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UNDERSTANDING PHYSICS

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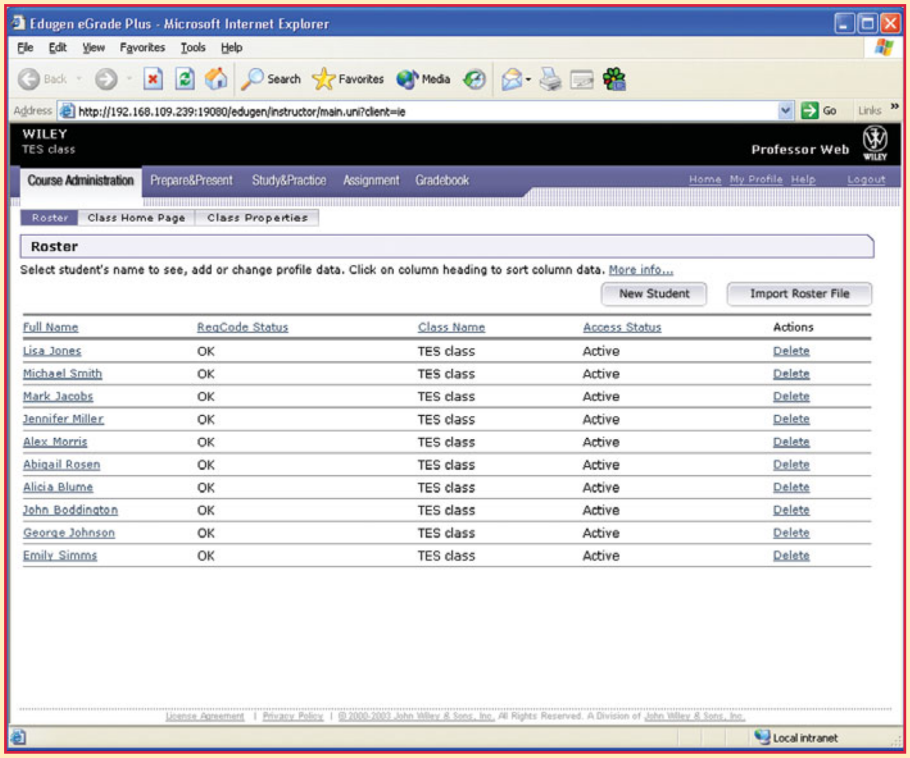

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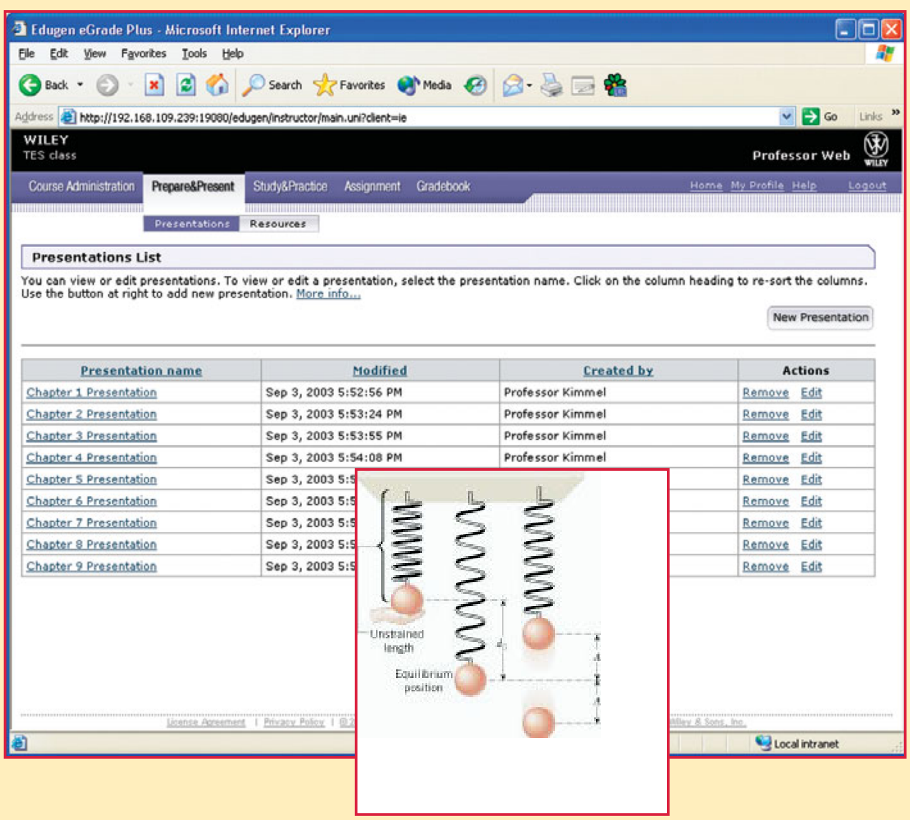

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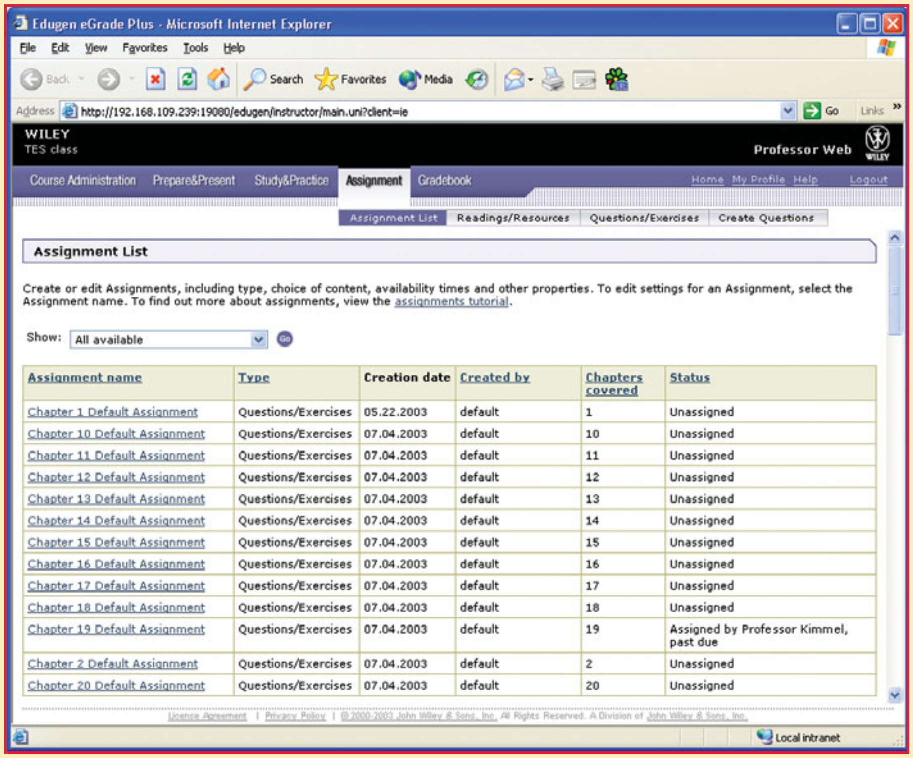

Assignment name	Type	Creation date	Created by	Chapters covered	Status
Chapter 1 Default Assignment	Questions/Exercises	05.22.2003	default	1	Unassigned
Chapter 10 Default Assignment	Questions/Exercises	07.04.2003	default	10	Unassigned
Chapter 11 Default Assignment	Questions/Exercises	07.04.2003	default	11	Unassigned
Chapter 12 Default Assignment	Questions/Exercises	07.04.2003	default	12	Unassigned
Chapter 13 Default Assignment	Questions/Exercises	07.04.2003	default	13	Unassigned
Chapter 14 Default Assignment	Questions/Exercises	07.04.2003	default	14	Unassigned
Chapter 15 Default Assignment	Questions/Exercises	07.04.2003	default	15	Unassigned
Chapter 16 Default Assignment	Questions/Exercises	07.04.2003	default	16	Unassigned
Chapter 17 Default Assignment	Questions/Exercises	07.04.2003	default	17	Unassigned
Chapter 18 Default Assignment	Questions/Exercises	07.04.2003	default	18	Unassigned
Chapter 19 Default Assignment	Questions/Exercises	07.04.2003	default	19	Assigned by Professor Kimmel, past due
Chapter 2 Default Assignment	Questions/Exercises	07.04.2003	default	2	Unassigned
Chapter 20 Default Assignment	Questions/Exercises	07.04.2003	default	20	Unassigned

