures, the same number of fi gures as the least accu

rately known quantity being multiplied, the 4.5-cm width.

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There are two useful rules of thumb for determining the number of signifi cant

fi gures. The fi rst, concerning multiplication and division, is as follows: **In multiply**

**ing (dividing) two or more quantities, the number of signifi cant fi gures in the**

**fi nal product (quotient) is the same as the number of signifi cant fi gures in the**

***least accurate* of the factors being combined, where *least accurate* means *having***

***the lowest number of signifi cant fi gures*.**

To get the fi nal number of signifi cant fi gures, it’s usually necessary to do some

rounding. If the last digit dropped is less than 5, simply drop the digit. If the last

digit dropped is greater than or equal to 5, raise the last retained digit by one.

EXAMPLE 1.3 Installing a Carpet

Goal Apply the multiplication rule for signifi cant fi gures.

Problem A carpet is to be installed in a room of length 12.71 m and width 3.46 m. Find the area of the room, retain ing the proper number of signifi cant fi gures.

Strategy Count the signifi cant fi gures in each number. The smaller result is the number of signifi cant fi gures in the answer.

Solution

Count signifi cant fi gures: 12.71 m S 4 significant figures 3.46 m S 3 significant figures

Multiply the numbers, keeping only three digits: 12.71 m 3 3.46 m 5 43.976 6 m2 S 44.0 m2

Remarks In reducing 43.976 6 to three signifi cant fi gures, we used our rounding rule, adding 1 to the 9, which made 10 and resulted in carrying 1 to the unit’s place.

QUESTION 1.3

What would the answer have been if the width were given as 3.460 m?

EXERCISE 1.3

Repeat this problem, but with a room measuring 9.72 m long by 5.3 m wide.

Answer 52 m2

TIP 1.2 Using Calculators

Calculators were designed by engineers to yield as many digits as the memory of the calculator chip permitted, so be sure to round the fi nal answer down to the correct number of signifi cant fi gures.

Zeros may or may not be signifi cant fi gures. Zeros used to position the decimal point in such numbers as 0.03 and 0.007 5 are not signifi cant (but are useful in avoiding errors). Hence, 0.03 has one signifi cant fi gure, and 0.007 5 has two.

When zeros are placed after other digits in a whole number, there is a possibil ity of misinterpretation. For example, suppose the mass of an object is given as 1 500 g. This value is ambiguous, because we don’t know whether the last two zeros are being used to locate the decimal point or whether they represent signifi cant fi gures in the measurement.

Using scientifi c notation to indicate the number of signifi cant fi gures removes this ambiguity. In this case, we express the mass as 1.5 103 g if there are two sig nifi cant fi gures in the measured value, 1.50 103 g if there are three signifi cant fi gures, and 1.500 103 g if there are four. Likewise, 0.000 15 is expressed in scien tifi c notation as 1.5 10 4 if it has two signifi cant fi gures or as 1.50 10 4 if it has three signifi cant fi gures. The three zeros between the decimal point and the digit 1 in the number 0.000 15 are not counted as signifi cant fi gures because they only locate the decimal point. In this book, **most of the numerical examples and end of-chapter problems will yield answers having two or three signifi cant fi gures.**

For addition and subtraction, it’s best to focus on the number of decimal places in the quantities involved rather than on the number of signifi cant fi gures. **When numbers are added (subtracted), the number of decimal places in the result should equal the smallest number of decimal places of any term in the sum (difference)**. For example, if we wish to compute 123 (zero decimal places) 5.35 (two decimal places), the answer is 128 (zero decimal places) and not 128.35. If we compute the sum 1.000 1 (four decimal places) 0.000 3 (four deci mal places) 1.000 4, the result has the correct number of decimal places, namely four. Observe that the rules for multiplying signifi cant fi gures don’t work here because the answer has fi ve signifi cant fi gures even though one of the terms in the sum, 0.000 3, has only one signifi cant fi gure. Likewise, if we perform the subtrac tion 1.002 0.998 0.004, the result has three decimal places because each term in the subtraction has three decimal places.

To show why this rule should hold, we return to the fi rst example in which we added 123 and 5.35, and rewrite these numbers as 123.*xxx* and 5.35*x*. Digits writ ten with an *x* are completely unknown and can be any digit from 0 to 9. Now we line up 123.*xxx* and 5.35*x* relative to the decimal point and perform the addition, using the rule that an unknown digit added to a known or unknown digit yields an unknown:

123.*xxx*

5.35*x*

128.*xxx*

The answer of 128.xxx means that we are justifi ed only in keeping the number 128 because everything after the decimal point in the sum is actually unknown. The example shows that the controlling uncertainty is introduced into an addition or subtraction by the term with the smallest number of decimal places.

In performing any calculation, especially one involving a number of steps, there will always be slight discrepancies introduced by both the rounding process and the algebraic order in which steps are carried out. For example, consider 2.35 5.89/1.57. This computation can be performed in three different orders. First, we have 2.35 5.89 13.842, which rounds to 13.8, followed by 13.8/1.57 8.789 8, rounding to 8.79. Second, 5.89/1.57 3.751 6, which rounds to 3.75, resulting in 2.35 3.75 8.812 5, rounding to 8.81. Finally, 2.35/1.57 1.496 8 rounds to 1.50, and 1.50 5.89 8.835 rounds to 8.84. So three different algebraic orders, following the rules of rounding, lead to answers of 8.79, 8.81, and 8.84, respectively. Such minor discrepancies are to be expected, because the last signifi cant digit is only one representative from a range of possible values, depending on experimen tal uncertainty. The discrepancies can be reduced by carrying one or more extra digits during the calculation. In our examples, however, intermediate results will be rounded off to the proper number of signifi cant fi gures, and only those digits will be carried forward. In experimental work, more sophisticated techniques are used to determine the accuracy of an experimental result.

1.5 CONVERSION OF UNITS

Sometimes it’s necessary to convert units from one system to another. Conversion n

factors between the SI and U.S. customary systems for units of length are as follows:

o

t

s

o

B

k

c

1 mile 1 609 m 1.609 km 1 ft 0.304 8 m 30.48 cm

o

t

S

/

s

e

n

1 m 39.37 in. 3.281 ft 1 in. 0.025 4 m 2.54 cm

r

a

B

.

E

y

A more extensive list of conversion factors can be found on the inside front cover

l

l

i

B

of this book.

Units can be treated as algebraic quantities that can “cancel” each other. We can make a fraction with the conversion that will cancel the units we don’t want,

1.5 Conversion of Units 9

This road sign near Raleigh, North Carolina, shows distances in miles and kilometers. How accurate are the conversions?

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and multiply that fraction by the quantity in question. For example, suppose we

want to convert 15.0 in. to centimeters. Because 1 in. 2.54 cm, we fi nd that

15.0 in. 5 15.0 in. 3 a2.54 cm

1.00in. ~~b~~ 5 38.1 cm

The next two examples show how to deal with problems involving more than

one conversion and with powers.

EXAMPLE 1.4 Pull Over, Buddy!

Goal Convert units using several conversion factors.

Problem If a car is traveling at a speed of 28.0 m/s, is the driver exceeding the speed limit of 55.0 mi/h?

Strategy Meters must be converted to miles and seconds to hours, using the conversion factors listed on the inside front cover of the book. Here, three factors will be used.

Solution

Convert meters to miles: 28.0 m/s 5 a28.0 ms ~~b~~ a 1.00 mi

1 609 m~~b~~ 5 1.74 3 1022 mi/s

Convert seconds to hours: 1.74 3 1022 mi/s 5 a1.74 3 1022 mis ~~b~~ a60.0 smin~~b~~ a60.0 min

h ~~b~~

62.6 mi/h

Remarks The driver should slow down because he’s exceeding the speed limit.

QUESTION 1.4

Repeat the conversion, using the relationship 1.00 m/s 2.24 mi/h. Why is the answer slightly different?

EXERCISE 1.4

Convert 152 mi/h to m/s.

Answer 68.0 m/s

EXAMPLE 1.5 Press the Pedal to the Metal

Goal Convert a quantity featuring powers of a unit.

Problem The traffi c light turns green, and the driver of a high-performance car slams the accelerator to the fl oor. The accelerometer registers 22.0 m/s2. Convert this reading to km/min2.

Strategy Here we need one factor to convert meters to kilometers and another two factors to convert seconds squared to minutes squared.

Solution

Multiply by the three factors:22.0 m

1.00 s2 a 1.00 km

1.00 3 103 m~~b~~ a 60.0 s

1.00 min~~b~~

2

5 79.2 km min2

Remarks Notice that in each conversion factor the numerator equals the denominator when units are taken into account. A common error in dealing with squares is to square the units inside the parentheses while forgetting to square the numbers!

1.6 Estimates and Order-of-Magnitude Calculations 11

QUESTION 1.5

What time conversion factor would be used to further convert the answer to km/h2?

EXERCISE 1.5

Convert 4.50 103 kg/m3 to g/cm3.

Answer 4.50 g/cm3

1.6 ESTIMATES AND ORDER-OF-MAGNITUDE CALCULATIONS

Getting an exact answer to a calculation may often be diffi cult or impossible, either for mathematical reasons or because limited information is available. In these cases, estimates can yield useful approximate answers that can determine whether a more precise calculation is necessary. Estimates also serve as a partial check if the exact calculations are actually carried out. If a large answer is expected but a small exact answer is obtained, there’s an error somewhere.

For many problems, knowing the approximate value of a quantity—within a factor of 10 or so—is suffi cient. This approximate value is called an **order-of magnitude** estimate, and requires fi nding the power of 10 that is closest to the actual value of the quantity. For example, 75 kg 102 kg, where the symbol means “is on the order of” or “is approximately.” Increasing a quantity by three orders of magnitude means that its value increases by a factor of 103  1 000.

Occasionally the process of making such estimates results in fairly crude answers, but answers ten times or more too large or small are still useful. For example, suppose you’re interested in how many people have contracted a certain disease. Any estimates under ten thousand are small compared with Earth’s total population, but a million or more would be alarming. So even relatively imprecise information can provide valuable guidance.

In developing these estimates, you can take considerable liberties with the num bers. For example, p 1, 27 10, and 65 100. To get a less crude estimate, it’s permissible to use slightly more accurate numbers (e.g., p 3, 27 30, 65 70). Better accuracy can also be obtained by systematically underestimating as many numbers as you overestimate. Some quantities may be completely unknown, but it’s standard to make reasonable guesses, as the examples show.

EXAMPLE 1.6 Brain Cells Estimate

Goal Develop a simple estimate.

Problem Estimate the number of cells in the human brain.

Strategy Estimate the volume of a human brain and divide by the estimated volume of one cell. The brain is located in the upper portion of the head, with a volume that could be approximated by a cube 20 cm on a side.

Solution

Brain cells, consisting of about 10% neurons and 90% glia, vary greatly in size, with dimensions ranging from a few microns to a meter or so. As a guess, take *d*  10 microns as a typical dimension and consider a cell to be a cube with each side having that length.

Estimate of the volume of a human brain: *V*brain 5 ,3 < 10.2 m2 3 5 8 3 1023 m3 < 1 3 1022 m3 Estimate the volume of a cell: *V*cell 5 *d* 3 < 110 3 1026 m2 3 5 1 3 10215 m3 Divide the volume of a brain by the volume of a cell: number of cells 5 *V*brain

*V*cell5 0.01 m3

1 3 10215 m3 5 1 3 1013 cells

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Remarks Notice how little attention was paid to obtaining precise values. That’s the nature of an estimate.

QUESTION 1.6

Would 1012 cells also be a reasonable estimate? What about 109 cells? Explain.

EXERCISE 1.6

Estimate the total number of cells in the human body.

Answer 1014 (Answers may vary.)

EXAMPLE 1.7 Stack One-Dollar Bills to the Moon

Goal Estimate the number of stacked objects required to reach a given height.

Problem How many one-dollar bills, stacked one on top of the other, would reach the Moon?

Strategy The distance to the Moon is about 400 000 km. Guess at the number of dollar bills in a millimeter, and multiply the distance by this number, after converting to consistent units.

Solution

1 mm a103 mm

1 m ~~b~~ a103 m

We estimate that ten stacked bills form a layer of 1 mm. Convert mm to km:

10 bills

1 km ~~b~~ 5 107 bills 1 km

Multiply this value by the approximate lunar distance:

# of dollar bills , 14 3 105 km2 a107 bills

1 km ~~b~~ 5 4 3 1012 bills

Remarks That’s the same order of magnitude as the U.S. national debt!

QUESTION 1.7

Based on the answer, about how many stacked pennies would reach the Moon?

EXERCISE 1.7

How many pieces of cardboard, typically found at the back of a bound pad of paper, would you have to stack up to match the height of the Washington monument, about 170 m tall?

Answer 105 (Answers may vary.)

EXAMPLE 1.8 Number of Galaxies in the Universe

Goal Estimate a volume and a number density, and combine. 

Problem Given that astronomers can see about 10 billion light years into space

A

S

and that there are 14 galaxies in our local group, 2 million light years from the next

A

N

d

local group, estimate the number of galaxies in the observable universe. (Note:

n

a

,

m

One light year is the distance traveled by light in one year, about 9.5 1015 m.) (See

a

e

t

S

-

Fig. 1.3.)

F

D

H

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h

t

Strategy From the known information, we can estimate the number of galaxies

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c

S

per unit volume. The local group of 14 galaxies is contained in a sphere a million

T

S

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s

lightyears in radius, with the Andromeda group in a similar sphere, so there are

m

a

i

l

l

i

about 10 galaxies within a volume of radius 1million light years. Multiply that num

W

.

R

ber density by the volume of the observable universe.

Solution

Compute the approximate volume *Vlg* of the local group of galaxies:

FIGURE 1.3 In this deep-space

photograph, there are few stars—just

galaxies without end.

*Vlg* 5 43p*r* 3 , 1106 ly2 3 5 1018 ly3

1.7 Coordinate Systems 13

Estimate the density of galaxies: density of galaxies 5 # of galaxies V*lg*

1018 ly3 5 10217 galaxies

ly3

Compute the approximate volume of the observable

universe:

, 10 galaxies

*Vu* 5 43p*r* 3 , 11010 ly2 3 5 1030 ly3

Multiply the density of galaxies by *Vu*: # of galaxies (density of galaxies)*Vu* 5 a10217 galaxies

ly3 ~~b~~ 11030 ly3 2

1013 galaxies

Remarks Notice the approximate nature of the compu tation, which uses 4p/3 1 on two occasions and 14 10 for the number of galaxies in the local group. This is completely justifi ed: Using the actual numbers would be pointless, because the other assumptions in the prob lem—the size of the observable universe and the idea that the local galaxy density is representative of the den sity everywhere—are also very rough approximations. Further, there was nothing in the problem that required using volumes of spheres rather than volumes of cubes. Despite all these arbitrary choices, the answer still gives useful information, because it rules out a lot of reason able possible answers. Before doing the calculation, a guess of a billion galaxies might have seemed plausible.

1.7 COORDINATE SYSTEMS

QUESTION 1.8

Of the fourteen galaxies in the local group, only one, the Milky Way, is not a dwarf galaxy. Estimate the number of galaxies in the universe that are not dwarfs.

EXERCISE 1.8

Given that the nearest star is about 4 light years away and that the galaxy is roughly a disk 100 000 light years across and a thousand light years thick, estimate the number of stars in the Milky Way galaxy.

Answer 1012 stars (Estimates will vary. The actual answer is probably close to 4 1011 stars.)

Many aspects of physics deal with locations in space, which require the defi nition of a coordinate system. A point on a line can be located with one coordinate, a point in a plane with two coordinates, and a point in space with three.