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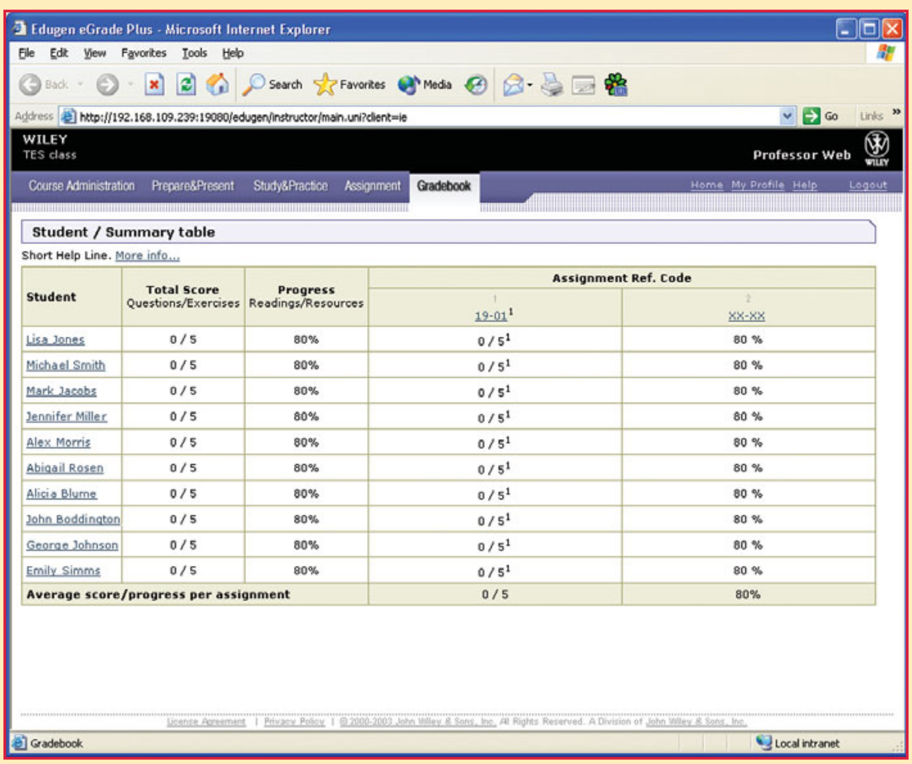

Student	Total Score Questions/Exercises	Progress Readings/Resources	Assignment Ref. Code 19-01	XX-XX
Lisa Jones	0 / 5	80%	0 / 5[1]	80 %
Michael Smith	0 / 5	80%	0 / 5[1]	80 %
Mark Jacobs	0 / 5	80%	0 / 5[1]	80 %
Jennifer Miller	0 / 5	80%	0 / 5[1]	80 %
Alex Morris	0 / 5	80%	0 / 5[1]	80 %
Abigail Rosen	0 / 5	80%	0 / 5[1]	80 %
Alicia Blume	0 / 5	80%	0 / 5[1]	80 %
John Boddington	0 / 5	80%	0 / 5[1]	80 %
George Johnson	0 / 5	80%	0 / 5[1]	80 %
Emily Simms	0 / 5	80%	0 / 5[1]	80 %
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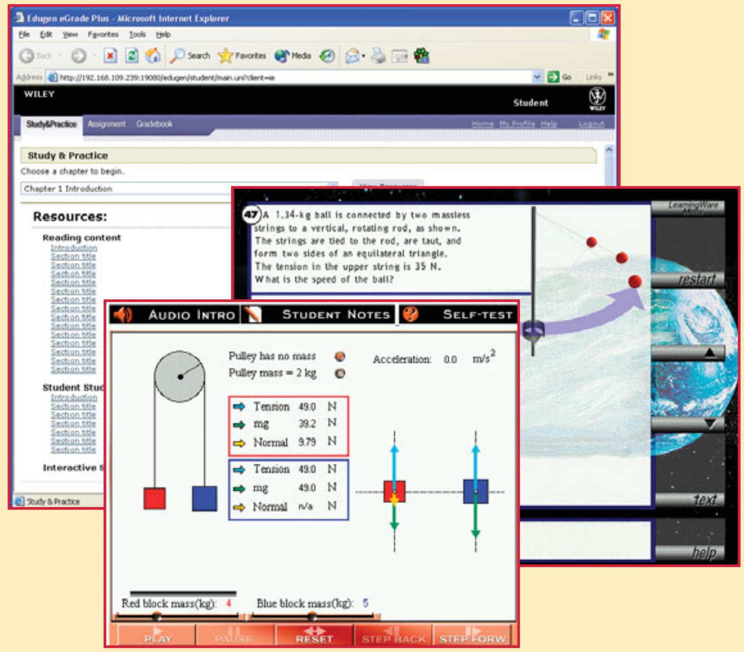
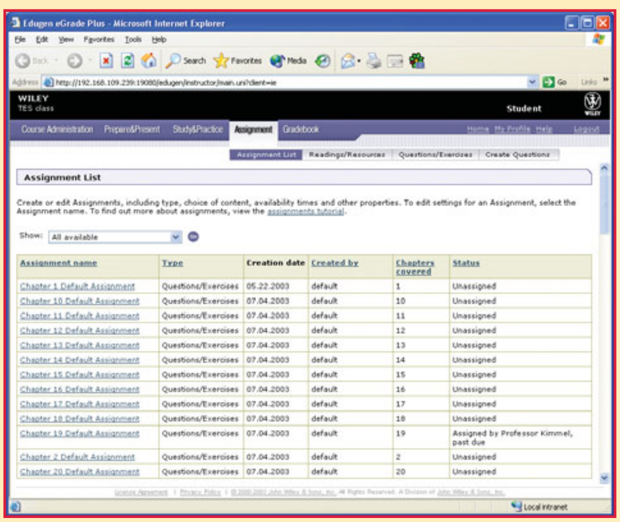


Complete Assignments / Get Help with Problem Solving



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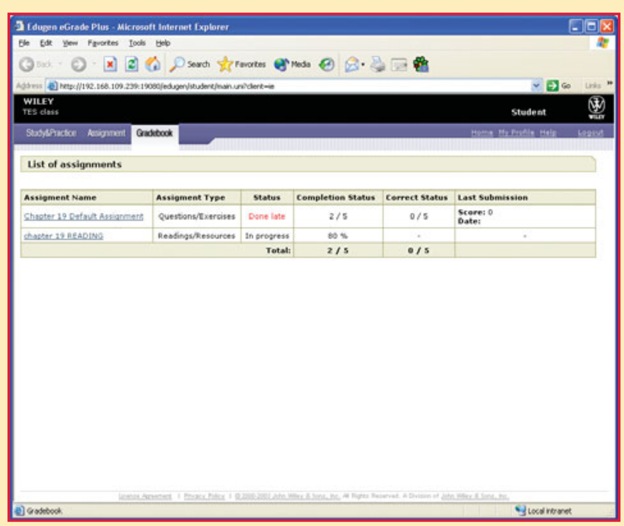

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UNDERSTANDING PHYSICS

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Understanding Physics is based on *Fundamentals of Physics* by David Halliday, Robert Resnick, and Jearl Walker.

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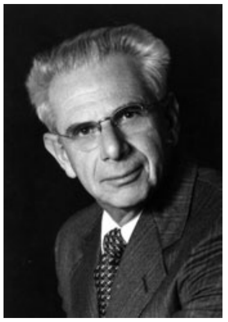

This book is dedicated to Arnold Arons, whose pioneering work in physics education and reviews of early chapters have had a profound influence on our work.

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This book was set in 10/12 Times Ten Roman by Progressive and
printed and bound by Von Hoffmann Press. The cover was printed by Von Hoffmann Press.

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Library of Congress Cataloging in Publication Data:

Understanding physics / Karen Cummings . . . [et al.]; with additional members of the
Activity Based Physics Group.
p. cm.
Includes index.
ISBN 0-471-37099-1
1. Physics. I. Cummings, Karen. II. Activity Based Physics Group.

QC23.2.U54 2004
530—dc21 2003053481

L.C. Call no. Dewey Classification No. L.C. Card No.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Preface

Welcome to *Understanding Physics*. This book is built on the foundations of the 6th Edition of Halliday, Resnick, and Walker's *Fundamentals of Physics* which we often refer to as HRW 6th. The HRW 6th text and its ancestors, first written by David Halliday and Robert Resnick, have been best-selling introductory physics texts for the past 40 years. It sets the standard against which many other texts are judged. You are probably thinking, "Why mess with success?" Let us try to explain.

Why a Revised Text?

A physics major recently remarked that after struggling through the first half of his junior level mechanics course, he felt that the course was now going much better. What had changed? Did he have a better background in the material they were covering now? "No," he responded. "I started reading the book before every class. That helps me a lot. I wish I had done it in Physics One and Two." Clearly, this student learned something very important. It is something most physics instructors wish they could teach all of their students as soon as possible. Namely, no matter how smart your students are, no matter how well your introductory courses are designed and taught, your students will master more physics if they learn how to read an "understandable" textbook carefully.

We know from surveys that the vast majority of introductory physics students do not read their textbooks carefully. We think there are two major reasons why: (1) many students complain that physics textbooks are impossible to understand and too abstract, and (2) students are extremely busy juggling their academic work, jobs, personal obligations, social lives and interests. So they develop strategies for passing physics without spending time on careful reading. We address both of these reasons by making our revision to the sixth edition of *Fundamentals of Physics* easier for students to understand and by providing the instructor with more **Reading Exercises** (formerly known as Checkpoints) and additional strategies for encouraging students to read the text carefully. Fortunately, we are attempting to improve a fine textbook whose active author, Jearl Walker, has worked diligently to make each new edition more engaging and understandable.

In the next few sections we provide a summary of how we are building upon HRW 6th and shaping it into this new textbook.

A Narrative That Supports Student Learning

One of our primary goals is to help students make sense of the physics they are learning. We cannot achieve this goal if students see physics as a set of disconnected mathematical equations that each apply only to a small number of specific situations. We stress conceptual and qualitative understanding and continually make connections between mathematical equations and conceptual ideas. We also try to build on ideas that students can be expected to already understand, based on the resources they bring from everyday experiences.

In *Understanding Physics* we have tried to tell a story that flows from one chapter to the next. Each chapter begins with an introductory section that discusses why new topics introduced in the chapter are important, explains how the chapter builds on previous chapters, and prepares students for those that follow. We place explicit emphasis on basic concepts that recur throughout the book. We use extensive forward and backward referencing to reinforce connections between topics. For example, in the introduction of Chapter 16 on Oscillations we state: "Although your study of simple harmonic motion will enhance your understanding of mechanical systems it is also vital to understanding the topics in electricity and magnetism encountered in Chapters 30-37. Finally, a knowledge of SHM provides a basis for understanding the wave nature of light and how atoms and nuclei absorb and emit energy."

Emphasis on Observation and Experimentation

Observations and concrete everyday experiences are the starting points for development of mathematical expressions. Experiment-based theory building is a major feature of the book. We build ideas on experience that students either already have or can easily gain through careful observation.

Whenever possible, the physical concepts and theories developed in *Understanding Physics* grow out of simple observations or experimental data that can be obtained in typical introductory physics laboratories. We want our readers to develop the habit of asking themselves: What do our observations, experiences and data imply about the natural laws of physics? How do we know a given statement is true? Why do we believe we have developed correct models for the world?

Toward this end, the text often starts a chapter by describing everyday observations with which students are familiar. This makes *Understanding Physics* a text that is both relevant to students' everyday lives and draws on existing student knowledge. We try to follow Arnold Arons' principle "idea first, name after." That is, we make every attempt to begin a discussion by using everyday language to describe common experiences. Only then do we introduce formal physics terminology to represent the concepts being discussed. For example, everyday pushes, pulls, and their impact on the motion of an object are discussed before introducing the term "force" or Newton's Second Law. We discuss how a balloon shrivels when placed in a cold environment and how a pail of water cools to room temperature before introducing the ideal gas law or the concept of thermal energy transfer.

The "idea first, name after" philosophy helps build patterns of association between concepts students are trying to learn and knowledge they already have. It also helps students reinterpret their experiences in a way that is consistent with physical laws.

Examples and illustrations in *Understanding Physics* often present data from modern computer-based laboratory tools. These tools include computer-assisted data acquisition systems and digital video analysis software. We introduce students to these tools at the end of Chapter 1. Examples of these techniques are shown in Figs. P-1 and P-2 (on the left) and Fig. P-3 on the next page. Since many instructors use these computer tools in the laboratory or in lecture demonstrations, these tools are part of the introductory physics experience for more and more of our students. The use of real data has a number of advantages. It connects the text to the students' experience in other parts of the course and it connects the text directly to real world experience. Regardless of whether data acquisition and analysis tools are used in the student's own laboratory, our use of realistic rather that idealized data helps students develop an appreciation of the role that data evaluation and analysis plays in supporting theory.

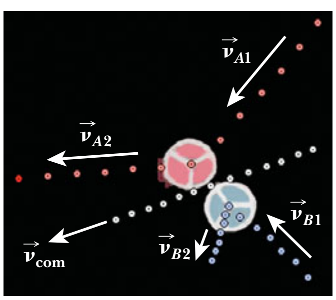

FIGURE P-1 ■ A video analysis shows that the center of mass of a two-puck system moves at a constant velocity.

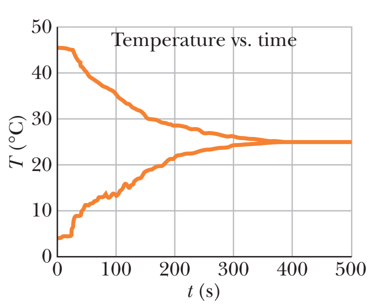

FIGURE P-2 ■ Electronic temperature sensors reveal that if equal amounts of hot and cold water mix the final temperature is the average of the initial temperatures.

FIGURE P-3 ■ A video analysis of human motion reveals that in free fall the center of mass of an extended body moves in a parabolic path under the influence of the Earth's gravitational force.

Using Physics Education Research

In re-writing the text we have taken advantage of two valuable findings of physics education research. One is the identification of concepts that are especially difficult for many students to learn. The other is the identification of active learning strategies to help students develop a more robust understanding of physics.

Addressing Learning Difficulties

Extensive scholarly research exists on the difficulties students have in learning physics.[1] We have made a concerted effort to address these difficulties. In *Understanding Physics,* issues that are known to confuse students are discussed with care. This is true even for topics like the nature of force and its effect on velocity and velocity changes that may seem trivial to professional physicists. We write about subtle, often counter-intuitive topics with carefully chosen language and examples designed to draw out and remediate common alternative student conceptions. For example, we know that students have trouble understanding passive forces such as normal and friction forces.[2] How can a rigid table exert a force on a book that rests on it? In Section 6-4 we present an idealized model of a solid that is analogous to an inner spring mattress with the repulsion forces between atoms acting as the springs. In addition, we invite our readers to push on a table with a finger and experience the fact that as they push harder on the table the table pushes harder on them in the opposite direction.