A coordinate system used to specify locations in space consists of the following:

• A fi xed reference point *O*, called the *origin*

• A set of specifi ed axes, or directions, with an appropriate scale and labels on the axes

• Instructions on labeling a point in space relative to the origin and axes

One convenient and commonly used coordinate system is the **Cartesian coordi** *y* (m)

**nate system**, sometimes called the **rectangular coordinate system**. Such a system in two dimensions is illustrated in Figure 1.4. An arbitrary point in this system 10

is labeled with the coordinates (*x*, *y*). For example, the point *P* in the fi gure has

(*x, y*)

coordinates (5, 3). If we start at the origin *O*, we can reach *P* by moving 5 meters horizontally to the right and then 3 meters vertically upwards. In the same way, the

*Q*

5

*P*

point *Q* has coordinates ( 3, 4), which corresponds to going 3 meters horizontally

to the left of the origin and 4 meters vertically upwards from there.

(–3, 4) (5, 3)

Positive *x* is usually selected as right of the origin and positive *y* upward from *O*

the origin, but in two dimensions this choice is largely a matter of taste. (In three

5 10

*x* (m)

dimensions, however, there are “right-handed” and “left-handed” coordinates, which lead to minus sign differences in certain operations. These will be addressed as needed.)

FIGURE 1.4 Designation of points in a two-dimensional Cartesian coor dinate system. Every point is labeled with coordinates (*x*, *y*).

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Sometimes it’s more convenient to locate a point in space by its **plane polar**

(*r,* )

θ

θ

*O*

*r*

= 0°

θ

**coordinates** (*r*, u), as in Figure 1.5. In this coordinate system, an origin *O* and a reference line are selected as shown. A point is then specifi ed by the distance *r* from the origin to the point and by the angle u between the reference line and a line drawn from the origin to the point. The standard reference line is usually selected to be the positive *x*-axis of a Cartesian coordinate system. The angle u is con sidered positive when measured counterclockwise from the reference line and negative when measured clockwise. For example, if a point is specifi ed by the polar

Reference

line

FIGURE 1.5 A polar coordinate system.

*y*

sin = *yr*

θ

cos = *xr*

coordinates 3 m and 60°, we locate this point by moving out 3 m from the origin at an angle of 60° above (counterclockwise from) the reference line. A point speci fi ed by polar coordinates 3 m and 60° is located 3 m out from the origin and 60° below (clockwise from) the reference line.

1.8 TRIGONOMETRY

Consider the right triangle shown in Active Figure 1.6, where side *y* is opposite the angle u, side *x* is adjacent to the angle u, and side *r* is the hypotenuse of the tri angle. The basic trigonometric functions defi ned by such a triangle are the ratios of the lengths of the sides of the triangle. These relationships are called the sine (sin), cosine (cos), and tangent (tan) functions. In terms of u, the basic trigonomet ric functions are as follows:1

θ

tan = *xy*

θ

θ

*r y x*

sin u 5side opposite u

hypotenuse 5 *yr*

cos u 5side adjacent to u

hypotenuse 5 *xr* **[1.1]**

*x*

tan u 5side opposite u

ACTIVE FIGURE 1.6

Certain trigonometric functions of a right triangle.

TIP 1.3 Degrees vs.

Radians

When calculating trigonomet ric functions, make sure your calculator setting—degrees or radians—is consistent with the degree measure you’re using in a given problem.

side adjacent to u 5 *yx*

For example, if the angle u is equal to 30°, then the ratio of *y* to *r* is always 0.50; that is, sin 30° 0.50. Note that the sine, cosine, and tangent functions are quanti ties without units because each represents the ratio of two lengths.

Another important relationship, called the **Pythagorean theorem**, exists between the lengths of the sides of a right triangle:

*r* 2  *x*2  *y*2 **[1.2]**

Finally, it will often be necessary to fi nd the values of inverse relationships. For example, suppose you know that the sine of an angle is 0.866, but you need to know the value of the angle itself. The inverse sine function may be expressed as sin 1 (0.866), which is a shorthand way of asking the question “What angle has a sine of 0.866?” Punching a couple of buttons on your calculator reveals that this angle is 60.0°. Try it for yourself and show that tan 1 (0.400) 21.8°. Be sure that your calculator is set for degrees and not radians. In addition, the inverse tangent function can return only values between 90° and 90°, so when an angle is in the second or third quadrant, it’s necessary to add 180° to the answer in the calcu lator window.

The defi nitions of the trigonometric functions and the inverse trigonometric functions, as well as the Pythagorean theorem, can be applied to *any* right trian gle, regardless of whether its sides correspond to *x*- and *y*-coordinates.

These results from trigonometry are useful in converting from rectangular coordinates to polar coordinates, or vice versa, as the next example shows.

1Many people use the mnemonic *SOHCAHTOA* to remember the basic trigonometric formulas: *S*ine *O*pposite/ *H*ypotenuse, *C*osine *A*djacent/*H*ypotenuse, and *T*angent *O*pposite/*A*djacent. (Thanks go to Professor Don Chodrow for pointing this out.)

EXAMPLE 1.9 Cartesian and Polar Coordinates

Goal Understand how to convert from plane rectangular coordinates to plane polar coordinates and vice versa.

Problem **(a)** The Cartesian coordinates of a point in the *xy*-plane are (*x*, *y*) ( 3.50 m, 2.50 m), as shown in Active Figure 1.7. Find the polar coordinates of this point. **(b)** Con vert (*r*, u) (5.00 m, 37.0°) to rectangular coordinates.

Strategy Apply the trigonometric functions and their inverses, together with the Pythagorean theorem.

Solution

**(a)** Cartesian to Polar

Take the square root of both sides of Equation 1.2 to

ACTIVE FIGURE 1.7

(Example 1.9) Converting from Cartesian coordinates to polar coordinates.

1.8 Trigonometry 15

*y* (m)

θ

*x* (m)

*r*

(–3.50, –2.50)

fi nd the radial coordinate: *r* 5 "*x* 2 1 *y*2 5 "123.50 m2 2 1 122.50 m2 2 5 4.30 m

Use Equation 1.1 for the tangent function to fi nd the angle with the inverse tangent, adding 180° because the angle is actually in third quadrant:

**(b)** Polar to Cartesian

tan u 5 *yx* 5 22.50 m

23.50 m 5 0.714

u 5 tan21 10.7142 5 35.5° 1 180° 5 216°

Use the trigonometric defi nitions, Equation 1.1. *x*  *r* cos u (5.00 m) cos 37.0° 3.99 m *y*  *r* sin u (5.00 m) sin 37.0° 3.01 m

Remarks When we take up vectors in two dimensions in Chapter 3, we will routinely use a similar process to fi nd the direction and magnitude of a given vector from its components, or, conversely, to fi nd the components from the vector’s magnitude and direction.

QUESTION 1.9

Starting with the answers to part (b), work backwards to recover the given radius and angle. Why are there slight dif ferences from the original quantities?

EXERCISE 1.9

**(a)** Find the polar coordinates corresponding to (*x*, *y*) ( 3.25 m, 1.50 m). **(b)** Find the Cartesian coordinates cor responding to (*r*, u) (4.00 m, 53.0°)

Answers **(a)** (*r*, u) (3.58 m, 155°) **(b)** (*x*, *y*) (2.41 m, 3.19 m)

EXAMPLE 1.10 How High Is the Building?

Goal Apply basic results of trigonometry.

Problem A person measures the height of a building by walk

ing out a distance of 46.0 m from its base and shining a fl ash

light beam toward the top. When the beam is elevated at an

angle of 39.0° with respect to the horizontal, as shown in Fig

ure 1.8, the beam just strikes the top of the building. Find the

height of the building and the distance the fl ashlight beam has

to travel before it strikes the top of the building.

Strategy Refer to the right triangle shown in the fi gure. We know the angle, 39.0°, and the length of the side adjacent to it. Because the height of the building is the side opposite the angle, we can use the tangent function. With the adjacent and opposite sides known, we can then fi nd the hypotenuse with the Pythagorean theorem.

Height

39.0°

46.0 m

FIGURE 1.8 (Example 1.10)

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Solution

Use the tangent of the given angle: tan 39.0° 5 height

46.0 m

Solve for the height: Height (tan 39.0°)(46.0 m) (0.810)(46.0 m) 37.3 m

Find the hypotenuse of the triangle: *r* 5 "*x* 2 1 *y*2 5 "137.3 m2 2 1 146.0 m2 2 5 59.2 m

Remarks In a later chapter, right-triangle trigonometry is often used when working with vectors.

QUESTION 1.10

Could the distance traveled by the light beam be found without using the Pythagorean Theorem? How?

EXERCISE 1.10

While standing atop a building 50.0 m tall, you spot a friend standing on a street corner. Using a protractor and dangling a plumb bob, you fi nd that the angle between the horizontal and the direction to the spot on the sidewalk where your friend is standing is 25.0°. Your eyes are located 1.75 m above the top of the building. How far away from the foot of the building is your friend?

Answer 111 m

1.9 PROBLEM-SOLVING STRATEGY

Most courses in general physics require the student to learn the skills used in solv

ing problems, and examinations usually include problems that test such skills. This

brief section presents some useful suggestions that will help increase your success

in solving problems. An organized approach to problem solving will also enhance

your understanding of physical concepts and reduce exam stress. Throughout the

book, there will be a number of sections labeled “Problem-Solving Strategy,” many

of them just a specializing of the list given below (and illustrated in Fig. 1.9).

Read Problem

General Problem-Solving Strategy

Draw Diagram

Label physical quantities

Identify principle(s); list data Choose Equation(s)

Solve Equation(s)

Substitute known values

Check Answer

FIGURE 1.9 A guide to problem solving.

1. **Read** the problem carefully at least twice. Be sure you understand the nature of the problem before proceeding further.

2. **Draw** a diagram while rereading the problem.

3. **Label** all physical quantities in the diagram, using letters that remind you what the quantity is (e.g., *m* for mass). Choose a coordinate system and label it. 4. **Identify** physical principles, the knowns and unknowns, and list them. Put cir cles around the unknowns.

5. **Equations**, the relationships between the labeled physical quantities, should be written down next. Naturally, the selected equations should be consistent with the physical principles identifi ed in the previous step.

6. **Solve** the set of equations for the unknown quantities in terms of the known. Do this algebraically, without substituting values until the next step, except where terms are zero.

7. **Substitute** the known values, together with their units. Obtain a numerical value with units for each unknown.

8. **Check** your answer. Do the units match? Is the answer reasonable? Does the plus or minus sign make sense? Is your answer consistent with an order of mag nitude estimate?

This same procedure, with minor variations, should be followed throughout the course. The fi rst three steps are extremely important, because they get you men

1.9 Problem-Solving Strategy 17

tally oriented. Identifying the proper concepts and physical principles assists you

in choosing the correct equations. The equations themselves are essential, because

when you understand them, you also understand the relationships between the

physical quantities. This understanding comes through a lot of daily practice.

Equations are the tools of physics: To solve problems, you have to have them

at hand, like a plumber and his wrenches. Know the equations, and understand

what they mean and how to use them. Just as you can’t have a conversation without

knowing the local language, you can’t solve physics problems without knowing and

understanding the equations. This understanding grows as you study and apply

the concepts and the equations relating them.

Carrying through the algebra for as long as possible, substituting numbers only

at the end, is also important, because it helps you think in terms of the physi

cal quantities involved, not merely the numbers that represent them. Many begin

ning physics students are eager to substitute, but once numbers are substituted it’s

harder to understand relationships and easier to make mistakes.

The physical layout and organization of your work will make the fi nal product

more understandable and easier to follow. Although physics is a challenging disci

pline, your chances of success are excellent if you maintain a positive attitude and

keep trying.

EXAMPLE 1.11 A Round Trip by Air

Goal Illustrate the Problem-Solving Strategy.

Problem An airplane travels 4.50 102 km due east and then travels an unknown distance due north. Finally, it returns to its starting point by traveling a distance of 525 km. How far did the airplane travel in the northerly direction?

Strategy We’ve fi nished reading the problem (step 1), and have drawn a diagram (step 2) in Figure 1.10 and labeled it (step 3). From the dia gram, we recognize a right triangle and identify (step 4) the principle involved: the Pythagorean theorem. Side *y* is the unknown quantity, and the other sides are known.

Solution

Write the Pythagorean theorem (step 5): *r* 2  *x* 2 + *y*2

W

FIGURE 1.10 (Example 1.11)

N S

E

*r*

*x* = 450 km

*r* = 525 km

*y* = ?

*y*

*x*

Solve symbolically for *y* (step 6): *y*2 5 *r* 2 2 *x* 2 S *y* 5 1"*r* 2 2 *x* 2 Substitute the numbers, with units (step 7): *y* 5 "1525 km2 2 2 14.50 3 102 km2 2 5 270 km

Remarks Note that the negative solution has been disregarded, because it’s not physically meaningful. In checking (step 8), note that the units are correct and that an approximate answer can be obtained by using the easier quanti ties, 500 km and 400 km. Doing so gives an answer of 300 km, which is approximately the same as our calculated answer of 270 km.

QUESTION 1.11

What is the answer if both the distance traveled due east and the direct return distance are both doubled?

EXERCISE 1.11

A plane fl ies 345 km due south, then turns and fl ies 615 km at a heading 45.0° north of east, until it’s due east of its starting point. If the plane now turns and heads for home, how far will it have to go?

Answer 509 km

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SUMMARY

1.1 Standards of Length, Mass, and Time The physical quantities in the study of mechanics can be expressed in terms of three fundamental quantities: length, mass, and time, which have the SI units meters (m), kilograms (kg), and seconds (s), respectively.

1.2 The Building Blocks of Matter

Matter is made of atoms, which in turn are made up of a relatively small nucleus of protons and neutrons within a cloud of electrons. Protons and neutrons are composed of still smaller particles, called quarks.

1.3 Dimensional Analysis

Dimensional analysis can be used to check equations and to assist in deriving them. When the dimensions on both sides of the equation agree, the equation is often correct up to a numerical factor. When the dimensions don’t agree, the equation must be wrong.

1.4 Uncertainty in Measurement

and Signifi cant Figures

No physical quantity can be determined with complete accuracy. The concept of signifi cant fi gures affords a basic method of handling these uncertainties. A signifi cant fi g ure is a reliably known digit, other than a zero, used to locate the decimal point. The two rules of signifi cant fi gures are as follows:

**1.** When multiplying or dividing using two or more quan tities, the result should have the same number of sig nifi cant fi gures as the quantity having the fewest sig nifi cant fi gures.

**2.** When quantities are added or subtracted, the number of decimal places in the result should be the same as in the quantity with the fewest decimal places.

Use of scientifi c notation can avoid ambiguity in sig nifi cant fi gures. In rounding, if the last digit dropped is less than 5, simply drop the digit, otherwise raise the last retained digit by one.

1.5 Conversion of Units

Units in physics equations must always be consistent. In solving a physics problem, it’s best to start with consistent units, using the table of conversion factors on the inside front cover as necessary.

Converting units is a matter of multiplying the given quantity by a fraction, with one unit in the numerator

and its equivalent in the other units in the denominator, arranged so the unwanted units in the given quantity are cancelled out in favor of the desired units.

1.6 Estimates and Order-of-Magnitude Calculations Sometimes it’s useful to fi nd an approximate answer to a question, either because the math is diffi cult or because information is incomplete. A quick estimate can also be used to check a more detailed calculation. In an order of-magnitude calculation, each value is replaced by the closest power of ten, which sometimes must be guessed or estimated when the value is unknown. The computation is then carried out. For quick estimates involving known values, each value can fi rst be rounded to one signifi cant fi gure.

1.7 Coordinate Systems

The Cartesian coordinate system consists of two perpen dicular axes, usually called the *x*-axis and *y*-axis, with each axis labeled with all numbers from negative infi nity to positive infi nity. Points are located by specifying the *x*- and *y*-values. Polar coordinates consist of a radial coordinate *r* which is the distance from the origin, and an angular coor dinate u which is the angular displacement from the posi tive *x*-axis.