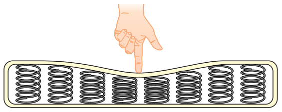

FIGURE P-4 ■ Compressing an innerspring mattress with a force. The mattress exerts an oppositely directed force, with the same magnitude, back on the finger.

Incorporating Active Learning Opportunities

We designed *Understanding Physics* to be more interactive and to foster thoughtful reading. We have retained a number of the excellent Checkpoint questions found at the end of HRW 6th chapter sections. We now call these questions **Reading Exercises.** We have created many new Reading Exercises that require students to reflect on the material in important chapter sections. For example, just after reading Section 6-2 that introduces the two-dimensional free-body diagram, students encounter Reading Exercise 6-1. This multiple-choice exercise requires students to identify the free-body diagram for a helicopter that experiences three non-collinear forces. The distractors were based on common problems students have with the construction of free-body diagrams. When used in "Just-In-Time Teaching" assignments or for in-class group discussion, this type of reading exercise can help students learn a vital problem solving skill as they read.

[1] L. C. McDermott and E. F. Redish, "Resource Letter PER-1: Physics Education Research," *Am. J. Phys.* **67**, 755-767 (1999)

[2] John J. Clement, "Expert novice similarities and instruction using analogies," *Int. J. Sci. Ed. 20*, 1271-1286 (1998)

We also created a set of **Touchstone Examples.** These are carefully chosen sample problems that illustrate key problem solving skills and help students learn how to use physical reasoning and concepts as an essential part of problem solving. We selected some of these touchstone examples from the outstanding collection of sample problems in HRW 6th and we created some new ones. In order to retain the flow of the narrative portions of each chapter, we have reduced the overall number of sample problems to those necessary to exemplify the application of fundamental principles. Also, we chose touchstone examples that require students to combine conceptual reasoning with mathematical problem-solving skills. Few, if any, of our touchstone examples are solvable using simple "plug-and-chug" or algorithmic pattern matching techniques.

Alternative problems have been added to the extensive, classroom tested end-of-chapter problem sets selected from HRW 6th. The design of these new problems are based on the authors' knowledge of research on student learning difficulties. Many of these new problems require careful qualitative reasoning. They explicitly connect conceptual understanding to quantitative problem solving. In addition, estimation problems, video analysis problems, and "real life" or "context rich" problems have been included.

The organization and style of *Understanding Physics* has been modified so that it can be easily used with other research-based curricular materials that make up what we call *The Physics Suite*. The *Suite* and its contents are explained at length at the end of this preface.

Reorganizing for Coherence and Clarity

For the most part we have retained the organization scheme inherited from HRW 6th. Instructors are familiar with the general organization of topics in a typical course sequence in calculus-based introductory physics texts. In fact, ordering of topics and their division into chapters is the same for 27 of the 38 chapters. The order of some topics has been modified to be more pedagogically coherent. Most of the reorganization was done in Chapters 3 through 10 where we adopted a sequence known as *New Mechanics*. In addition, we decided to move HRW 6th Chapter 25 on capacitors so it becomes the last chapter on DC circuits. Capacitors are now introduced in Chapter 28 in *Understanding Physics*.

The New Mechanics Sequence

HRW 6th and most other introductory textbooks use a familiar sequence in the treatment of classical mechanics. It starts with the development of the kinematic equations to describe constantly accelerated motion. Then two-dimensional vectors and the kinematics of projectile motion are treated. This is followed by the treatment of dynamics in which Newton's Laws are presented and used to help students understand both one- and two-dimensional motions. Finally energy, momentum conservation, and rotational motion are treated.

About 12 years ago when Priscilla Laws, Ron Thornton, and David Sokoloff were collaborating on the development of research-based curricular materials, they became concerned about the difficulties students had working with two-dimensional vectors and understanding projectile motion before studying dynamics.

At the same time Arnold Arons was advocating the introduction of the concept of momentum before energy.[3] Arons argued that (1) the momentum concept is simpler than the energy concept, in both historical and modern contexts and (2) the study

[3] Private Communication between Arnold Arons and Priscilla Laws by means of a document entitled "Preliminary Notes and Suggestions," August 19, 1990; and Arnold Arons, *Development of Concepts of Physics* (Addison-Wesley, Reading MA, 1965)

of momentum conservation entails development of the concept of center-of-mass which is needed for a proper development of energy concepts. Additionally, the impulse-momentum relationship is clearly an alternative statement of Newton's Second Law. Hence, its placement immediately after the coverage of Newton's laws is most natural.

In order to address these concerns about the traditional mechanics sequence, a small group of physics education researchers and curriculum developers convened in 1992 to discuss the introduction of a new order for mechanics.[4] One result of the conference was that Laws, Sokoloff, and Thornton have successfully incorporated a new sequence of topics in the mechanics portions of various curricular materials that are part of the Physics Suite discussed below.[5] These materials include *Workshop Physics*, the *RealTime Physics Laboratory Module in Mechanics*, and the *Interactive Lecture Demonstrations*. This sequence is incorporated in this book and has required a significant reorganization and revisions of HRW 6th Chapters 2 through 10.

The New Mechanics sequence incorporated into Chapters 2 through 10 of understanding physics includes:

- Chapter 2: One-dimensional kinematics using constant horizontal accelerations and vertical free fall as applications.
- Chapter 3: The study of one-dimensional dynamics begins with the application of Newton's laws of motion to systems with one or more forces acting along a single line. Readers consider observations that lead to the postulation of "gravity" as a constant invisible force acting vertically downward.
- Chapter 4: Two-dimensional vectors, vector displacements, unit vectors and the decomposition of vectors into components are treated.
- Chapter 5: The study of kinematics and dynamics is extended to two-dimensional motions with forces along only a single line. Examples include projectile motion and circular motion.
- Chapter 6: The study of kinematics and dynamics is extended to two-dimensional motions with two-dimensional forces.
- Chapters 7 & 8: Topics in these chapters deal with impulse and momentum change, momentum conservation, particle systems, center of mass, and the motion of the center-of-mass of an isolated system.
- Chapters 9 & 10: These chapters introduce kinetic energy, work, potential energy, and energy conservation.

Just-in-Time Mathematics

In general, we introduce mathematical topics in a "just-in-time" fashion. For example, we treat one-dimensional vector concepts in Chapter 2 along with the development of one-dimensional velocity and acceleration concepts. We hold the introduction of two- and three-dimensional vectors, vector addition and decomposition until Chapter 4, immediately before students are introduced to two-dimensional motion and forces in Chapters 5 and 6. We do not present vector products until they are needed. We wait to introduce the dot product until Chapter 9 when the concept of physical work is presented. Similarly, the cross product is first presented in Chapter 11 in association with the treatment of torque.

[4] The New Mechanics Conference was held August 6-7, 1992 at Tufts University. It was attended by Pat Cooney, Dewey Dykstra, David Hammer, David Hestenes, Priscilla Laws, Suzanne Lea, Lillian McDermott, Robert Morse, Hans Pfister, Edward F. Redish, David Sokoloff, and Ronald Thornton.

[5] Laws, P. W. "A New Order for Mechanics" pp. 125-136, *Proceedings of the Conference on the Introductory Physics Course*, Rensselaer Polytechnic Institute, Troy New York, May 20-23, Jack Wilson, Ed. 1993 (John Wiley & Sons, New York 1997)

Notation Changes

Mathematical notation is often confusing, and ambiguity in the meaning of a mathematical symbol can prevent a student from understanding an important relationship. It is also difficult to solve problems when the symbols used to represent different quantities are not distinctive. Some key features of the new notation include:

- We adhere to recent notation guidelines set by the U.S. National Institute of Standard and Technology Special Publication 811 (SP 811).
- We try to balance our desire to use familiar notation and our desire to avoid using the same symbol for different variables. For example, p is often used to denote momentum, pressure, and power. We have chosen to use lower case p for momentum and capital P for pressure since both variables appear in the kinetic theory derivation. But we stick with the convention of using capital P for power since it does not commonly appear side by side with pressure in equations.
- We denote vectors with an arrow instead of bolding so handwritten equations can be made to look like the printed equations.
- We label each vector component with a subscript that explicitly relates it to its coordinate axis. This eliminates the common ambiguity about whether a quantity represents a magnitude which is a scalar or a vector component which is not a scalar.
- We often use subscripts to spell out the names of objects that are associated with mathematical variables even though instructors and students will tend to use abbreviations. We also stress the fact that one object is exerting a force on another with an arrow in the subscript. For example, the force exerted by a rope on a block would be denoted as $\vec{F}_{\text{rope}\rightarrow\text{block}}$.

Our notation scheme is summarized in more detail in Appendix A4.

Encouraging Text Reading

We have described a number of changes that we feel will improve this textbook and its readability. But even the best textbook in the world is of no help to students who do not read it. So it is important that instructors make an effort to encourage busy students to develop effective reading habits. In our view the single most effective way to get students to read this textbook is to assign appropriate reading, reading exercises, and other reading questions after every class. Some effective ways to follow up on reading question assignments include:

1. Employ a method called "Just-In-Time-Teaching" (or JiTT) in which students submit their answers to questions about reading before class using just plain email or one of the many available computer based homework systems (Web Assign or E-Grade for example). You can often read enough answers before class to identify the difficult questions that need more discussion in class;
2. Ask students to bring the assigned questions to class and use the answers as a basis for small group discussions during the class period;
3. Assign multiple choice questions related to each section or chapter that can be graded automatically with a computer-based homework system; and
4. Require students to submit chapter summaries. Because this is a very effective assignment, we intentionally avoided doing chapter summaries for students.

Obviously, all of these approaches are more effective when students are given some credit for doing them. Thus you should arrange to grade all, or a random sample, of the submissions as incentives for students to read the text and think about the answers to Reading Exercises on a regular basis.

The Physics Suite

In 1997 and 1998, Wiley's physics editor, Stuart Johnson, and an informally constituted group of curriculum developers and educational reformers known as the *Activity Based Physics Group* began discussing the feasibility of integrating a broad array of curricular materials that are physics education research-based. This led to the assembly of an *Activity Based Physics Suite* that includes this textbook. The *Physics Suite* also includes materials that can be combined in different ways to meet the needs of instructors working in vastly different learning environments. The *Interactive Lecture Demonstration Series*[6] is designed primarily for use in lecture sessions. Other *Suite* materials can be used in laboratory settings including the *Workshop Physics Activity Guide,*[7] the *Real Time Physics Laboratory* modules,[8] and *Physics by Inquiry.*[9] Additional elements in the collection are suitable for use in recitation sessions such as the University of Washington *Tutorials in Introductory Physics* (available from Prentice Hall)[10] and a set of *Quantitative Tutorials*[11] developed at the University of Maryland. The *Activity Based Physics Suite* is rounded out with a collection of thinking problems developed at the University of Maryland. In addition to this **Understanding Physics** text, the Physics Suite elements include:

1. **Teaching Physics with the Physics Suite** by Edward F. Redish (University of Maryland). This book is not only the "Instructors Manual" for *Understanding Physics*, but it is also a book for anyone who is interested in learning about recent developments in physics education. It is a handbook with a variety of tools for improving both teaching and learning of physics—from new kinds of homework and exam problems, to surveys for figuring out what has happened in your class, to tools for taking and analyzing data using computers and video. The book comes with a Resource CD containing 14 conceptual and 3 attitude surveys, and more than 250 thinking problems covering all areas of introductory physics, resource materials from commercial vendors on the use of computerized data acquisition and video, and a variety of other useful reference materials. (Instructors can obtain a complimentary copy of the book and Resource CD, from John Wiley & Sons.)
2. **RealTime Physics** by David Sokoloff (University of Oregon), Priscilla Laws (Dickinson College), and Ronald Thornton (Tufts University). *RealTime Physics* is a set of laboratory materials that uses computer-assisted data acquisition to help students build concepts, learn representation translation, and develop an understanding of the empirical base of physics knowledge. There are three modules in the collection: Module 1: Mechanics (12 labs), Module 2: Heat and Thermodynamics (6 labs), and Module 3: Electric Circuits (8 labs). (Available both in print and in electronic form on *The Physics Suite CD.*)

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[6]David R. Sokoloff and Ronald K. Thornton, "Using Interactive Lecture Demonstrations to Create an Active Learning Environment." *The Physics Teacher*, **35**, 340-347, September 1997.

[7]Priscilla W. Laws, *Workshop Physics Activity Guide*, Modules 1-4 w/ Appendices (John Wiley & Sons, New York, 1997).

[8]David R. Sokoloff, *RealTime Physics*, Modules 1-2, (John Wiley & Sons, New York, 1999).

[9]Lillian C. McDermott and the Physics Education Group at the University of Washington, *Physics by Inquiry* (John Wiley & Sons, New York, 1996).

[10]Lillian C. McDermott, Peter S. Shaffer, and the Physics Education Group at the University of Washington, *Tutorials in Introductory Physics*, First Edition (Prentice-Hall, Upper Saddle River, NJ, 2002).

[11]Richard N. Steinberg, Michael C. Wittmann, and Edward F. Redish, "Mathematical Tutorials in Introductory Physics," in, *The Changing Role Of Physics Departments In Modern Universities,* Edward F. Redish and John S. Rigden, editors, AIP Conference Proceedings **399**, (AIP, Woodbury NY, 1997), 1075-1092.

3. **Interactive Lecture Demonstrations** by David Sokoloff (University of Oregon) and Ronald Thornton (Tufts University). ILDs are worksheet-based guided demonstrations designed to focus on fundamental principles and address specific naïve conceptions. The demonstrations use computer-assisted data acquisition tools to collect and display high quality data in real time. Each ILD sequence is designed for delivery in a single lecture period. The demonstrations help students build concepts through a series of instructor led steps involving prediction, discussions with peers, viewing the demonstration and reflecting on its outcome. The ILD collection includes sequences in mechanics, thermodynamics, electricity, optics and more. (Available both in print and in electronic form on *The Physics Suite CD.*)

4. **Workshop Physics** by Priscilla Laws (Dickinson College). *Workshop Physics* consists of a four part activity guide designed for use in calculus-based introductory physics courses. Workshop Physics courses are designed to replace traditional lecture and laboratory sessions. Students use computer tools for data acquisition, visualization, analysis and modeling. The tools include computer-assisted data acquisition software and hardware, digital video capture and analysis software, and spreadsheet software for analytic mathematical modeling. Modules include classical mechanics (2 modules), thermodynamics & nuclear physics, and electricity & magnetism. (Available both in print and in electronic form on *The Physics Suite CD.*)

5. **Tutorials in Introductory Physics** by Lillian C. McDermott, Peter S. Shaffer and the Physics Education Group at the University of Washington. These tutorials consist of a set of worksheets designed to supplement instruction by lectures and textbook in standard introductory physics courses. Each tutorial is designed for use in a one-hour class session in a space where students can work in small groups using simple inexpensive apparatus. The emphasis in the tutorials is on helping students deepen their understanding of critical concepts and develop scientific reasoning skills. There are tutorials on mechanics, electricity and magnetism, waves, optics, and other selected topics. (Available in print from Prentice Hall, Upper Saddle River, New Jersey.)