1.8 Trigonometry

The three most basic trigonometric functions of a right tri angle are the sine, cosine, and tangent, defi ned as follows:

sin u 5side opposite u

hypotenuse 5 *yr*

cos u 5side adjacent to u

hypotenuse 5 *xr* **[1.1]**

tan u 5side opposite u

side adjacent to u 5 *yx*

The **Pythagorean theorem** is an important relationship between the lengths of the sides of a right triangle:

*r* 2  *x*2  *y*2 **[1.2]**

where *r* is the hypotenuse of the triangle and *x* and *y* are the other two sides.

FOR ADDITIONAL STUDENT RESOURCES, GO TO WWW.SERWAYPHYSICS.COM MULTIPLE-CHOICE QUESTIONS

**1.** Newton’s second law of motion (Chapter 4) says that the mass of an object times its acceleration is equal to the net force on the object. Which of the following gives the correct units for force? (a) kg m/s2 (b) kg m2/s2

(c) kg/m s2 (d) kg m2/s (e) none of these

**2.** Suppose two quantities, *A* and *B*, have different dimen sions. Determine which of the following arithmetic operations *could* be physically meaningful. (a) *A*  *B* (b) *B*  *A* (c) *A*  *B* (d) *A*/*B* (e) *AB*

**3.** A rectangular airstrip measures 32.30 m by 210 m, with the width measured more accurately than the length. Find the area, taking into account signifi cant fi gures. (a) 6.783 0 103 m2 (b) 6.783 103 m2 (c) 6.78

103 m2 (d) 6.8 103 m2 (e) 7 103 m2

**4.** Use the rules for signifi cant fi gures to fi nd the answer to the addition problem 21.4 15 17.17 4.003. (a) 57.573 (b) 57.57 (c) 57.6 (d) 58 (e) 60

**5.** The Roman cubitus is an ancient unit of measure equiv alent to about 445 mm. Convert the 2.00-m-height of a basketball forward to cubiti. (a) 2.52 cubiti (b) 3.12 cubiti (c) 4.49 cubiti (d) 5.33 cubiti (e) none of these

**6.** A house is advertised as having 1 420 square feet under roof. What is the area of this house in square meters? (a) 115 m2 (b) 132 m2 (c) 176 m2 (d) 222 m2 (e) none of these

**7.** Which of the following is the best estimate for the mass of all the people living on Earth? (a) 2 108 kg (b) 1 109 kg (c) 2 1010 kg (d) 3 1011 kg (e) 4 1012 kg

CONCEPTUAL QUESTIONS

**1.** Estimate the order of magnitude of the length, in meters, of each of the following: (a) a mouse, (b) a pool cue, (c) a basketball court, (d) an elephant, (e) a city block.

**2.** What types of natural phenomena could serve as time standards?

**3.** Find the order of magnitude of your age in seconds.

**4.** An object with a mass of 1 kg weighs approximately 2 lb. Use this information to estimate the mass of the follow ing objects: (a) a baseball; (b) your physics textbook; (c) a pickup truck.

**5.** (a) Estimate the number of times your heart beats in a month. (b) Estimate the number of human heartbeats in an average lifetime.

**6.** Estimate the number of atoms in 1 cm3 of a solid. (Note that the diameter of an atom is about 10 10 m.)

PROBLEMS

The Problems for this chapter may be

assigned online at WebAssign.

1, 2, 3 straightforward, intermediate, challenging GP denotes guided problem

ecp denotes enhanced content problem

biomedical application

denotes full solution available in *Student Solutions Manual/ Study Guide*

SECTION 1.3 DIMENSIONAL ANALYSIS

**1.** The period of a simple pendulum, defi ned as the time necessary for one complete oscillation, is measured in time units and is given by

Problems 19

**8.** Find the polar coordinates corresponding to a point located at ( 5.00, 12.00) in Cartesian coordinates. (a) (13.0, 67.4°) (b) (13.0, 113°) (c) (14.2, 67.4°) (d) (14.2, 113°) (e) (19, 72.5°)

**9.** At a horizontal distance of 45 m from a tree, the angle of elevation to the top of the tree is 26°. How tall is the tree? (a) 22 m (b) 31 m (c) 45 m (d) 16 m (e) 11 m

**10.** What is the approximate number of breaths a person takes over a period of 70 years? (a) 3 106 breaths (b) 3 107 breaths (c) 3 108 breaths (d) 3 109 breaths (e) 3 1010 breaths

**11.** Which of the following relationships is dimensionally consistent with an expression yielding a value for accel eration? Acceleration has the units of distance divided by time squared. In these equations, *x* is a distance, *t* is time, and *v* is velocity with units of distance divided by time. (a) *v*/*t* 2 (b) *v*/*x*2 (c) *v*2/*t* (d) *v*2/*x* (e) none of these

**7.** The height of a horse is sometimes given in units of “hands.” Why is this a poor standard of length?

**8.** How many of the lengths or time intervals given in Tables 1.2 and 1.3 could you verify, using only equip ment found in a typical dormitory room?

**9.** If an equation is dimensionally correct, does this mean that the equation must be true? If an equation is not dimensionally correct, does this mean that the equa tion can’t be true?

**10.** Why is the metric system of units considered superior to most other systems of units?

**11.** How can an estimate be of value even when it is off by an order of magnitude? Explain and give an example.

*T* 5 2pÅ,*g*

where is the length of the pendulum and *g* is the accel eration due to gravity, in units of length divided by time squared. Show that this equation is dimensionally consis tent. (You might want to check the formula using your keys at the end of a string and a stopwatch.)

**2.** (a) Suppose that the displacement of an object is related to time according to the expression *x*  *Bt* 2. What are the dimensions of *B*? (b) A displacement is related to time as *x*  *A* sin (2p*ft*), where *A* and *f* are constants. Find the dimensions of *A*. (*Hint:* A trigonometric function appear

ing in an equation must be dimensionless.)

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**3.** A shape that covers an area *A* and has a uniform height *h* has a volume *V*  *Ah*. (a) Show that *V*  *Ah* is dimension ally correct. (b) Show that the volumes of a cylinder and

the volume by multiplying by the length. (d) Explain why the answers don’t agree in the third signifi cant fi gure.

of a rectangular box can be written in the form *V*  *Ah*, identifying *A* in each case. (Note that *A*, sometimes called the “footprint” of the object, can have any shape and that the height can, in general, be replaced by the average thickness of the object.)

**12.** The radius of a circle is measured to be (10.5 0.2) m. Calculate (a) the area and (b) the circumference of the circle, and give the uncertainty in each value.

**13.** Carry out the following arithmetic operations: (a) the sum of the measured values 756, 37.2, 0.83, and 2.5; (b) the product 0.003 2 356.3; (c) the product 5.620 p.

**4.** Each of the following equations was given by a student during an examination:

2*mv* 2 5 12*mv*02 1 !*mgh v* 5 *v*0 1 *at* 2 *ma* 5 *v* 2

1

Do a dimensional analysis of each equation and explain why the equation can’t be correct.

**5.** Newton’s law of universal gravitation is represented by *F* 5 *GMm*

*r* 2

where *F* is the gravitational force, *M* and *m* are masses, and *r* is a length. Force has the SI units kg · m/s2. What are the SI units of the proportionality constant *G*?

**6.** ecp Kinetic energy *KE* (Chapter 5) has dimensions kg · m2/s2. It can be written in terms of the momentum *p* (Chapter 6) and mass *m* as

*KE* 5 *p*2

2*m*

(a) Determine the proper units for momentum using dimensional analysis. (b) Refer to Problem 5. Given the units of force, write a simple equation relating a constant force *F* exerted on an object, an interval of time *t* during which the force is applied, and the resulting momentum of the object, *p.*

SECTION 1.4 UNCERTAINTY IN MEASUREMENT AND SIGNIFICANT FIGURES

**7.** A fi sherman catches two striped bass. The smaller of the two has a measured length of 93.46 cm (two decimal places, four signifi cant fi gures), and the larger fi sh has a measured length of 135.3 cm (one decimal place, four signifi cant fi gures). What is the total length of fi sh caught for the day?

**8.** A rectangular plate has a length of (21.3 0.2) cm and a width of (9.8 0.1) cm. Calculate the area of the plate, including its uncertainty.

**9.** How many signifi cant fi gures are there in (a) 78.9 0.2, (b) 3.788 109, (c) 2.46 10 6, (d) 0.003 2

**10.** The speed of light is now defi ned to be 2.997 924 58 108 m/s. Express the speed of light to (a) three signifi cant fi gures, (b) fi ve signifi cant fi gures, and (c) seven signifi - cant fi gures.

**11.** ecp A block of gold has length 5.62 cm, width 6.35 cm, and height 2.78 cm. (a) Calculate the length times the width and round the answer to the appropriate num ber of signifi cant fi gures. (b) Now multiply the rounded result of part (a) by the height and again round, obtain ing the volume. (c) Repeat the process, fi rst fi nding the width times the height, rounding it, and then obtaining

**14.** (a) Using your calculator, fi nd, in scientifi c notation with appropriate rounding, (a) the value of (2.437 104) (6.521 1 109)/(5.37 104) and (b) the value of (3.141 59 102)(27.01 104)/(1 234 106).

SECTION 1.5 CONVERSION OF UNITS

**15.** A fathom is a unit of length, usually reserved for measur ing the depth of water. A fathom is approximately 6 ft in length. Take the distance from Earth to the Moon to be 250 000 miles, and use the given approximation to fi nd the distance in fathoms.

**16.** A furlong is an old British unit of length equal to 0.125 mi, derived from the length of a furrow in an acre of ploughed land. A fortnight is a unit of time correspond ing to two weeks, or 14 days and nights. Find the speed of light in megafurlongs per fortnight. (One megafurlong equals a million furlongs.)

**17.** A fi rkin is an old British unit of volume equal to 9 gallons. How many cubic meters are there in 6.00 fi rkins?

**18.** Find the height or length of these natural wonders in kilometers, meters, and centimeters: (a) The longest cave system in the world is the Mammoth Cave system in Cen tral Kentucky, with a mapped length of 348 miles. (b) In the United States, the waterfall with the greatest single drop is Ribbon Falls in California, which drops 1 612 ft. (c) At 20 320 feet, Mount McKinley in Alaska is America’s highest mountain. (d) The deepest canyon in the United States is King’s Canyon in California, with a depth of 8 200 ft.

**19.** A rectangular building lot measures 1.00 102 ft by 1.50 102 ft. Determine the area of this lot in square meters (m2).

**20.** Using the data in Table 1.3 and the appropriate conver sion factors, fi nd the age of Earth in years.

**21.** Using the data in Table 1.1 and the appropriate conver sion factors, fi nd the distance to the nearest star in feet.

**22.** Suppose your hair grows at the rate of 1/32 inch per day. Find the rate at which it grows in nanometers per sec ond. Because the distance between atoms in a molecule is on the order of 0.1 nm, your answer suggests how rapidly atoms are assembled in this protein synthesis.

**23.** The speed of light is about 3.00 108 m/s. Convert this fi gure to miles per hour.

**24.** A house is 50.0 ft long and 26 ft wide and has 8.0-ft-high ceilings. What is the volume of the interior of the house in cubic meters and in cubic centimeters?

**25.** The amount of water in reservoirs is often measured in acre-ft. One acre-ft is a volume that covers an area of one acre to a depth of one foot. An acre is 43 560 ft2. Find the

volume in SI units of a reservoir containing 25.0 acre-ft of water.

**26.** The base of a pyramid covers an area of 13.0 acres (1 acre 43 560 ft2) and has a height of 481 ft (Fig. P1.26). If the volume of a pyramid is given by the expression *V*  *bh*/3, where *b* is the area of the base and *h* is the height, fi nd the volume of this pyramid in cubic meters.



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**34.** ecp Bacteria and other prokaryotes are found deep underground, in water, and in the air. One micron (10−6 m) is a typical length scale associated with these microbes. (a) Estimate the total number of bacteria and other pro

karyotes in the biosphere of the Earth. (b) Estimate the total mass of all such microbes. (c) Discuss the relative importance of humans and microbes to the ecology of planet Earth. Can *Homo sapiens* survive without them?

SECTION 1.7 COORDINATE SYSTEMS

**35.** A point is located in a polar coordinate system by the co ordinates *r*  2.5 m and u 35°. Find the *x*- and *y* co ordinates of this point, assuming that the two coordi nate systems have the same origin.

**36.** A certain corner of a room is selected as the origin of a rectangular coordinate system. If a fl y is crawling on an adjacent wall at a point having coordinates (2.0, 1.0), where the units are meters, what is the distance of the fl y from the corner of the room?

©

R

FIGURE P1.26

**37.** Express the location of the fl y in Problem 36 in polar

coordinates.

**27.** A quart container of ice cream is to be made in the form of a cube. What should be the length of a side, in centi meters? (Use the conversion 1 gallon 3.786 liter.)

SECTION 1.6 ESTIMATES AND ORDER

OF-MAGNITUDE CALCULATIONS

*Note:* In developing answers to the problems in this sec tion, you should state your important assumptions, includ ing the numerical values assigned to parameters used in the solution.

**28.** A hamburger chain advertises that it has sold more than 50 billion hamburgers. Estimate how many pounds of hamburger meat must have been used by the chain and how many head of cattle were required to furnish the meat.

**29.** Estimate the number of Ping-Pong balls that would fi t into a typical-size room (without being crushed). In your solution, state the quantities you measure or estimate and the values you take for them.

**30.** Estimate the number of people in the world who are suffering from the common cold on any given day. (Answers may vary. Remember that a person suffers from a cold for about a week.)

**31.** ecp (a) About how many microorganisms are found in the human intestinal tract? (A typical bacterial length scale is 10−6 m. Estimate the intestinal volume and assume one hundredth of it is occupied by bacteria.) (b) Discuss your answer to part (a). Are these bacteria benefi cial, dangerous, or neutral? What functions could they serve?

**32.** ecp Grass grows densely everywhere on a quarter-acre plot of land. What is the order of magnitude of the num ber of blades of grass? Explain your reasoning. Note that 1 acre 43 560 ft2.

**33.** An automobile tire is rated to last for 50 000 miles. Esti mate the number of revolutions the tire will make in its lifetime.

**38.** Two points in a rectangular coordinate system have the coordinates (5.0, 3.0) and ( 3.0, 4.0), where the units are centimeters. Determine the distance between these points.

**39.** Two points are given in polar coordinates by (*r*, u) (2.00 m, 50.0°) and (*r*, u (5.00 m, 50.0°), respectively. What is the distance between them?

**40.** ecp Given points (*r*1, u1) and (*r*2, u2) in polar coordinates, obtain a general formula for the distance between them. Simplify it as much as possible using the identity cos2 u sin2 u 1. *Hint:* Write the expressions for the two points in Cartesian coordinates and substitute into the usual dis tance formula.

SECTION 1.8 TRIGONOMETRY

**41.** For the triangle shown in Figure P1.41, what are (a) the length of the unknown side, (b) the tangent of u, and (c) the sine of f?

θ

6.00 m

9.00 mφ

FIGURE P1.41

**42.** A ladder 9.00m long leans against the side of a building. If the ladder is inclined at an angle of 75.0° to the hori zontal, what is the horizontal distance from the bottom of the ladder to the building?

**43.** A high fountain of water is located at the center of a circu lar pool as shown in Figure P1.43. Not wishing to get his feet wet, a student walks around the pool and measures its circumference to be 15.0 m. Next, the student stands

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at the edge of the pool and uses a protractor to gauge the angle of elevation at the bottom of the fountain to be 55.0°. How high is the fountain?

55.0

FIGURE P1.43

**44.** A right triangle has a hypotenuse of length 3.00 m, and one of its angles is 30.0°. What are the lengths of (a) the side opposite the 30.0° angle and (b) the side adjacent to the 30.0° angle?

**45.** In Figure P1.45, fi nd (a) the side opposite u, (b) the side adjacent to f, (c) cos u, (d) sin f, and (e) tan f.

φ

5.00

3.00

θ

4.00

FIGURE P1.45

**46.** In a certain right triangle, the two sides that are perpen dicular to each other are 5.00 m and 7.00 m long. What is the length of the third side of the triangle?

**47.** In Problem 46, what is the tangent of the angle for which 5.00 m is the opposite side?

**48.** GP A woman measures the angle of elevation of a mountaintop as 12.0°. After walking 1.00 km closer to the mountain on level ground, she fi nds the angle to be 14.0°. (a) Draw a picture of the problem, neglecting the height of the woman's eyes above the ground. *Hint:* Use two triangles. (b) Select variable names for the mountain height (suggestion: *y*) and the woman’s original distance from the mountain (suggestion: *x*) and label the pic ture. (c) Using the labeled picture and the tangent func

tion, write two trigonometric equations relating the two selected variables. (d) Find the height *y* of the mountain by fi rst solving one equation for *x* and substituting the result into the other equation.

**49.** A surveyor measures the distance across a straight river by the following method: Starting directly across from a tree on the opposite bank, he walks 100 m along the riverbank to establish a baseline. Then he sights across to the tree. The angle from his baseline to the tree is 35.0°. How wide is the river?

**50.** ecp Refer to Problem 48. Suppose the mountain height is *y*, the woman’s original distance from the mountain is *x*, and the angle of elevation she measures from the hori zontal to the top of the mountain is u. If she moves a dis tance *d* closer to the mountain and measures an angle of elevation f, fi nd a general equation for the height of the mountain *y* in terms of *d*, f, and u, neglecting the height of her eyes above the ground.

ADDITIONAL PROBLEMS

**51.** (a) One of the fundamental laws of motion states that the acceleration of an object is directly proportional to the resultant force on it and inversely proportional to its mass. If the proportionality constant is defi ned to have no dimensions, determine the dimensions of force. (b) The newton is the SI unit of force. According to the results for (a), how can you express a force having units of new tons by using the fundamental units of mass, length, and time?

**52.** (a) Find a conversion factor to convert from miles per hour to kilometers per hour. (b) For a while, federal law mandated that the maximum highway speed would be 55 mi/h. Use the conversion factor from part (a) to fi nd the speed in kilometers per hour. (c) The maximum highway speed has been raised to 65 mi/h in some places. In kilo meters per hour, how much of an increase is this over the 55-mi/h limit?

**53.** One cubic centimeter (1.0 cm3) of water has a mass of 1.0 10 3 kg. (a) Determine the mass of 1.0 m3 of water. (b) Assuming that biological substances are 98% water, estimate the masses of a cell with a diameter of 1.0 mm, a human kidney, and a fl y. Take a kidney to be roughly a sphere with a radius of 4.0 cm and a fl y to be roughly a cylinder 4.0 mm long and 2.0 mm in diameter.

**54.** Soft drinks are commonly sold in aluminum containers. To an order of magnitude, how many such containers are thrown away or recycled each year by U.S. consumers? How many tons of aluminum does this represent? In your solution, state the quantities you measure or estimate and the values you take for them.

**55.** The displacement of an object moving under uniform acceleration is some function of time and the accelera tion. Suppose we write this displacement as *s*  *kamt n*, where *k* is a dimensionless constant. Show by dimensional analysis that this expression is satisfi ed if *m*  1 and *n*  2. Can the analysis give the value of *k*?

**56.** Compute the order of magnitude of the mass of (a) a bathtub fi lled with water and (b) a bathtub fi lled with pennies. In your solution, list the quantities you estimate and the value you estimate for each.

**57.** You can obtain a rough estimate of the size of a mole cule by the following simple experiment: Let a droplet of oil spread out on a smooth surface of water. The result ing oil slick will be approximately one molecule thick. Given an oil droplet of mass 9.00 10 7 kg and density 918 kg/m3 that spreads out into a circle of radius 41.8 cm on the water surface, what is the order of magnitude of the diameter of an oil molecule?

**58.** ecp Sphere 1 has surface area *A*1 and volume *V*1, and sphere 2 has surface area *A*2 and volume *V*2. If the radius of sphere 2 is double the radius of sphere 1, what is the

ratio of (a) the areas, *A*2/*A*1 and (b) the volumes, *V*2/*V*1?

**59.** Estimate the number of piano tuners living in New York City. This question was raised by the physicist Enrico Fermi, who was well known for making order-of magnitude calculations.

**60.** In 2007, the U.S. national debt was about $9 trillion.

Problems 23

any of these calculations, try to guess at the answers. You may be very surprised.)

**61.** (a) How many seconds are there in a year? (b) If one micrometeorite (a sphere with a diameter on the order of 10 6 m) struck each square meter of the Moon each sec ond, estimate the number of years it would take to cover the Moon with micrometeorites to a depth of one meter. (*Hint:* Consider a cubic box, 1 m on a side, on the Moon, and fi nd how long it would take to fi ll the box.)

(a) If payments were made at the rate of $1 000 per sec ond, how many years would it take to pay off the debt, assuming that no interest were charged? (b) A dollar bill is about 15.5 cm long. If nine trillion dollar bills were laid end to end around the Earth’s equator, how many times would they encircle the planet? Take the radius of the Earth at the equator to be 6 378 km. (*Note:* Before doing

**62.** Imagine that you are the equipment manager of a profes sional baseball team. One of your jobs is to keep baseballs on hand for games. Balls are sometimes lost when play ers hit them into the stands as either home runs or foul balls. Estimate how many baseballs you have to buy per season in order to make up for such losses. Assume that your team plays an 81-game home schedule in a season.

2

Craig Breedlove, fi ve times world land speed record holder, acceler ates across the Black Rock Desert in Gerlach, Nevada, in his jet powered car, Spirit of America, on its fi rst test run on September 6, 1997. Subsequent jet-powered cars have broken the sound barrier on land.

2.1 Displacement

2.2 Velocity

2.3 Acceleration

2.4 Motion Diagrams

2.5 One-Dimensional Motion with Constant

Acceleration

2.6 Freely Falling Objects

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MOTION IN ONE DIMENSION

Life is motion. Our muscles coordinate motion microscopically to enable us to walk and jog. Our hearts pump tirelessly for decades, moving blood through our bodies. Cell wall mecha nisms move select atoms and molecules in and out of cells. From the prehistoric chase of antelopes across the savanna to the pursuit of satellites in space, mastery of motion has been critical to our survival and success as a species.

The study of motion and of physical concepts such as force and mass is called dynamics. The part of dynamics that describes motion without regard to its causes is called kinematics. In this chapter the focus is on kinematics in one dimension: motion along a straight line. This kind of motion—and, indeed, *any* motion—involves the concepts of displacement, velocity, and acceleration. Here, we use these concepts to study the motion of objects undergoing constant acceleration. In Chapter 3 we will repeat this discussion for objects moving in two dimensions.

The fi rst recorded evidence of the study of mechanics can be traced to the people of ancient Sumeria and Egypt, who were interested primarily in understanding the motions of heavenly bodies. The most systematic and detailed early studies of the heavens were conducted by the Greeks from about 300 B.C. to A.D. 300. Ancient scientists and laypeople regarded the Earth as the center of the Universe. This geocentric model was accepted by such notables as Aris

totle (384–322 B.C.) and Claudius Ptolemy (about A.D. 140). Largely because of the authority of Aristotle, the geocentric model became the accepted theory of the Universe until the 17th century.

About 250 B.C., the Greek philosopher Aristarchus worked out the details of a model of the Solar System based on a spherical Earth that rotated on its axis and revolved around the Sun. He proposed that the sky appeared to turn westward because the Earth was turning eastward. This model wasn’t given much consideration because it was believed that a turn

ing Earth would generate powerful winds as it moved through the air. We now know that the Earth carries the air and everything else with it as it rotates.

The Polish astronomer Nicolaus Copernicus (1473–1543) is credited with initiating the revolution that fi nally replaced the geocentric model. In his system, called the heliocentric model, Earth and the other planets revolve in circular orbits around the Sun.

24

This early knowledge formed the foundation for the work of Galileo Galilei (1564–1642), who stands out as the dominant facilitator of the entrance of physics into the modern era. In 1609 he became one of the fi rst to make astronomical observations with a telescope. He observed mountains on the Moon, the larger satellites of Jupiter, spots on the Sun, and the phases of Venus. Galileo’s observations convinced him of the correctness of the Copernican theory. His quantitative study of motion formed the foundation of Newton’s revolutionary work in the next century.

2.1 DISPLACEMENT

Motion involves the displacement of an object from one place in space and time to another. Describing motion requires some convenient coordinate system and a specifi ed origin. A **frame of reference** is a choice of coordinate axes that defi nes the starting point for measuring any quantity, an essential fi rst step in solving vir

tually any problem in mechanics (Fig. 2.1). In Active Figure 2.2a, for example, a car moves along the *x*-axis. The coordinates of the car at any time describe its posi tion in space and, more importantly, its *displacement* at some given time of interest.

The **displacement**  *x* of an object is defi ned as its *change in position*, and is given by

*x*  *xf*  *xi* **[2.1]**

where the initial position of the car is labeled *xi* and the fi nal position is *xf* . (The indices *i* and *f* stand for initial and fi nal, respectively.)

**SI unit: meter (m)**

We will use the Greek letter delta, , to denote a change in any physical quantity. From the defi nition of displacement, we see that *x* (read “delta ex”) is positive if *xf* is greater than *xi* and negative if *xf* is less than *xi*. For example, if the car moves from point to point so that the initial position is *xi*  30 m and the fi nal position is *xf*  52 m, the displacement is *x*  *xf*  *xi*  52 m 30 m 22 m. However, if the car moves from point to point , then the initial position is *xi*  38 m and the fi nal position is *xf*  53 m, and the displacement is *x*  *xf*  *xi*  53 m 38 m 91 m. A positive answer indicates a displacement in the posi tive *x*-direction, whereas a negative answer indicates a displacement in the negative *x*-direction. Active Figure 2.2b displays the graph of the car’s position as a func

tion of time.

Because displacement has both a magnitude (size) and a direction, it’s a vector quantity, as are velocity and acceleration. In general, **a vector quantity is charac terized by having both a magnitude and a direction**. By contrast, **a scalar quantity**

*x* (m)

2.1 Displacement 25 Text not available due to copyright restrictions

O Defi nition of displacement

Tip 2.1 A Displacement Isn’t a Distance!

The displacement of an object is *not* the same as the distance it travels. Toss a tennis ball up and catch it. The ball travels a *distance* equal to twice the maximum height reached, but its *displace ment* is zero.

ACTIVE FIGURE 2.2



60

**LIMIT**

60 50 40 30 20 10 0 10 20 30 40 50 60

*x*

(a) A car moves back and forth along a straight line taken to





**30 km/h LIMIT**

 *x* (m)

40

20

0

20

*t*

be the *x*-axis. Because we are interested only in the car’s transla tional motion, we can model it as a particle. (b) Graph of position vs. time for the motion

60 50 40 30 20 10 0 10 20 30 40 50 60 

**30 km/h**

(a)

40

60

*x* (m)

0 10 20 30 40 50 (b)

of the “particle.”

*t* (s)

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Tip 2.2 Vectors Have Both a Magnitude and a Direction.

Scalars have size. Vectors, too, have size, but they also indicate a direction.

Defi nition of average speed R

**has magnitude, but no direction**. Scalar quantities such as mass and temperature are completely specifi ed by a numeric value with appropriate units; no direction is involved.

Vector quantities will be usually denoted in boldface type with an arrow over the top of the letter. For example, **v**S represents velocity and **a**S denotes an acceleration, both vector quantities. In this chapter, however, it won’t be necessary to use that notation because in one-dimensional motion an object can only move in one of two directions, and these directions are easily specifi ed by plus and minus signs.

2.2 VELOCITY

In everyday usage the terms *speed* and *velocity* are interchangeable. In physics, how ever, there’s a clear distinction between them: Speed is a scalar quantity, having only magnitude, whereas velocity is a vector, having both magnitude and direction.

Why must velocity be a vector? If you want to get to a town 70 km away in an hour’s time, it’s not enough to drive at a speed of 70 km/h; you must travel in the correct direction as well. This is obvious, but shows that velocity gives considerably more information than speed, as will be made more precise in the formal defi nitions.

The **average speed** of an object over a given time interval is the total distance traveled divided by the total time elapsed:

Average speed ; total distance

total time

**SI unit: meter per second (m/s)**

In symbols, this equation might be written *v*  *d*/*t*, with the letter *v* understood in context to be the average speed, not a velocity. Because total distance and total time are always positive, the average speed will be positive, also. The defi nition of average speed completely ignores what may happen between the beginning and the end of the motion. For example, you might drive from Atlanta, Georgia, to St. Petersburg, Florida, a distance of about 500 miles, in 10 hours. Your average speed is 500 mi/10 h 50 mi/h. It doesn’t matter if you spent two hours in a traffi c jam traveling only 5 mi/h and another hour at a rest stop. For average speed, only the total distance traveled and total elapsed time are important.

EXAMPLE 2.1 The Tortoise and the Hare

Goal Apply the concept of average speed.

Problem A turtle and a rabbit engage in a footrace over a distance of 4.00 km. The rabbit runs 0.500 km and then stops for a 90.0-min nap. Upon awakening, he remembers the race and runs twice as fast. Finishing the course in a total time of 1.75 h, the rabbit wins the race. **(a)** Calculate the average speed of the rabbit. **(b)** What was his average speed before he stopped for a nap?

Strategy Finding the overall average speed in part (a) is just a matter of dividing the total distance by the total time. Part (b) requires two equations and two unknowns, the latter turning out to be the two different average speeds: *v*1 before the nap and *v*2 after the nap. One equation is given in the statement of the problem (*v*2  2*v*1), whereas the other comes from the fact the rabbit ran for only 15 minutes because he napped for 90 minutes.

Solution

**(a)** Find the rabbit’s overall average speed.

Apply the equation for average speed: Average speed ; total distance total time 5 4.00 km

1.75 h

2.29 km/h

2.2 Velocity 27

**(b)** Find the rabbit’s average speed before his nap.

Sum the running times, and set the sum equal to 0.25 h: *t*1  *t*2  0.250 h

*v*11*d*2

Substitute *t*1  *d*1/*v*1 and *t*2  *d*2/*v*2: (1) *d*1

*v*25 0.250 h

Substitute *v*2  2*v*1 and the values of *d*1 and *d*2 into Equation (1):

(2) 0.500 km

*v*113.50 km

2*v*15 0.250 h

Solve Equation (2) for *v*1: *v*1  9.00 km/h

Remark As seen in this example, average speed can be calculated regardless of any variation in speed over the given time interval.

QUESTION 2.1

Does a doubling of an object’s average speed always double the magnitude of its displacement in a given amount of time? Explain.

EXERCISE 2.1

Estimate the average speed of the Apollo spacecraft in meters per second, given that the craft took fi ve days to reach the Moon from Earth. (The Moon is 3.8 × 108 m from Earth.)

Answer ~ 900 m/s

Unlike average speed, **average velocity** is a vector quantity, having both a mag

nitude and a direction. Consider again the car of Figure 2.2, moving along the

road (the *x*-axis). Let the car’s position be *xi* at some time *ti* and *xf* at a later time *tf* .

In the time interval *t*  *tf*  *ti*, the displacement of the car is *x*  *xf*  *xi*.

The average velocity *~~v~~* during a time interval *t* is the displacement *x*

O Defi nition of average velocity

divided by *t*:

D*t* 5 *x f* 2 *xi*

*~~v~~* ; D*x*

**SI unit: meter per second (m/s)**

*tf* 2 *ti***[2.2]**

TABLE 2.1

**Position of the Car at**

Unlike the average speed, which is always positive, the average velocity of an object in one dimension can be either positive or negative, depending on the sign of the displacement. (The time interval *t* is always positive.) In Figure 2.2a, for example, the average velocity of the car is positive in the upper illustration, a posi

tive sign indicating motion to the right along the *x*-axis. Similarly, a negative aver age velocity for the car in the lower illustration of the fi gure indicates that it moves to the left along the *x*-axis.