6. **Physics by Inquiry** by Lillian C. McDermott and the Physics Education Group at the University of Washington. This self-contained curriculum consists of a set of laboratory-based modules that emphasize the development of fundamental concepts and scientific reasoning skills. Beginning with their observations, students construct a coherent conceptual framework through guided inquiry. Only simple inexpensive apparatus and supplies are required. Developed primarily for the preparation of precollege teachers, the modules have also proven effective in courses for liberal arts students and for underprepared students. The amount of material is sufficient for two years of academic study. (Available in print.)

7. **The Activity Based Physics Tutorials** by Edward F. Redish and the University of Maryland Physics Education Research Group. These tutorials, like those developed at the University of Washington, consist of a set of worksheets developed to supplement lectures and textbook work in standard introductory physics courses. But these tutorials integrate the computer software and hardware tools used in other Suite elements including computer data acquisition, digital video analysis, simulations, and spreadsheet analysis. Although these tutorials include a range of classical physics topics, they also include additional topics in modern physics. (Available only in electronic form on *The Physics Suite CD.*)

8. **The Understanding Physics Video CD for Students** by Priscilla Laws, et. al.: This CD contains a collection of the video clips that are introduced in *Understanding Physics* narrative and alternative problems. The CD includes a number of QuickTime movie segments of physical phenomena along with the QuickTime player

software. Students can view video clips as they read the text. If they have video analysis software available, they can reproduce data presented in text graphs or complete video analyses based on assignments designed by instructors.

9. **The Physics Suite CD.** This CD contains a variety of the Suite Elements in electronic format (Microsoft Word files). The electronic format allows instructors to modify and reprint materials to better fit into their individual course syllabi. The CD contains much useful material including complete electronic versions of the following: *RealTime Physics*, *Interactive Lecture Demonstrations, Workshop Physics, Activity Based Physics Tutorials.*

A Final Word to the Instructor

Over the past decade we have learned how valuable it is for us as teachers to focus on what most students actually need to do to learn physics, and how valuable it can be for students to work with research-based materials that promote active learning. We hope you and your students find this book and the other *Physics Suite* materials helpful in your quest to make physics both more exciting and understandable to your students.

Supplements for Use with Understanding Physics

Instructor Supplements

1. **Instructor's Solution Manual** prepared by Anand Batra (Howard University). This manual provides worked-out solutions for most of the end-of-chapter problems.
2. **Test Bank** by J. Richard Christman (U. S. Coast Guard Academy). This manual includes more than 2500 multiple-choice questions adapted from HRW 6th. These items are also available in the *Computerized Test Bank* (see below).
3. **Instructor's Resource CD.** This CD contains: The entire *Instructor's Solutions Manual* in both Microsoft Word© (IBM and Macintosh) and PDF files. A *Computerized Test Bank,* for use with both PCs and Macintosh computers with full editing features to help you customize tests. And all text illustrations, suitable for classroom projection, printing, and web posting.
4. **Online Homework and Quizzing:** *Understanding Physics* supports WebAssign and eGrade, two programs that give instructors the ability to deliver and grade homework and quizzes over the Internet.
5. **The Wiley Physics Demonstration Videos** by David Maiullo of Rutgers University consist of over a hundred classic physics demonstrations that will engage and instruct your students. Filmed, edited and produced by a professional film crew, the demonstrations include lying on a bed of nails, breaking glass with sound, and, in a show of atmospheric pressure, crushing a 55-gallon drum. Each demonstration is labeled according to the Physics Instructional Resource Association's demonstration classifying system. This system identifies the area, topic and concept presented in each demonstration. Go to www.pira.nu for more information about the Physics Instructional Resources Association and to download a spreadsheet of the demonstration classification systems.
6. **Wiley Physics Simulations CD-ROM** contains 50 interactive simulations (Java applets) that can be used for classroom demonstrations.

Student Supplements

1. **Student Study Guide** by J. Richard Christman (U. S. Coast Guard Academy). This student study guide provides chapter overviews, hints for solving selected end-of-chapter problems, and self-quizzes.

2. **Student Solutions Manual** by J. Richard Christman (U. S. Coast Guard Academy). This manual provides students with complete worked-out solutions for approximately 450 of the odd-numbered end-of-chapter problems.

Acknowledgements

Many individuals helped us create this book. The authors are grateful to the individuals who attended the weekend retreats at Airlie Center in 1997 and 1998 and to our editor, Stuart Johnson and to John Wiley & Sons for sponsoring the sessions. It was in these retreats that the ideas for *Understanding Physics* crystallized. We are grateful to Jearl Walker, David Halliday and Bob Resnick for graciously allowing us to attempt to make their already fine textbook better.

The authors owe special thanks to Sara Settlemyer who served as an informal project manager for the past few years. Her contributions included physics advice (based on her having completed Workshop Physics courses at Dickinson College), her use of Microsoft Word, Adobe Illustrator, Adobe Photoshop and Quark XPress to create the manuscript and visuals for this edition, and skillful attempts to keep our team on task—a job that has been rather like herding cats.

Karen Cummings: I would like to say "Thanks!" to: Bill Lanford (for endless advice, use of the kitchen table and convincing me that I really could keep the same address for more than a few years in a row), Ralph Kartel Jr. and Avery Murphy (for giving me an answer when people asked why I was working on a textbook), Susan and Lynda Cummings (for the comfort, love and support that only sisters can provide), Jeff Marx, Tim French and the poker crew (for their friendship and laughter), my colleagues at Southern Connecticut and Rensselaer, especially Leo Schowalter, Jim Napolitano and Jack Wilson (for the positive influence you have had on my professional life) and my students at Southern Connecticut and Rensselaer, Ron Thornton, Priscilla Laws, David Sokoloff, Pat Cooney, Joe Redish, Ken and Pat Heller and Lillian C. McDermott (for helping me learn how to teach).

Priscilla Laws: First of all I would like thank my husband and colleague Ken Laws for his quirky physical insights, for the Chapter 11 Kneecap puzzler, for the influence of his physics of dance work on this book, and for waiting for me countless times while I tried to finish "just one more thing" on this book. Thanks to my daughter Virginia Jackson and grandson Adam for all the fun times that keep me sane. My son Kevin Laws deserves special mention for sharing his creativity with us—best exemplified by his murder mystery problem, *A(dam)nable Man,* reprinted here as problem 5-68. I would like to thank Juliet Brosing of Pacific University who adapted many of the Workshop Physics problems developed at Dickinson for incorporation into the alternative problem collection in this book. Finally, I am grateful to my Dickinson College colleagues Robert Boyle, Kerry Browne, David Jackson, and Hans Pfister for advice they have given me on a number of topics.

Joe Redish: I would like to thank Ted Jacobsen for discussions of our chapter on relativity and Dan Lathrop for advice on the sources of the Earth's magnetic field, as well as many other of my colleagues at the University of Maryland for discussions on the teaching of introductory physics over many years.

Pat Cooney: I especially thank my wife Margaret for her patient support and constant encouragement and I am grateful to my colleagues at Millersville University: John Dooley, Bill Price, Mike Nolan, Joe Grosh, Tariq Gilani, Conrad Miziumski, Zenaida Uy, Ned Dixon, and Shawn Reinfried for many illuminating conversations.

We also appreciate the absolutely essential role many reviewers and classroom testers played. We took our reviewers very seriously. Several reviewers and testers deserve special mention. First and foremost is Arnold Arons who managed to review 29 of the 38 chapters either from the original HRW 6th material or from our early drafts before he passed away in February 2001. Vern Lindberg from the Rochester

Institute of Technology deserves special mention for his extensive and very insightful reviews of most of our first 18 chapters. Ed Adelson from Ohio State did a particularly good job reviewing most of our electricity chapters. Classroom tester Maxine Willis from Gettysburg Area High School deserves special recognition for compiling valuable comments that her advanced placement physics students made while class testing Chapters 1-12 of the preliminary version. Many other reviewers and class testers gave us useful comments in selected chapters.

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We would like to thank our proof readers Georgia Mederer and Ernestine Franco, our copyeditor Helen Walden, and our illustrator Julie Horan.