As an example, we can use the data in Table 2.1 to fi nd the average velocity in the time interval from point to point (assume two digits are signifi cant):

*~~v~~* 5 D*x*

D*t* 5 52 m 2 30 m

10 s 2 0 s 5 2.2 m/s

Aside from meters per second, other common units for average velocity are feet per second (ft/s) in the U.S. customary system and centimeters per second (cm/s) in the cgs system.

To further illustrate the distinction between speed and velocity, suppose we’re watching a drag race from the Goodyear blimp. In one run we see a car follow the straight-line path from to shown in Figure 2.3 during the time interval *t*,

**Various Times**

**Position *t* (s) *x* (m)**  0 30 10 52 20 38 30 0 40 37 50 53

*x xf xi*

FIGURE 2.3 A drag race viewed from a blimp. One car follows the red straight-line path from to , and a second car follows the blue curved path.

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and in a second run a car follows the curved path during the same interval. From

the defi nition in Equation 2.2, the two cars had the same average velocity because

they had the same displacement *x*  *xf*  *xi* during the same time interval *t*.

The car taking the curved route, however, traveled a greater distance and had the

higher average speed.

QUICK QUIZ 2.1 Figure 2.4

shows the unusual path of a

**L L**

**A**

**BT**

**O**

**OF**

**2 0 1 0 4 0 5 0 4 0 3 0 3 0 1 0 2 0 1 0 2 0 3 0 4 0 5 0 4 0 3 0 2 0 1 0**

**FO**

**O**

**TB**

**A**

**LL**

confused football player. After receiving a kickoff at his own goal, he runs downfi eld to within inches of a touchdown, then reverses direction and races back until he’s tackled at the exact location where he fi rst caught the ball. During this run, which took 25 s, what is (a) the

0 yd 50 yd

100 yd

total distance he travels, (b) his

FIGURE 2.4 (Quick Quiz 2.1) The path followed by a confused football player.

Graphical Interpretation of Velocity

displacement, and (c) his aver age velocity in the *x*-direction? (d) What is his average speed?

TIP 2.3 Slopes of Graphs

The word *slope* is often used in reference to the graphs of physi cal data. Regardless of the type of data, the *slope* is given by

Slope 5 change in vertical axis change in horizontal axis

Slope carries units.

TIP 2.4 Average Velocity vs. Average Speed

Average velocity is *not* the same as average speed. If you run from *x*  0 m to *x*  25 m and back to your starting point in a time interval of 5 s, the average veloc ity is zero, whereas the average speed is 10 m/s.

If a car moves along the *x*-axis from to to , and so forth, we can plot the positions of these points as a function of the time elapsed since the start of the motion. The result is a **position vs. time graph** like those of Figure 2.5. In Figure 2.5a, the graph is a straight line because the car is moving at constant velocity. The same displacement *x* occurs in each time interval *t*. In this case, the aver

age velocity is always the same and is equal to *x*/ *t*. Figure 2.5b is a graph of the data in Table 2.1. Here, the position vs. time graph is not a straight line because the velocity of the car is changing. Between any two points, however, we can draw a straight line just as in Figure 2.5a, and the slope of that line is the average veloc

ity *x*/ *t* in that time interval. In general, **the average velocity of an object during the time interval**  ***t* is equal to the slope of the straight line joining the initial and fi nal points on a graph of the object’s position versus time.**

From the data in Table 2.1 and the graph in Figure 2.5b, we see that the car fi rst moves in the positive *x*-direction as it travels from to , reaches a position of 52 m at time *t*  10 s, then reverses direction and heads backwards. In the fi rst 10 s of its motion, as the car travels from to , its average velocity is 2.2 m/s, as previously calculated. In the fi rst 40 seconds, as the car goes from to , its displacement is *x*  37 m (30 m) 67 m. So the average velocity in this interval, which equals the slope of the blue line in Figure 2.5b from to , is *~~v~~*  *x*/ *t*  ( 67 m)/(40 s) 1.7 m/s. In general, there will be a different aver age velocity between any distinct pair of points.

Instantaneous Velocity

Average velocity doesn’t take into account the details of what happens during an interval of time. On a car trip, for example, you may speed up or slow down a num ber of times in response to the traffi c and the condition of the road, and on rare occasions even pull over to chat with a police offi cer about your speed. What is most important to the police (and to your own safety) is the speed of your car and the direction it was going at a particular instant in time, which together determine the car’s **instantaneous velocity.**

*x* (m)

60

60

*x* (m)

2.2 Velocity 29

FIGURE 2.5 (a) Posi tion vs. time graph for the

40  20

0

–20

–40

40

20

0

–20 –40

motion of a car moving along the *x*-axis at constant velocity. (b) Position vs. time graph for the motion of a car with changing velocity, using the data in Table 2.1. The average velocity in the time interval from *t*  0 s to *t*  30 s is the slope of the blue straight line connecting and .

–60 *t* (s) 50403020100 (a)

–60

50403020100 (b)

*t* (s)

So in driving a car between two points, the average velocity must be computed over an interval of time, but the magnitude of instantaneous velocity can be read on the car’s speedometer.

The instantaneous velocity *v* is the limit of the average velocity as the time interval *t* becomes infi nitesimally small:

O Defi nition of instantaneous velocity

D*x*

D*t***[2.3]**

**SI unit: meter per second (m/s)**

The notation lim

*v* ; lim D*t* S0

D*t* S0 means that the ratio *x*/ *t* is repeatedly evaluated for smaller and smaller time intervals *t*. As *t* gets extremely close to zero, the ratio *x*/ *t* gets closer and closer to a fi xed number, which is defi ned as the instantaneous velocity.

To better understand the formal defi nition, consider data obtained on our vehi cle via radar (Table 2.2). At *t*  1.00 s, the car is at *x*  5.00 m, and at *t*  3.00 s, it’s at *x*  52.5 m. The average velocity computed for this interval *x*/ *t*  (52.5 m 5.00 m)/(3.00 s 1.00 s) 23.8 m/s. This result could be used as an estimate for the velocity at *t*  1.00 s, but it wouldn’t be very accurate because the speed changes considerably in the two-second time interval. Using the rest of the data, we can con struct Table 2.3. As the time interval gets smaller, the average velocity more closely approaches the instantaneous velocity. Using the fi nal interval of only 0.010 0 s, we fi nd that the average velocity is *~~v~~* 5 D*x*/D*t* 5 0.470 m/0.010 0 s 5 47.0 m/s. Because 0.010 0 s is a very short time interval, the actual instantaneous velocity is probably very close to this latter average velocity, given the limits on the car’s abil ity to accelerate. Finally using the conversion factor on the inside front cover of the book, we see that this is 105 mi/h, a likely violation of the speed limit.

TABLE 2.2

**Positions of a Car at Specifi c Instants of Time**

***t* (s) *x* (m)**

1.00 5.00 1.01 5.47 1.10 9.67 1.20 14.3

1.50 26.3 2.00 34.7 3.00 52.5

TABLE 2.3

**Calculated Values of the Time Intervals, Displacements, and Average Velocities for the Car of Table 2.2 Time Interval (s)**  ***t* (s)**  ***x* (m) *~~v~~* (m/s)** 1.00 to 3.00 2.00 47.5 23.8 1.00 to 2.00 1.00 29.7 29.7 1.00 to 1.50 0.50 21.3 42.6 1.00 to 1.20 0.20 9.30 46.5 1.00 to 1.10 0.10 4.67 46.7 1.00 to 1.01 0.01 0.470 47.0

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FIGURE 2.6 Graph representing

the motion of the car from the data

in Table 2.2. The slope of the blue

line represents the average velocity

for smaller and smaller time intervals

and approaches the slope of the green

tangent line.

*x* (m)

50.0

40.0

30.0

20.0

10.0

*t* (s) 1.00 1.50 2.00 2.50

3.00

As can be seen in Figure 2.6, the chords formed by the blue lines gradually

approach a tangent line as the time interval becomes smaller. **The slope of the**

**line tangent to the position vs. time curve at “a given time” is defi ned to be the**

**instantaneous velocity at that time.**

**The instantaneous speed of an object, which is a scalar quantity, is defi ned as**

**the magnitude of the instantaneous velocity.** Like average speed, instantaneous

speed (which we will usually call, simply, “speed”) has no direction associated with

it and hence carries no algebraic sign. For example, if one object has an instanta

neous velocity of 15 m/s along a given line and another object has an instanta

neous velocity of 15 m/s along the same line, both have an instantaneous speed

of 15 m/s.

EXAMPLE 2.2 Slowly Moving Train

Goal Obtain average and instantaneous velocities from a 10

graph.

8

Problem A train moves slowly along a straight portion of

6

track according to the graph of position versus time in Figure 4

*x* (m)

10 8

6

4

*x* (m)

2.7a. Find **(a)** the average velocity for the total trip, **(b)** the

2

2

average velocity during the fi rst 4.00 s of motion, **(c)** the aver age velocity during the next 4.00 s of motion, **(d)** the instanta

*t* (s) 10

*t* (s) 128642

10

neous velocity at *t*  2.00 s, and **(e)** the instantaneous velocity

128642

(a)

(b)

at *t*  9.00 s.

Strategy The average velocities can be obtained by substitut

FIGURE 2.7 (a) (Example 2.2) (b) (Exercise 2.2)

ing the data into the defi nition. The instantaneous velocity at *t*  2.00 s is the same as the average velocity at that point because the position vs. time graph is a straight line, indicating constant velocity. Finding the instantaneous velocity when *t*  9.00 s requires sketching a line tangent to the curve at that point and fi nding its slope.

Solution

**(a)** Find the average velocity from to .

Calculate the slope of the dashed blue line: *~~v~~* 5 D*x*

D*t* 5 10.0 m

12.0 s 5 10.833 m/s

**(b)** Find the average velocity during the fi rst 4 seconds of

the train’s motion.

D*t* 5 4.00 m

Again, fi nd the slope: *~~v~~* 5 D*x*

**(c)** Find the average velocity during the next 4 seconds. *v* 5 D*x*

4.00 s 5 11.00 m/s

Here, there is no change in position, so the displacement *x* is zero:

D*t* 5 0 m

4.00 s 5 0 m/s

**(d)** Find the instantaneous velocity at *t*  2.00 s.

This is the same as the average velocity found in (b), because the graph is a straight line:

**(e)** Find the instantaneous velocity at *t*  9.00 s. The tangent line appears to intercept the *x*-axis at (3.0 s,

2.3 Acceleration 31

*v*  1.00 m/s

*v* 5 D*x*

D*t* 5 4.5 m 2 0 m

0 m) and graze the curve at (9.0 s, 4.5 m). The instanta neous velocity at *t*  9.00 s equals the slope of the tan gent line through these points:

9.0 s 2 3.0 s 5 0.75 m/s

Remarks From the origin to , the train moves at constant speed in the positive *x*-direction for the fi rst 4.00 s, because the position vs. time curve is rising steadily toward positive values. From to , the train stops at *x*  4.00 m for 4.00 s. From to , the train travels at increasing speed in the positive *x*-direction.

QUESTION 2.2

Would a vertical line in a graph of position versus time make sense? Explain.

EXERCISE 2.2

Figure 2.7b graphs another run of the train. Find (a) the average velocity from to ; (b) the average and instanta neous velocities from to ; (c) the approximate instantaneous velocity at *t*  6.0 s; and (d) the average and instan taneous velocity at *t*  9.0 s.

Answers (a) 0 m/s (b) both are 0.5 m/s (c) 2 m/s (d) both are 2.5 m/s

2.3 ACCELERATION

Going from place to place in your car, you rarely travel long distances at con

stant velocity. The velocity of the car increases when you step harder on the gas

pedal and decreases when you apply the brakes. The velocity also changes when

you round a curve, altering your direction of motion. The changing of an object’s

velocity with time is called **acceleration.**

Average Acceleration

A car moves along a straight highway as in Figure 2.8. At time *ti* it has a velocity of

*vi*, and at time *tf* its velocity is *vf* , with *v*  *vf*  *vi* and *t*  *tf*  *ti*.

The average acceleration *~~a~~* during the time interval *t* is the change in veloc ity *v* divided by *t*:

D*t* 5 *vf* 2 *vi*

O Defi nition of average acceleration

*~~a~~* ; D*v*

*tf* 2 *ti***[2.4]**

**SI unit: meter per second per second (m/s2)**

For example, suppose the car shown in Figure 2.8 accelerates from an initial velocity of *vi*  10 m/s to a fi nal velocity of *vf*  20 m/s in a time interval of 2 s. *ti*

(Both velocities are toward the right, selected as the positive direction.) These val *vi*

ues can be inserted into Equation 2.4 to fi nd the average acceleration:

*~~a~~* 5 D*v*

D*t* 5 20 m/s 2 10 m/s

2 s5 15 m/s2

*tf*

*vf*

Acceleration is a vector quantity having dimensions of length divided by the time squared. Common units of acceleration are meters per second per second ((m/s)/s, which is usually written m/s2) and feet per second per second (ft/s2). An

FIGURE 2.8 A car moving to the right accelerates from a velocity of *vi* to a velocity of *vf* in the time interval *t*  *tf*  *ti*.

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average acceleration of 5 m/s2 means that, on average, the car increases its veloc

ity by 5 m/s every second in the positive *x*-direction.

TIP 2.5 Negative

Acceleration

Negative acceleration doesn’t nec essarily mean an object is slowing down. If the acceleration is nega tive and the velocity is also nega tive, the object is speeding up!

For the case of motion in a straight line, the direction of the velocity of an object and the direction of its acceleration are related as follows: **When the object’s veloc ity and acceleration are in the same direction, the speed of the object increases with time. When the object’s velocity and acceleration are in opposite directions, the speed of the object decreases with time.**

To clarify this point, suppose the velocity of a car changes from 10 m/s to 20 m/s in a time interval of 2 s. The minus signs indicate that the velocities of the car are in the negative *x*-direction; they do *not* mean that the car is slowing down! The average acceleration of the car in this time interval is

D*t* 5 220 m/s 2 1210 m/s2

*a* 5 D*v*

2 s 5 25 m/s2

TIP 2.6 Deceleration

The word *deceleration* means a reduction in speed, a slowing down. Some confuse it with a negative acceleration, which can

speed something up. (See Tip 2.5.)

Defi nition of instantaneous acceleration R

The minus sign indicates that the acceleration vector is also in the negative *x*-direction. Because the velocity and acceleration vectors are in the same direc tion, the speed of the car must increase as the car moves to the left. Positive and negative accelerations specify directions relative to chosen axes, not “speeding up” or “slowing down.” The terms “speeding up” or “slowing down” refer to an increase and a decrease in speed, respectively.

QUICK QUIZ 2.2 **True or False? (a)** A car must always have an acceleration in the same direction as its velocity. **(b)** It’s possible for a slowing car to have a positive acceleration. **(c)** An object with constant nonzero acceleration can never stop and remain at rest.

Instantaneous Acceleration

The value of the average acceleration often differs in different time intervals, so it’s useful to defi ne the **instantaneous acceleration**, which is analogous to the instantaneous velocity discussed in Section 2.2.

The instantaneous acceleration *a* is the limit of the average acceleration as the time interval *t* goes to zero:

*a* ; lim D*t* S0

D*v*

D*t***[2.5]**

*v*

Slope = *a–* = Δ*v* Δ*t*

**SI unit: meter per second per second (m/s2)**

Here again, the notation lim

D*t* S0 means that the ratio *v*/ *t* is evaluated for smaller

and smaller values of *t*. The closer *t* gets to zero, the closer the ratio gets to a fi xed number, which is the instantaneous acceleration.

Figure 2.9, a **velocity vs. time graph**, plots the velocity of an object against time.

*vf* Δ*v*  *vi*

Δ*t*

*t*

*tf ti*

The graph could represent, for example, the motion of a car along a busy street. The average acceleration of the car between times *ti* and *tf*can be found by deter mining the slope of the line joining points and . If we imagine that point is brought closer and closer to point , the line comes closer and closer to becoming tangent at . The **instantaneous acceleration of an object at a given time equals the slope of the tangent to the velocity vs. time graph at that time.** From now on, we will use the term *acceleration* to mean “instantaneous acceleration.”

In the special case where the velocity vs. time graph of an object’s motion is a

FIGURE 2.9 Velocity vs. time graph for an object moving in a straight line. The slope of the blue line connecting points and is defi ned as the aver

age acceleration in the time interval *t*  *tf*  *ti*.

straight line, the instantaneous acceleration of the object at any point is equal to its average acceleration. This also means that the tangent line to the graph overlaps the graph itself. In that case, the object’s acceleration is said to be *uniform*, which means that it has a constant value. Constant acceleration problems are important in kinematics and will be studied extensively in this and the next chapter.

*v*

(a) *a*

(d)

*t t*

*v*

(b) *a*

(e)

*t t*

*v*

(c) *a*

(f)

*t t*

FIGURE 2.10 (Quick Quiz 2.3) Match each velocity vs. time graph to its corresponding acceleration vs. time graph.

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QUICK QUIZ 2.3 Parts (a), (b), and (c) of Figure 2.10 represent three graphs of the velocities of different objects moving in straight-line paths as functions of time. The possible accelerations of each object as functions of time are shown in parts (d), (e), and (f). Match each velocity vs. time graph with the acceleration vs. time graph that best describes the motion.

EXAMPLE 2.3 Catching a Fly Ball

Goal Apply the defi nition of instantaneous acceleration.

Problem A baseball player moves in a straight-line path in order to catch a fl y ball hit to the outfi eld. His velocity as a function of time is shown in Figure 2.11a. Find his

*v* (m/s)

4

3

*v* (m/s)

4

3

2

2

instantaneous acceleration at points , , and .

1

1

Strategy At each point, the velocity vs. time graph is a

straight line segment, so the instantaneous acceleration

*t* (s)

*t* (s)

will be the slope of that segment. Select two points on each segment and use them to calculate the slope.

*O* 1 2 3 4 (a)

*O* 1 2 3 4 (b)

Solution

Acceleration at .

The acceleration at equals the slope of the line con necting the points (0 s, 0 m/s) and (2.0 s, 4.0 m/s):

Acceleration at .

FIGURE 2.11 (a) (Example 2.3) (b) (Exercise 2.3)

*a* 5 D*v*

D*t* 5 4.0 m/s 2 0

2.0 s 2 0 5 12.0 m/s2

*v*  0, because the segment is horizontal: *a* 5 D*v*

D*t* 5 4.0 m/s 2 4.0 m/s

3.0 s 2 2.0 s 5 0 m/s2

Acceleration at .

D*t* 5 2.0 m/s 2 4.0 m/s

The acceleration at equals the slope of the line con necting the points (3.0 s, 4.0 m/s) and (4.0 s, 2.0 m/s):

*a* 5 D*v*

4.0 s 2 3.0 s 5 22.0 m/s2

Remarks Assume the player is initially moving in the positive *x*-direction. For the fi rst 2.0 s, the ballplayer moves in the positive *x*-direction (the velocity is positive) and steadily accelerates (the curve is steadily rising) to a maximum speed of 4.0 m/s. He moves for 1.0 s at a steady speed of 4.0 m/s and then slows down in the last second (the *v* vs. *t* curve is falling), still moving in the positive *x*-direction (*v* is always positive).

QUESTION 2.3

Can the tangent line to a velocity vs. time graph ever be vertical? Explain.

EXERCISE 2.3

Repeat the problem, using Figure 2.11b.

Answer The accelerations at , , and are 3.0 m/s2, 1.0 m/s2, and 0 m/s2, respectively.

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ACTIVE FIGURE 2.12

(a) Motion diagram for a car moving

**v**

at constant velocity (zero accelera 

(a)

tion). (b) Motion diagram for a car

undergoing constant acceleration in

the direction of its velocity. The veloc

ity vector at each instant is indicated

**v**

by a red arrow and the constant ac 

(b)

celeration vector by a violet arrow.

**a**

(c) Motion diagram for a car under

going constant acceleration in the

direction *opposite* the velocity at each

**v**

instant. 

(c)

**a**

2.4 MOTION DIAGRAMS

Velocity and acceleration are sometimes confused with each other, but they’re very different concepts, as can be illustrated with the help of motion diagrams. A **motion diagram** is a representation of a moving object at successive time intervals, with velocity and acceleration vectors sketched at each position, red for velocity vectors and violet for acceleration vectors, as in Active Figure 2.12. The time inter

vals between adjacent positions in the motion diagram are assumed equal. A motion diagram is analogous to images resulting from a stroboscopic photo graph of a moving object. Each image is made as the strobe light fl ashes. Active Figure 2.12 represents three sets of strobe photographs of cars moving along a straight roadway from left to right. The time intervals between fl ashes of the stro boscope are equal in each diagram.

In Active Figure 2.12a, the images of the car are equally spaced: The car moves the same distance in each time interval. This means that the car moves with *con stant positive velocity* and has *zero acceleration*. The red arrows are all the same length (constant velocity) and there are no violet arrows (zero acceleration).

In Active Figure 2.12b, the images of the car become farther apart as time pro gresses and the velocity vector increases with time, because the car’s displacement between adjacent positions increases as time progresses. The car is moving with a *positive velocity* and a constant *positive acceleration*. The red arrows are successively longer in each image, and the violet arrows point to the right.

In Active Figure 2.12c, the car slows as it moves to the right because its dis placement between adjacent positions decreases with time. In this case, the car moves initially to the right with a constant negative acceleration. The velocity vec tor decreases in time (the red arrows get shorter) and eventually reaches zero, as would happen when the brakes are applied. Note that the acceleration and velocity vectors are *not* in the same direction. The car is moving with a *positive velocity*, but with a *negative acceleration*.

Try constructing your own diagrams for various problems involving kinematics.

QUICK QUIZ 2.4 The three graphs in Active Figure 2.13 represent the position vs. time for objects moving along the *x*-axis. Which, if any, of these graphs is not physically possible?

ACTIVE FIGURE 2.13

(Quick Quiz 2.4) Which position vs. time curve is impossible?

*x*

*t*

(a)

*x*

*t*

(b)

*x*

*t*

(c)

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(a)

QUICK QUIZ 2.5 Figure 2.14a is a diagram of a multifl ash image of an air puck moving to the right on a horizontal surface. The images sketched are separated by equal time intervals, and the fi rst and last images show the puck at rest. (a) In Figure 2.14b, which color graph best shows the puck’s position (b)

as a function of time? (b) In Figure 2.14c, which color graph best shows the puck’s velocity as a function of time? (c) In Figure 2.14d, which color graph best shows the puck’s acceleration as a function of time?

*x*

+

*t O v*

2.5 ONE-DIMENSIONAL MOTION

WITH CONSTANT ACCELERATION

Many applications of mechanics involve objects moving with *constant acceleration*. This type of motion is important because it applies to numerous objects in nature, such as an object in free fall near Earth’s surface (assuming air resistance can be neglected). A graph of acceleration versus time for motion with constant accelera

tion is shown in Active Figure 2.15a. **When an object moves with constant accel eration, the instantaneous acceleration at any point in a time interval is equal to the value of the average acceleration over the entire time interval.** Consequently, the velocity increases or decreases at the same rate throughout the motion, and a

plot of *v* versus *t* gives a straight line with either positive, zero, or negative slope. Because the average acceleration equals the instantaneous acceleration when *a* is constant, we can eliminate the bar used to denote average values from our defi n ing equation for acceleration, writing *~~a~~*  *a*, so that Equation 2.4 becomes

*a* 5 *vf* 2 *vi*

*tf* 2 *ti*

The observer timing the motion is always at liberty to choose the initial time, so for convenience, let *ti*  0 and *tf* be any arbitrary time *t*. Also, let *vi*  *v*0 (the initial velocity at *t*  0) and *vf*  *v* (the velocity at any arbitrary time *t*). With this notation, we can express the acceleration as

*a* 5 *v* 2 *v*0

*t*

or

*v* 5 *v*0 1 *at* (for constant *a*) **[2.6]**

Equation 2.6 states that the acceleration *a* steadily changes the initial velocity *v*0 by an amount *at*. For example, if a car starts with a velocity of 2.0 m/s to the right

(c) +

*t*

*O*

–

*a*

+

*t*

(d)

*O*

–

FIGURE 2.14 (Quick Quiz 2.5) Choose the correct graphs.

*a*

Slope = 0

*a*

*t*

0

(a)

*v*

Slope = *a*

*at*

*v*0

*v*

*v*0

*t*

*t*

0

and accelerates to the right with *a*  6.0 m/s2, it will have a velocity of 14 m/s

(b)

after 2.0 s have elapsed:

*v*  *v*0  *at*  2.0 m/s (6.0 m/s2)(2.0 s) 14 m/s

*x*

The graphical interpretation of *v* is shown in Active Figure 2.15b. The velocity var

ies linearly with time according to Equation 2.6, as it should for constant accelera tion.

Because the velocity is increasing or decreasing *uniformly* with time, we can express the average velocity in any time interval as the arithmetic average of the initial velocity *v*0 and the fi nal velocity *v*:

Slope = *v*

*x* 0

Slope = *v*0

*~~v~~* 5 *v*0 1 *v*

2(for constant *a*) **[2.7]**

Remember that this expression is valid only when the acceleration is constant, in which case the velocity increases uniformly.

We can now use this result along with the defi ning equation for average veloc ity, Equation 2.2, to obtain an expression for the displacement of an object as a

0 *t ~~t~~*

(c)

ACTIVE FIGURE 2.15

A particle moving along the *x*-axis with constant acceleration *a*. (a) the acceleration vs. time graph, (b) the velocity vs. time graph, and (c) the position vs. time graph.

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TABLE 2.4

**Equations for Motion in a Straight Line Under**

**Constant Acceleration**

**Equation Information Given by Equation**

*v*  *v*0  *at* Velocity as a function of time

D*x* 5 *v*0*t* 1 12*at* 2 Displacement as a function of time

*v*2  *v* 02  2*a*  *x* Velocity as a function of displacement

Note: Motion is along the *x*-axis. At *t*  0, the velocity of the particle is *v*0.

function of time. Again, we choose *ti*  0 and *tf*  *t*, and for convenience, we write

*x*  *xf*  *xi*  *x*  *x*0. This results in

D*x* 5 *~~vt~~* 5 a*v*0 1 *v*

2 ~~b~~*t*

D*x* 5 12 1*v*0 1 *v*2*t* (for constant *a*) **[2.8]**

We can obtain another useful expression for displacement by substituting the

equation for *v* (Eq. 2.6) into Equation 2.8:

D*x* 5 12 1*v*0 1 *v*0 1 *at*2*t*

D*x* 5 *v*0*t* 1 12*at* 2 (for constant *a*) **[2.9]**

This equation can also be written in terms of the position *x*, since *x*  *x*  *x*0.

Active Figure 2.15c shows a plot of *x* versus *t* for Equation 2.9, which is related to the

graph of velocity vs. time: The area under the curve in Active Figure 2.15b is equal

to *v*0*t* 1 12*at* 2, which is equal to the displacement *x*. In fact, **the area under the**

**graph of *v* versus *t* for any object is equal to the displacement**  ***x* of the object.**

Finally, we can obtain an expression that doesn’t contain time by solving Equa

tion 2.6 for *t* and substituting into Equation 2.8, resulting in

*a* ~~b~~ 5 *v* 2 2 *v*02

D*x* 5 12 1*v* 1 *v*0 2 a*v* 2 *v*0

2*a*

*v* 2 5 *v*02 1 2*a* D*x* (for constant *a*) **[2.10]**

Equations 2.6 and 2.9 together can solve any problem in one-dimensional motion with constant acceleration, but Equations 2.7, 2.8, and, especially, 2.10 are some times convenient. The three most useful equations—Equations 2.6, 2.9, and 2.10—are listed in Table 2.4.

The best way to gain confi dence in the use of these equations is to work a num ber of problems. There is usually more than one way to solve a given problem, depending on which equations are selected and what quantities are given. The dif ference lies mainly in the algebra.

PROBLEM-SOLVING STRATEGY

ACCELERATED MOTION

The following procedure is recommended for solving problems involving accel erated motion.

1. **Read** the problem.

2. **Draw** a diagram, choosing a coordinate system, labeling initial and fi nal points, and indicating directions of velocities and accelerations with arrows. 3. **Label** all quantities, circling the unknowns. Convert units as needed.

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4. **Equations** from Table 2.4 should be selected next. All kinematics problems in this chapter can be solved with the fi rst two equations, and the third is often convenient.

5. **Solve** for the unknowns. Doing so often involves solving two equations for two unknowns. It’s usually more convenient to substitute all known values before solving.

6. **Check** your answer, using common sense and estimates.

Most of these problems reduce to writing the kinematic equations from Table 2.4 and then substituting the correct values into the constants *a*, *v*0, and *x*0 from the given information. Doing this produces two equations—one linear and one quadratic—for two unknown quantities.

EXAMPLE 2.4 The Daytona 500

Goal Apply the basic kinematic equations.

Problem **(a)** A race car starting from rest accelerates at a constant rate of 5.00 m/s2. What is the velocity of the car after it has traveled 1.00 102 ft? **(b)** How much time has elapsed?

Strategy **(a)** We’ve read the problem, drawn the diagram in Figure 2.16, and chosen a coordinate system (steps 1 and 2). We’d like to fi nd the velocity *v* after a certain known displacement *x*. The acceleration *a* is also known, as is the initial velocity *v*0 (step 3, labeling, is complete), so the third equation in Table 2.4 looks

TIP 2.7 Pigs Don’t Fly

After solving a problem, you should think about your answer and decide whether it seems rea sonable. If it isn’t, look for your mistake!

*v*0 = 0 *v* = ? *x* = 0 *x* = 30.5 m + *x*

FIGURE 2.16 (Example 2.4)

most useful for solving part (a). Given the velocity, the fi rst equation in Table 2.4 can then be used to fi nd the time in part (b).

Solution

**(a)** Convert units of *x* to SI, using the information in the inside front cover.

1.00 3 102 ft 5 11.00 3 102 ft2 a 1 m

3.28 ft~~b~~ 5 30.5 m

Write the kinematics equation for *v* 2 (step 4): *v* 2  *v* 02  2*a*  *x*

Solve for *v*, taking the positive square root because the car moves to the right (step 5):

*v* 5 "*v*02 1 2*a* D*x*

Substitute *v*0  0, *a*  5.00 m/s2, and *x*  30.5 m: *v* 5 "*v*02 1 2*a* D*x* 5 "102 2 1 215.00 m/s2 2 130.5 m2 17.5 m/s

**(b)** How much time has elapsed?

Apply the fi rst equation of Table 2.4: *v*  *at*  *v*0

Substitute values and solve for time *t*: 17.5 m/s (5.00 m/s2)*t*

*t* 5 17.5 m/s

5.0 m/s2 5 3.50 s

Remarks The answers are easy to check. An alternate technique is to use D*x* 5 *v*0*t* 1 12*at* 2 to fi nd *t* and then use the equation *v*  *v*0  *at* to fi nd *v*.

QUESTION 2.4

What is the fi nal speed if the displacement is increased by a factor of 4?

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EXERCISE 2.4

Suppose the driver in this example now slams on the brakes, stopping the car in 4.00 s. Find (a) the acceleration and (b) the distance the car travels while braking, assuming the acceleration is constant.

Answers (a) *a*  4.38 m/s2 (b) *d*  35.0 m

EXAMPLE 2.5 Car Chase

Goal Solve a problem involving two objects, one moving at constant acceleration and the other at constant velocity.