Last but not least we would like to acknowledge the efforts of the Wiley staff; Senior Acquisitions Editor, Stuart Johnson, Ellen Ford (Senior Development Editor), Justin Bow (Program Assistant), Geraldine Osnato (Project Editor), Elizabeth Swain (Senior Production Editor), Hilary Newman (Senior Photo Editor), Anna Melhorn (Illustration Editor), Kevin Murphy (Senior Designer), and Bob Smith (Marketing Manager). Their dedication and attention to endless details was essential to the production of this book.

Brief Contents

Contents

Appendices

do the *Reading Exercises* at the end of many sections in each chapter. We attempt to present both the experimental results that support theories and some of the reasoning that has gone into the development of theories. However, you will understand the physics only when you make your own observations and are actively engaged in reasoning. So, it is critical that you observe a physical phenomenon directly or ponder the outcome of an experiment that we describe. Then you need to *think* about whether the explanation of the phenomenon we present makes sense. In addition, you must test and refine your understanding of theoretical concepts by applying them to solving problems included at the end of each chapter. Solving problems requires you to use both the physical principles you have learned and the mathematical relationships that describe these principles. Finally, if possible, you will want to test your understanding of physical systems by predicting the outcomes of experiments that you can perform in a basic introductory physics laboratory.

We hope this book will help you enjoy the practice of physics as much as we do.

(Left to right): Priscilla W. Laws, Edward F. Redish, Karen Cummings, and Patrick J. Cooney. Photo by David Hildebrand.

1 Measurement

You can watch the Sun set and disappear over a calm ocean, once while lying on the beach, and then once again if you stand up. This is a surprising observation! Furthermore, if you measure the time between the two sunsets, you can approximate the Earth's radius by using an understanding of the shape and motion of the Earth relative to the Sun along with some basic high school mathematics.

How can such a simple observation be used to measure the Earth?

The answer is in this chapter.

1-1 Introduction

Physics is the study of the basic components of the universe and their interactions. The fact that you can use the time difference between sunsets while lying on the beach and then standing to estimate the size of the earth is indeed surprising to most people. It is one example of how the interplay between mathematics, theoretical principles, and observations allow us to develop a deeper understanding of the physical world. In fact, the ongoing quest of physics is to develop a unified set of ideas to explain apparently different phenomena. Scientific theories are only valid if they serve to explain and predict the outcomes of new observations and experiments. Many theories in physics are expressed in mathematical equations, and predictions usually involve quantities that can be measured.

Measurement is the process of associating numbers with physical quantities. In fact, *physical quantities are defined in terms of the procedures used to measure them*. But the numbers that result from measurements are not meaningful unless people who are using and interpreting them know what was measured and what units were used to obtain the numbers. For example, if you were asked to go to a store to buy 27, you would immediately ask 27 of what? If you were told 27 containers of milk, you might ask 27 of what size or unit—pints, quarts, or gallons? Unambiguous communication with others about the results of a scientific measurement requires agreement on (1) the definition of the physical quantity and (2) the basic units used for comparison when the measurements are made.

The focus in this chapter will be on the fundamental physical quantities and measurement processes used to study motion. Later on we introduce additional physical quantities defined for the study of thermal interactions, electricity, magnetism, and light. You will learn about common elements of physical measurements, reasons why precise measurements are highly valued, and the international system of standard basic units that allows scientists all over the world to communicate with each other.

1-2 Basic Measurements in the Study of Motion

A long jumper speeds up along a runway, leaps into the air, and then comes to a sudden stop in a sand pit. How can such a motion be described and studied scientifically?

In studying motion, at least three questions come to mind. How far has something moved and in what directions? How long did it take? How much stuff was moved? Let's consider length, time, and mass, the three basic physical quantities used in the study of motion. How are they usually defined? What procedures are used to measure them on an everyday basis?

Length: Our "How far?" question involves being able to measure the distance between two points. Suppose you had no measuring instrument. Is there any way you could meaningfully ask and answer the question, "What is the total distance that the jumper ran?" The only approach possible would be to compare this distance to the size of one of your body parts such as your hand or foot. It is not surprising that the hand and the foot have been used throughout history as basic units of measurement. The distance can then be described as a ratio between it and a convenient item chosen to be a length standard.

Time: To answer the question, "How long did it take?" you need to be able to measure a time interval. To do this, you define the time between repetitive events as a standard. Historically, repetitive events that have been used as time standards have included the day (the time it takes for the Sun to appear to revolve around the Earth), the year, and the time it takes for a pendulum of a certain length to swing back and

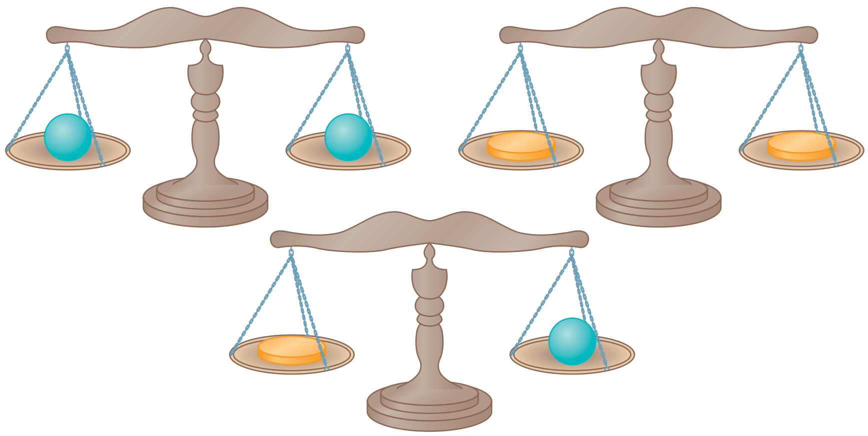


FIGURE 1-1 ■ A common method of determining mass assumes two objects have the same mass if they balance each other.

forth. A time interval, or time duration, is measured by determining how many years have passed or how many swings of a pendulum have occurred during the interval being measured.

Mass: Mass is a measure of "amount of stuff." Throughout recorded history, merchants and scientists have used balances to determine how many units of "standard mass" are needed to balance whatever is being measured. (See Fig. 1-1.) A standard of mass can be a certain object that everyone agrees should be used. Replicas of the standard mass that balance with it can be passed around and used by many people.

The everyday procedures outlined above for measuring length, time, and mass share common elements that characterize all physical quantities.

1. These quantities are defined by the procedures used to measure them.
2. Their measurement always involves the determination of a ratio between a unit, known as a base quantity, and the quantity being measured.
3. Such comparisons can only be made with limited precision.

As you will see, there are often many alternative procedures that can be used to measure the same quantity. Indeed, a major factor in the progress of science and technology has been the discovery of better, more **precise** methods of measurement.

READING EXERCISE 1-1: List one common base unit used for time, for length, and for mass not mentioned in the discussion in this section. ■

READING EXERCISE 1-2: What is a more precise base unit for length measurement that is reliable over a period of years—a 12-inch ruler or your foot? Explain the reason for your answer. ■

READING EXERCISE 1-3: What problems might arise when using the length of the day as a standard unit of time? ■

1-3 The Quest for Precision

Using a grocery store spring scale to find an apple's mass is fine for shopping purposes. But a mass can be determined to a far greater precision with a chemical microbalance. At best, the apple's mass can only be determined to the nearest gram, whereas the chemistry lab sample can be determined to the nearest hundred-thousandth of a gram.

Throughout history people have sought to measure physical quantities as precisely as possible, because reducing measurement uncertainties has been of tremendous importance in commerce, navigation, astronomical observation, engineering, and scientific research. For example, in 1707, the British navy lost almost 2000 men when four warships ran aground because navigators were unable to measure longitude with sufficient precision. In 1714, as a result of this mishap and others, the British government offered a prize of £20,000 (current value about $12 million) to anyone who could devise a scheme to measure longitude to within half a degree. John Harrison, a self-educated clockmaker, collected the prize in 1765 after designing a series of elaborate chronometers. His early models were driven by a combination of rust-proof brass and self-lubricating wooden gears that kept time to within 1 second per day.