Problem A car traveling at a constant speed of 24.0 m/s passes a trooper hidden behind a billboard, as in Figure 2.17. One second after the speeding car passes the bill board, the trooper sets off in chase with a constant accel eration of 3.00 m/s2. **(a)** How long does it take the trooper to overtake the speeding car? **(b)** How fast is the trooper going at that time?

Strategy Solving this problem involves two simultane ous kinematics equations of position, one for the trooper and the other for the car. Choose *t*  0 to correspond to the time the trooper takes up the chase, when the car is at *x*car  24.0 m because of its head start (24.0 m/s 1.00 s). The trooper catches up with the car when their positions are the same, which suggests setting *x*trooper  *x*car and solv ing for time, which can then be used to fi nd the trooper’s speed in part (b).

Solution

**(a)** How long does it take the trooper to overtake the car?

*v*car = 24.0 m/s

*a*car = 0

*a*trooper = 3.00 m/s2

*t*= –1.00 s *t*= 0 *t*= ? 





FIGURE 2.17 (Example 2.5) A speeding car passes a hidden trooper. When does the trooper catch up to the car?

Write the equation for the car’s displacement: D*x*car 5 *x*car 2 *x*0 5 *v*0*t* 1 12*a*car*t*2

Take *x*0  24.0 m, *v*0  24.0 m/s and *a*car  0. Solve for *x*car:

Write the equation for the trooper’s position, taking *x*0  0, *v*0  0, and atrooper  3.00 m/s2:

Set *x*trooper  *x*car, and solve the quadratic equation. (The quadratic formula appears in Appendix A, Equation A.8.) Only the positive root is meaningful.

**(b)** Find the trooper’s speed at this time.

*x*car  *x*0  *vt*  24.0 m (24.0 m/s)*t*

*x*trooper 5 12*a*trooper*t*2 5 12 13.00 m/s2 2*t*2 5 11.50 m/s2 2*t*2

(1.50 m/s2)*t*2  24.0 m (24.0 m/s)*t*

(1.50 m/s2)*t*2  (24.0 m/s)*t*  24.0 m 0 *t*  16.9 s

Substitute the time into the trooper’s velocity equation: *v*trooper  *v*0  *a*trooper *t*  0 (3.00 m/s2)(16.9 s) 50.7 m/s

Remarks The trooper, traveling about twice as fast as the car, must swerve or apply his brakes strongly to avoid a collision! This problem can also be solved graphically by plotting position versus time for each vehicle on the same graph. The intersection of the two graphs corresponds to the time and position at which the trooper overtakes the car.

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QUESTION 2.5

The graphical solution corresponds to fi nding the intersection of what two types of curves in the *xt*-plane?

EXERCISE 2.5

A motorist with an expired license tag is traveling at 10.0 m/s down a street, and a policeman on a motorcycle, taking another 5.00 s to fi nish his donut, gives chase at an acceleration of 2.00 m/s2. Find (a) the time required to catch the car and (b) the distance the trooper travels while overtaking the motorist.

Answers (a) 13.7 s (b) 188 m

EXAMPLE 2.6 Runway Length

Goal Apply kinematics to horizontal motion with two phases.

Problem A typical jetliner lands at a speed of 160 mi/h

Origin

*a*

*v v*

and decelerates at the rate of (10 mi/h)/s. If the plane trav els at a constant speed of 160 mi/h for 1.0 s after landing before applying the brakes, what is the total displacement of the aircraft between touchdown on the runway and coming to rest?

coasting

distance

*v*0 = 71.5 m/s *a* = 0

*t* = 1.0 s

braking distance +*x*

*v* = 71.5 m/s

0

*vf* = 0

*a* = –4.47 m/s2

Strategy See Figure 2.18. First, convert all quantities to SI units. The problem must be solved in two parts, or phases,

FIGURE 2.18 (Example 2.6) Coasting and braking distances for a landing jetliner.

corresponding to the initial coast after touchdown, followed by braking. Using the kinematic equations, fi nd the dis placement during each part and add the two displacements.

Solution

Convert units of speed and acceleration to SI: *v*0 5 1160 mi/h2 a 0.447 m/s 1.00 mi/h ~~b~~ 5 71.5 m/s

*a* 5 1210.0 1mi/h2/s2 a 0.447 m/s

1.00 mi/h ~~b~~ 5 24.47 m/s2

Taking *a*  0, *v*0  71.5 m/s, and *t*  1.00 s, fi nd the dis placement while the plane is coasting:D*x*coasting 5 *v*0*t* 1 12*at* 2 5 171.5 m/s2 11.00 s2 1 0 5 71.5 m

Use the time-independent kinematic equation to fi nd the displacement while the plane is braking.

*v* 2 5 *v*02 1 2*a*D*x*braking

2*a* 5 0 2 171.5 m/s2 2

Take *a*  4.47 m/s2 and *v*0  71.5 m/s. The negative sign on *a* means that the plane is slowing down.

D*x*braking 5 *v* 2 2 *v*02

2.00124.47 m/s2 2 5 572 m

Sum the two results to fi nd the total displacement: D*x*coasting 1 D*x*braking 5 72 m 1 572 m 5 644 m

Remarks To fi nd the displacement while braking, we could have used the two kinematics equations involving time, namely, D*x* 5 *v*0*t* 1 12*at* 2 and *v*  *v*0  *at*, but because we weren’t interested in time, the time-independent equation was easier to use.

QUESTION 2.6

How would the answer change if the plane coasted for 2.0 s before the pilot applied the brakes?

EXERCISE 2.6

A jet lands at 80.0 m/s, the pilot applying the brakes 2.00 s after landing. Find the acceleration needed to stop the jet within 5.00 102 m.

Answer *a*  9.41 m/s2

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EXAMPLE 2.7 The Acela: The Porsche of American Trains Goal Find accelerations and displacements from a velocity vs. time graph.

Problem The sleek high-speed electric train known as the Acela (pronounced ahh-sell-ah) is currently in ser vice on the Washington-New York-Boston run. The Acela consists of two power cars and six coaches and can carry 304 passengers at speeds up to 170 mi/h. In order to negotiate curves comfortably at high speeds, the train carriages tilt as much as 6° from the vertical, prevent

ing passengers from being pushed to the side. A velocity vs. time graph for the Acela is shown in Figure 2.19a. **(a)** Describe the motion of the Acela. **(b)** Find the peak acceleration of the Acela in miles per hour per sec

ond ((mi/h)/s) as the train speeds up from 45 mi/h to 170 mi/h. **(c)** Find the train’s displacement in miles between *t*  0 and *t*  200 s. **(d)** Find the average accel eration of the Acela and its displacement in miles in the interval from 200 s to 300 s. (The train has regenerative

Solution

**(a)** Describe the motion.

braking, which means that it feeds energy back into the utility lines each time it stops!) **(e)** Find the total displace ment in the interval from 0 to 400 s.

Strategy For part (a), remember that the slope of the tangent line at any point of the velocity vs. time graph gives the acceleration at that time. To fi nd the peak accel eration in part (b), study the graph and locate the point at which the slope is steepest. In parts (c) through (e), estimating the area under the curve gives the displace ment during a given period, with areas below the time axis, as in part (e), subtracted from the total. The aver age acceleration in part (d) can be obtained by substitut ing numbers taken from the graph into the defi nition of average acceleration, *~~a~~* 5 D*v*/D*t*.

From about 50 s to 50 s, the Acela cruises at a constant velocity in the *x*-direction. Then the train accelerates in the *x*-direction from 50 s to 200 s, reaching a top speed of about 170 mi/h, whereupon it brakes to rest at 350 s and reverses, steadily gaining speed in the *x*-direction.

**(b)** Find the peak acceleration.

D*t* 5 11.5 3 102 2 5.0 3 101 2 mi/h

Calculate the slope of the steepest tangent line, which connects the points (50 s, 50 mi/h) and (100 s, 150 mi/h) (the light blue line in Figure 2.19b):

**(c)** Find the displacement between 0 s and 200 s.

*a* 5 slope 5 D*v*  2.0 (mi/h)/s

11.0 3 102 2 5.0 3 101 2s

Using triangles and rectangles, approximate the area in Figure 2.19c:

Convert units to miles by converting hours to seconds:

**(d)** Find the average acceleration from 200 s to 300 s, and fi nd the displacement.

D*x*0 S 200 s 5 area1 1 area2 1 area3 1 area4 1 area5 (5.0 101 mi/h)(5.0 101 s)

(5.0 101 mi/h)(5.0 101 s)

(1.6 102 mi/h)(1.0 102 s)

1 12 15.0 3 101 s2 11.0 3 102 mi/h2

1 12 11.0 3 102 s2 11.7 3 102 mi/h 2 1.6 3 102 mi/h2 2.4 104 (mi/h)s

D*x*0 S 200 s < 2.4 3 104 mi #s

h a 1 h

3 600 s~~b~~ 5 6.7 mi

D*t* 5 11.0 3 101 2 1.7 3 102 2 mi/h

The slope of the green line is the average acceleration from 200 s to 300 s (Fig. 2.19b):

*~~a~~* 5 slope 5 D*v*

1.0 3 102 s

1.6 (mi/h)/s

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200

200

150

150

)

h

/i

m

(

*v*

100 50

0

*t* (s)

)

h

/i

m

(

*v*

100 50

0

*t*

*v*

*t* (s)

–50 0 50 100 150 200 250 300 350 400 –50

–100

(a)

–50 0 50 100 150 200 250 300 350 400 –50

–100

(b)

)

h

/i

m

(

*v*

200 150 100 50

0

5

4 3

12 6

*t* (s)

)

h

/i

m

(

*v*

200 150 100 50

0

0 50 100

*t* (s)

–50 0 50 100 200 250 300 350 400

150

–50

–100

(c)

–25

–50

–100

150 200 250 300 350 400 (d)

FIGURE 2.19 (Example 2.7) (a) Velocity vs. time graph for the Acela. (b) The slope of the steepest tangent blue line gives the peak acceleration, and the slope of the green line is the average acceleration between 200 s and 300 s. (c) The area under the velocity vs. time graph in some time interval gives the displacement of the Acela in that time interval. (d) (Exercise 2.7).

The displacement from 200 s to 300 s is equal to area6, which is the area of a triangle plus the area of a very narrow rectangle beneath the triangle:

**(e)** Find the total displacement from 0 s to 400 s.

D*x*200 S 300 s < 12 11.0 3 102 s2 11.7 3 102 2 1.0 3 101 2 mi/h (1.0 101 mi/h)(1.0 102 s)

9.0 103(mi/h)(s) 2.5 mi

The total displacement is the sum of all the individual displacements. We still need to calculate the displace ments for the time intervals from 300 s to 350 s and from 350 s to 400 s. The latter is negative because it’s below the time axis.

D*x*300 S 350 s < 12 15.0 3 101 s2 11.0 3 101 mi/h2 2.5 102(mi/h)(s)

D*x*350 S 400 s < 12 15.0 3 101 s2 125.0 3 101 mi/h2 1.3 103(mi/h)(s)

Find the total displacement by summing the parts: D*x*0 S 400 s < 12.4 3 104 1 9.0 3 103 1 2.5 3 102 1.3 103)(mi/h)(s) 8.9 mi

Remarks There are a number of ways to fi nd the approximate area under a graph. Choice of technique is a per sonal preference.

QUESTION 2.7

According to the graph in Figure 2.19a, at what different times is the acceleration zero?

EXERCISE 2.7

Suppose the velocity vs. time graph of another train is given in Figure 2.19d. Find (a) the maximum instantaneous acceleration and (b) the total displacement in the interval from 0 s to 4.00 102 s.

Answers (a) 1.0 (mi/h)/s (b) 4.7 mi

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2.6 FREELY FALLING OBJECTS 

When air resistance is negligible, all objects dropped under the infl uence of grav

ity near Earth’s surface fall toward Earth with the same constant acceleration. This

idea may seem obvious today, but it wasn’t until about 1600 that it was accepted.

Prior to that time, the teachings of the great philosopher Aristotle (384–322 B.C.)

had held that heavier objects fell faster than lighter ones.

According to legend, Galileo discovered the law of falling objects by observing

that two different weights dropped simultaneously from the Leaning Tower of Pisa

hit the ground at approximately the same time. Although it’s unlikely that this par

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GALILEO GALILEI

Italian Physicist and Astronomer (1564–1642)

Galileo formulated the laws that govern the motion of objects in free fall. He also investigated the motion of an object on an inclined plane, established the concept of relative motion, invented the thermometer, and discovered that the motion of a swinging pendulum could be used to measure time intervals. After designing and constructing his own telescope, he discovered four of Jupiter’s moons, found that our own Moon’s surface is rough, discovered sunspots and the phases of Venus, and showed that the Milky Way con sists of an enormous number of stars. Galileo publicly defended Nicolaus Copernicus’s assertion that the Sun is at the center of the Universe (the heliocentric system). He published *Dialogue Concerning Two New World Systems* to support the Copernican model, a view the Church declared to be heretical. After being taken to Rome in 1633 on a charge of heresy, he was sentenced to life imprison ment and later was confi ned to his villa at Arcetri, near Florence, where he died in 1642.

ticular experiment was carried out, we know that Galileo performed many system atic experiments with objects moving on inclined planes. In his experiments he rolled balls down a slight incline and measured the distances they covered in suc cessive time intervals. The purpose of the incline was to reduce the acceleration and enable Galileo to make accurate measurements of the intervals. (Some people refer to this experiment as “diluting gravity.”) By gradually increasing the slope of the incline he was fi nally able to draw mathematical conclusions about freely falling objects, because a falling ball is equivalent to a ball going down a vertical incline. Galileo’s achievements in the science of mechanics paved the way for New

ton in his development of the laws of motion, which we will study in Chapter 4. Try the following experiment: Drop a hammer and a feather simultaneously from the same height. The hammer hits the fl oor fi rst because air drag has a greater effect on the much lighter feather. On August 2, 1971, this same experi ment was conducted on the Moon by astronaut David Scott, and the hammer and feather fell with exactly the same acceleration, as expected, hitting the lunar sur face at the same time. In the idealized case where air resistance is negligible, such motion is called *free fall*.

The expression *freely falling object* doesn’t necessarily refer to an object dropped from rest. **A freely falling object is any object moving freely under the infl uence of gravity alone, regardless of its initial motion.** Objects thrown upward or down ward and those released from rest are all considered freely falling.

We denote the magnitude of the **free-fall acceleration** by the symbol *g*. The value of *g* decreases with increasing altitude, and varies slightly with latitude as well. At Earth’s surface, the value of *g* is approximately 9.80 m/s2. Unless stated otherwise, we will use this value for *g* in doing calculations. For quick estimates, use *g*  10 m/s2.

If we neglect air resistance and assume that the free-fall acceleration doesn’t vary with altitude over short vertical distances, then the motion of a freely falling object is the same as motion in one dimension under constant acceleration. This means that the kinematics equations developed in Section 2.6 can be applied. It’s conventional to defi ne “up” as the *y*-direction and to use *y* as the position vari

able. In that case the acceleration is *a*  *g*  9.80 m/s2. In Chapter 7, we study the variation in *g* with altitude.

QUICK QUIZ 2.6 A tennis player on serve tosses a ball straight up. While the ball is in free fall, does its acceleration (a) increase, (b) decrease, (c) increase and then decrease, (d) decrease and then increase, or (e) remain constant?

QUICK QUIZ 2.7 As the tennis ball of Quick Quiz 2.6 travels through the air, does its speed (a) increase, (b) decrease, (c) decrease and then increase, (d) increase and then decrease, or (e) remain the same?

QUICK QUIZ 2.8 A skydiver jumps out of a hovering helicopter. A few sec onds later, another skydiver jumps out, so they both fall along the same verti cal line relative to the helicopter. Both skydivers fall with the same accelera tion. Does the vertical distance between them (a) increase, (b) decrease, or

(c) stay the same? Does the difference in their velocities (d) increase, (e) de crease, or (f) stay the same? (Assume *g* is constant.)

2.6 Freely Falling Objects 43

EXAMPLE 2.8 Not a Bad Throw for a Rookie!

Goal Apply the kinematic equations to a freely falling object with a nonzero initial velocity.

Problem A stone is thrown from the top of a building with an initial velocity of 20.0 m/s straight upward, at an initial height of 50.0 m above the ground. The stone just misses the edge of the roof on its way down, as shown in

FIGURE 2.20 (Example 2.8) A

freely falling object is thrown upward

with an initial velocity of *v*0

20.0 m/s. Positions and velocities

are given for several times.

*t* = 0, *y*0 = 0

*v*0 = 20.0 m/s

*t* = 2.04 s

*y*max = 20.4 m *v* = 0

Figure 2.20. Determine **(a)** the time needed for the stone to reach its maximum height, **(b)** the maximum height, **(c)** the time needed for the stone to return to the height from which it was thrown and the velocity of the stone at that instant, **(d)** the time needed for the stone to reach the ground, and **(e)** the velocity and posi tion of the stone at *t*  5.00 s.

Strategy The diagram in Figure 2.20 estab lishes a coordinate system with *y*0  0 at the level at which the stone is released from the thrower’s hand, with *y* positive upward. Write the velocity and position kinematic equations for the stone, and substitute the given infor

mation. All the answers come from these two equations by using simple algebra or by just substituting the time. In part (a), for example, the stone comes to rest for an instant at its max

imum height, so set *v*  0 at this point and solve for time. Then substitute the time into the dis placement equation, obtaining the maximum height.

Solution

50.0 m

*t* = 4.08 s

*y* = 0

*v* = –20.0 m/s

*t* = 5.00 s

*y* = –22.5 m *v* = –29.0 m/s

*t* = 5.83 s

*y* = –50.0 m *v* = –37.1 m/s

**(a)** Find the time when the stone reaches its maximum

height.

Write the velocity and position kinematic equations: *v*  *at*  *v*0 D*y* 5 *y* 2 *y*0 5 *v*0*t* 1 12*at* 2

Substitute *a*  9.80 m/s2, *v*0  20.0 m/s, and *y*0  0 into the preceding two equations:

Substitute *v*  0, the velocity at maximum height, into Equation (1) and solve for time:

**(b)** Determine the stone’s maximum height.

**(1)** *v*  ( 9.80 m/s2)*t*  20.0 m/s **(2)** *y*  (20.0 m/s)*t*  (4.90 m/s2)*t*2

0 ( 9.80 m/s2)*t*  20.0 m/s *t* 5 220.0 m/s

29.80 m/s2 5 2.04 s

Substitute the time *t*  2.04 s into Equation (2): *y*max 5 120.0 m/s2 12.04 s2 2 14.90 m/s2 2 12.04 s2 2 5 20.4 m

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**(c)** Find the time the stone takes to return to its initial

position, and fi nd the velocity of the stone at that time.

Set y 0 in Equation (2) and solve *t*: 0 (20.0 m/s)*t*  (4.90 m/s2)*t*2 *t*(20.0 m/s 4.90 m/s2*t*)

*t*  4.08 s

Substitute the time into Equation (1) to get the velocity: *v*  20.0 m/s ( 9.80 m/s2)(4.08 s) 20.0 m/s

**(d)** Find the time required for the stone to reach the

ground.

In Equation (2), set *y*  50.0 m: 50.0 m (20.0 m/s)*t*  (4.90 m/s2)*t*2 Apply the quadratic formula and take the positive root: *t*  5.83 s

**(e)** Find the velocity and position of the stone at *t*  5.00 s.

Substitute values into Equations (1) and (2): *v*  ( 9.80 m/s2)(5.00 s) 20.0 m/s 29.0 m/s *y*  (20.0 m/s)(5.00 s) (4.90 m/s2)(5.00 s)2  22.5 m

Remarks Notice how everything follows from the two kinematic equations. Once they are written down and the constants correctly identifi ed as in Equations (1) and (2), the rest is relatively easy. If the stone were thrown down ward, the initial velocity would have been negative.

QUESTION 2.8

How would the answer to part (b), the maximum height, change if the person throwing the ball jumped upward at the instant he released the ball?

EXERCISE 2.8

A projectile is launched straight up at 60.0 m/s from a height of 80.0 m, at the edge of a sheer cliff. The projectile falls, just missing the cliff and hitting the ground below. Find (a) the maximum height of the projectile above the point of fi ring, (b) the time it takes to hit the ground at the base of the cliff, and (c) its velocity at impact.

Answers (a) 184 m (b) 13.5 s (c) 72.3 m/s

EXAMPLE 2.9 Maximum Height Derived

Goal Find the maximum height of a thrown projectile using symbols.

Problem Refer to Example 2.8. Use symbolic manipulation to fi nd **(a)** the time *t*max it takes the ball to reach its maximum height and **(b)** an expression for the maximum height that doesn’t depend on time. Answers should be expressed in terms of the quantities *v*0, *g*, and *y*0 only.

Strategy When the ball reaches its maximum height, its velocity is zero, so for part (a) solve the kinematics velocity equation for time *t* and set *v*  0. For part (b), substitute the expression for time found in part (a) into the displace ment equation, solving it for the maximum height.

Solution

**(a)** Find the time it takes the ball to reach its maximum

height.

Write the velocity kinematics equation: *v*  *at*  *v*0

Move *v*0 to the left side of the equation: *v*  *v*0  *at*

Divide both sides by *a*: *v* 2 *v*0

*a* 5 *ata* 5 *t*

Turn the equation around so that *t* is on the left and sub stitute *v*  0, corresponding to the velocity at maximum height:

Replace *t* by *t*max and substitute *a*  *g* :

**(b)** Find the maximum height.

2.6 Freely Falling Objects 45

**(1)** *t* 5 2*v*0

*a*

**(2)** *t* max 5 *v*0

*g*

Write the equation for the position *y* at any time: *y* 5 *y*0 1 *v*0*t* 1 12*at* 2 *y*max 5 *y*0 1 *v*0a2*v*0

*a* ~~b~~ 1 12*a* a2*v*0

2

Substitute *t*  *v*0/*a*, which corresponds to the time it takes to reach *y*max, the maximum height:

*a* ~~b~~

5 *y*0 2 *v*02

*a* 1 12*v*02

*a*

Combine the last two terms and substitute *a*  *g*: **(3)** *y*max 5 *y*0 1 *v*02

2*g*

Remarks Notice that *g*  9.8 m/s2, so the second term is positive overall. Equations (1)–(3) are much more useful than a numerical answer because the effect of changing one value can be seen immediately. For example, doubling the initial velocity *v*0 quadruples the displacement above the point of release. Notice also that *y*max could be obtained more readily from the time-independent equation, *v* 2  *v*02  2*a*  *y*.

QUESTION 2.9

By what factor would the maximum displacement above the rooftop be increased if the building were transported to the Moon, where *a* 5 216*g* ?

EXERCISE 2.9

(a) Using symbols, fi nd the time *tE* it takes for a ball to reach the ground on Earth if released from rest at height *y*0. (b) In terms of *tE*, how much time *tM* would be required if the building were on Mars, where *a*  0.385*g*? Answers (a) *tE* 5 Å2*y*0

*g* (b) *tM*  1.61*tE*

EXAMPLE 2.10 A Rocket Goes Ballistic

Goal Solve a problem involving a powered ascent followed by free-fall motion.

Problem A rocket moves straight upward, starting from rest with an acceleration of 29.4 m/s2. It runs out of fuel at the end of 4.00 s and continues to coast upward, reaching a maximum height before falling back to Earth. **(a)** Find the rocket’s velocity and position at the end of 4.00 s. **(b)** Find the maximum height the rocket reaches. **(c)** Find the velocity the instant before the rocket crashes on the ground.

Strategy Take *y*  0 at the launch point and *y* positive upward, as in Figure 2.21. The problem consists of two phases. In phase 1 the rocket has a net *upward* acceleration of 29.4 m/s2, and we can use the kinematic equations with constant acceleration *a* to fi nd the height and velocity of the rocket at the end of phase 1, when the fuel is burned up. In phase 2 the rocket is in free fall and has an acceleration of 9.80 m/s2, with initial velocity and position given by the results of phase 1. Apply the kinematic equations for free fall. FIGURE 2.21 (Example 2.10)

Two linked phases of motion for

a rocket that is launched, uses up

Rocket fuel

burns out



Phase 2

*a* = –9.80 m/s2

+*y*

Phase 1

*a* = 29.4 m/s2

Maximum

height *y*max *v* = 0

Rocket crashes after falling from *y*max 

its fuel, and crashes. *y* = 0 Launch

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Solution

**(a)** Phase 1: Find the rocket’s velocity and position

after 4.00 s.

Write the velocity and position kinematic equations: **(1)** *v*  *v*0  *at*

**(2)** D*y* 5 *y* 2 *y*0 5 *v*0*t* 1 12 *at* 2

Adapt these equations to phase 1, substituting

*a*  29.4 m/s2, *v*0  0, and *y*0  0: **(3)** *v*  (29.4 m/s2)*t* **(4)** *y* 5 12 129.4 m/s2 2*t*2 5 114.7 m/s2 2*t*2

Substitute *t*  4.00 s into Equations (3) and (4) to fi nd the rocket’s velocity *v* and position *y* at the time of burnout. These will be called *vb* and *yb*, respectively.

**(b)** Phase 2: Find the maximum height the rocket attains.

Adapt Equations (1) and (2) to phase 2, substituting *a*  9.8 m/s2, *v*0  *vb*  118 m/s, and *y*0  *yb*  235 m:

Substitute *v*  0 (the rocket’s velocity at maximum height) in Equation (5) to get the time it takes the rocket to reach its maximum height:

Substitute *t*  12.0 s into Equation (6) to fi nd the rocket’s maximum height:

**(c)** Phase 2: Find the velocity of the rocket just prior to impact.

Find the time to impact by setting *y*  0 in Equation (6) and using the quadratic formula:

*vb*  118 m/s and *yb*  235 m

**(5)** *v*  ( 9.8 m/s2)*t*  118 m/s

**(6)** *y* 5 235 m 1 1118 m/s2*t* 2 14.90 m/s2 2*t*2

0 5 129.8 m/s2 2*t* 1 118 m/s S *t* 5 118 m/s 9.80 m/s2 5 12.0 s

*y*max  235 m (118 m/s)(12.0 s) (4.90 m/s2)(12.0 s)2 945 m

0 235 m (118 m/s)*t*  (4.90 m/s)*t*2

*t*  25.9 s

Substitute this value of *t* into Equation (5): *v*  ( 9.80 m/s2)(25.9 s) 118 m/s 136 m/s

Remarks You may think that it is more natural to break this problem into three phases, with the second phase ending at the maximum height and the third phase a free fall from maximum height to the ground. Although this approach gives the correct answer, it’s an unnecessary complication. Two phases are suffi cient, one for each different acceleration.

QUESTION 2.10

If, instead, some fuel remains, at what height should the engines be fi red again to brake the rocket’s fall and allow a perfectly soft landing? (Assume the same acceleration as during the initial ascent.)

EXERCISE 2.10

An experimental rocket designed to land upright falls freely from a height of 2.00 102 m, starting at rest. At a height of 80.0 m, the rocket’s engines start and provide constant upward acceleration until the rocket lands. What acceleration is required if the speed on touchdown is to be zero? (Neglect air resistance.)

Answer 14.7 m/s2

SUMMARY

Multiple-Choice Questions 47D*t* 5 *vf* 2 *vi*

2.1 Displacement

The **displacement** of an object moving along the *x*-axis is

*~~a~~* ; D*v*

*tf* 2 *ti***[2.4]**

defi ned as the change in position of the object, *x*  *xf*  *xi* **[2.1]**

where *xi* is the initial position of the object and *xf* is its fi nal position.

A **vector** quantity is characterized by both a magnitude and a direction. A **scalar** quantity has a magnitude only.

2.2 Velocity

The **average speed** of an object is given by

Average speed ; total distance

total time

The **average velocity** *~~v~~* during a time interval *t* is the dis placement *x* divided by *t*.

D*t* 5 *xf* 2 *xi*

The **instantaneous acceleration** of an object at a certain time equals the slope of a velocity vs. time graph at that instant.

2.5 One-Dimensional Motion with Constant Acceleration

The most useful equations that describe the motion of an object moving with constant acceleration along the *x*-axis are as follows:

*v*  *v*0  *at* **[2.6]**

D*x* 5 *v*0*t* 1 12*at* 2 **[2.9]**

*v* 2  *v* 02  2*a*  *x* **[2.10]**

All problems can be solved with the fi rst two equations

*~~v~~* ; D*x*

*tf* 2 *ti***[2.2]**

alone, the last being convenient when time doesn’t explic itly enter the problem. After the constants are properly

The average velocity is equal to the slope of the straight line joining the initial and fi nal points on a graph of the position of the object versus time.

The slope of the line tangent to the position vs. time curve at some point is equal to the **instantaneous veloc ity** at that time. The **instantaneous speed** of an object is defi ned as the magnitude of the instantaneous velocity.

2.3 Acceleration

The **average acceleration** *~~a~~* of an object undergoing a change in velocity *v* during a time interval *t* is

identifi ed, most problems reduce to one or two equations in as many unknowns.

2.6 Freely Falling Objects

An object falling in the presence of Earth’s gravity exhibits a free-fall acceleration directed toward Earth’s center. If air friction is neglected and if the altitude of the falling object is small compared with Earth’s radius, then we can assume that the free-fall acceleration *g*  9.8 m/s2 is constant over the range of motion. Equations 2.6, 2.9, and 2.10 apply, with *a*  *g*.

FOR ADDITIONAL STUDENT RESOURCES, GO TO WWW.SERWAYPHYSICS.COM MULTIPLE-CHOICE QUESTIONS

**1.** An arrow is shot straight up in the air at an initial speed of 15.0 m/s. After how much time is the arrow heading downward at a speed of 8.00 m/s? (a) 0.714 s (b) 1.24 s (c) 1.87 s (d) 2.35 s (e) 3.22 s

**2.** A cannon shell is fi red straight up in the air at an initial speed of 225 m/s. After how much time is the shell at a height of 6.20 102 m and heading down? (a) 2.96 s (b) 17.3 s (c) 25.4 s (d) 33.6 s (e) 43.0 s

**3.** When applying the equations of kinematics for an object moving in one dimension, which of the following statements *must* be true? (a) The velocity of the object must remain constant. (b) The acceleration of the object must remain constant. (c) The velocity of the object must increase with time. (d) The position of the object must increase with time. (e) The velocity of the object must always be in the same direction as its acceleration.

**4.** A juggler throws a bowling pin straight up in the air. After the pin leaves his hand and while it is in the air, which statement is true? (a) The velocity of the pin is always in the same direction as its acceleration. (b) The velocity of the pin is never in the same direction as its

acceleration. (c) The acceleration of the pin is zero. (d) The velocity of the pin is opposite its acceleration on the way up. (e) The velocity of the pin is in the same direction as its acceleration on the way up.

**5.** A racing car starts from rest and reaches a fi nal speed *v* in a time *t*. If the acceleration of the car is constant dur ing this time, which of the following statements must be true? (a) The car travels a distance *vt*. (b) The aver age speed of the car is *v*/2. (c) The acceleration of the car is *v/t*. (d) The velocity of the car remains constant. (e) None of these

**6.** A pebble is dropped from rest from the top of a tall cliff and falls 4.9 m after 1.0 s has elapsed. How much farther does it drop in the next 2.0 seconds? (a) 9.8 m (b) 19.6 m (c) 39 m (d) 44 m (e) 27 m

**7.** An object moves along the *x*-axis, its position measured at each instant of time. The data are organized into an accurate graph of *x* vs. *t*. Which of the following quanti ties *cannot* be obtained from this graph? (a) the velocity at any instant (b) the acceleration at any instant (c) the displacement during some time interval (d) the average