HOW CAN TIME MEASUREMENTS BE USED TO DETERMINE LONGITUDE? Harrison's measurement technique is one of several examples of how a time standard and a knowledge of how fast something is moving are used to measure distance more precisely. In this case, since the Earth turns through 360° on its axis in 24 hours, a precise chronometer can be set so that it reads exactly noon when the Sun is at its highest point in a port with known longitude. Out at sea, the clock time that was set in port will differ from the local solar time by 4 minutes for each degree of longitude difference. Thus, the difference between the observed local noon and the clock reading can then be used to calculate longitude.

Of all the measured quantities, time and other measurements based on time are the most precise. By the end of the 20th century, many of us were wearing inexpensive digital watches driven by the oscillations of quartz crystals. These watches are 1000 times better than John Harrison's chronometer, since they are accurate to within 1 part in 10^8 or 1 thousandth of a second per day. Atomic clocks, precise to 3 billionths of a second per day, are now being used as time standards in many countries.

READING EXERCISE 1-4: A ship embarks from Southampton, England where its clock was set to 12:00:00 at local noon. After 14 days under sail its chronometer reads 12 h 20 min 13 s at the moment the Sun is highest in the sky (local noon). (a) By how many degrees has the ship's longitude changed? (b) Suppose the clock is not precise and has gained 2 minutes out of the 20 160 minutes that have elapsed since it set sail. How far off will the longitude measurement be? (c) The circumference of the Earth is 24 000 nautical miles. Suppose the ship was traveling along the equator. How many miles off course could the ship be if the uncertainty of longitude is 0.5°? ■

1-4 The International System of Units

In the past, communication between scientists was complicated by the fact that for every physical quantity there were a multitude of measurement procedures and basic units of comparison. In addition, there are so many physical quantities that it is a problem to organize them. Fortunately, these quantities are not all independent; for example, speed is the ratio of a length to a time. Thus, what we do is pick out—by international agreement—a small number of physical quantities, such as length and time, and assign standards to them alone. We then define all other physical quantities in terms of these *base quantities* and their standards (which we now call *base standards*). Speed, for example, is defined in terms of the base quantities length and time.

WHY IS IT IMPORTANT TO HAVE A STANDARD SYSTEM OF UNITS THAT IS USED BY ALL SCIENTISTS AND ENGINEERS? In December 1998, the National Aeronautics and Space Administration launched the *Mars Climate Orbiter* on a scientific mission to collect Martian climate data. Nine months later, on September 23, 1999, the *Orbiter* disappeared while approaching Mars at an unexpectedly low altitude. (See Fig. 1-2). An investigation revealed that the orbital calculations were incorrect due to an error in the transfer of information between the spacecraft's team in Colorado and the mission navigation team in California. One team was using English units such as feet and pounds for a critical calculation, while the other group assumed the result of the calculation was being reported in metric units such as meters and kilograms. This misunderstanding about the units being used cost U.S. taxpayers approximately 125 million dollars.

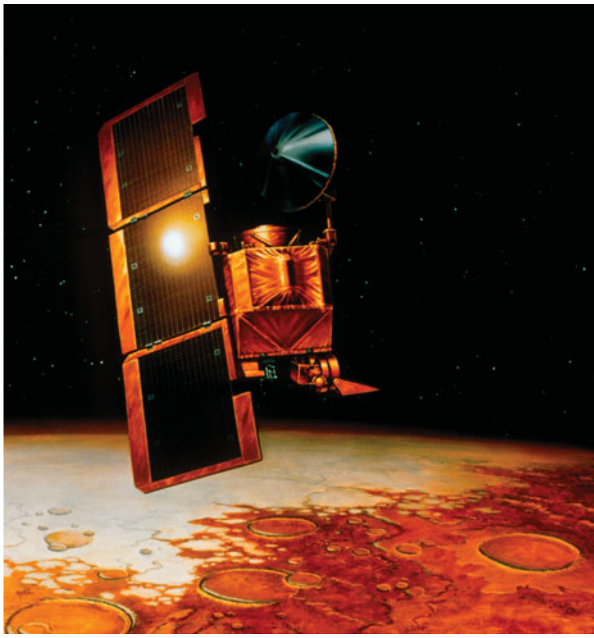


FIGURE 1-2 ■ The *Mars Climate Orbiter* failed to go into orbit around Mars and disappeared due to a miscalculation that resulted from confusion about what units were being used.

In 1971, the 14th General Conference on Weights and Measures recognized the need to use standard units for physical quantities. Conference attendees chose seven physical quantities as base quantities and defined a standard unit of measure for each one. Although other sets of physical quantities could be defined, the seven shown in Table 1-1 form the basis of the widely accepted International System of Units. The system is popularly known as the *metric system* or by its abbreviation, SI, which derives from its French name, *Système International*.

All other SI units are known as *derived units* because they can be expressed in terms of the base units. For example, the SI unit for power, called the **watt** (symbol: W), is defined in terms of the base units for mass, length, and time. As you will see in Chapter 9,

$$1 \text{ watt} = 1 \text{ W} = 1 \text{ kg} \cdot \text{m}^2/\text{s}^3. \tag{1-1}$$

The fact that the dozens of units used in different branches of physics can all be derived from a set of seven base units seems incredible and is a profound testimonial to the unity of physics.

To express the very large and very small quantities that we often run into in physics, we use *scientific notation*, which employs powers of 10. In this notation,

$$3\,560\,000\,000 \text{ m} = 3.56 \times 10^9 \text{ m} \tag{1-2}$$

and

$$0.000\,000\,492 \text{ s} = 4.92 \times 10^{-7} \text{ s}. \tag{1-3}$$

Scientific notation on computers sometimes takes on an even briefer look, as in 3.56 E9 and 4.92 E-7, where E stands for "exponent of ten." It is briefer still on some calculators, where E is replaced with an empty space.

TABLE 1-1
The SI Base Units

Quantity	Unit Name	Unit Symbol
Length	meter	m
Time	second	s
Mass	kilogram	kg
Amount of substance	mole	mol
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd

TABLE 1-2
Common Prefixes for SI Units

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

When reporting the results of very large or very small measurements, it is convenient to define prefixes that designate what power of ten a number has. For example, we can use the prefix kilo-, which represents 10^3, to express 1.0×10^3 grams as 1.0 kilogram. Some of the most common prefixes used in physics and engineering are listed in Table 1-2. A complete list of SI prefixes is included on the inside front cover. As you can see, each prefix represents a certain power of 10 as a factor. Attaching a prefix to an SI unit has the effect of multiplying it by the associated factor. Thus, we can express a particular electric power as

$$1.27 \times 10^9 \text{ watts} = 1.27 \text{ gigawatts} = 1.27 \text{ GW}, \tag{1-4}$$

or a particular length as

$$2.35 \times 10^{-9} \text{ m} = 2.35 \text{ nanometers} = 2.35 \text{ nm}. \tag{1-5}$$

Some prefixes, as used in milliliter, centimeter, kilogram, and megabyte, may be familiar to you.

Once we have set up a standard unit—say, for length—we must work out procedures by which any length, be it the distance to a star or the radius of a hydrogen atom, can be expressed in terms of the standard. Rulers, which approximate our length standard, give us one such procedure for measuring length. We can use a ruler to measure another length by counting how many times the standard can be fit, laid end-to-end, to the other length. The count is our assigned length and is given in terms of the standard's unit. However, many of our comparisons must be indirect. You cannot use a ruler, for example, to measure the distance to a star or the radius of an atom. Figure 1-3 shows an image of the surface of a crystal of silicon obtained with a modern scanning probe microscope.

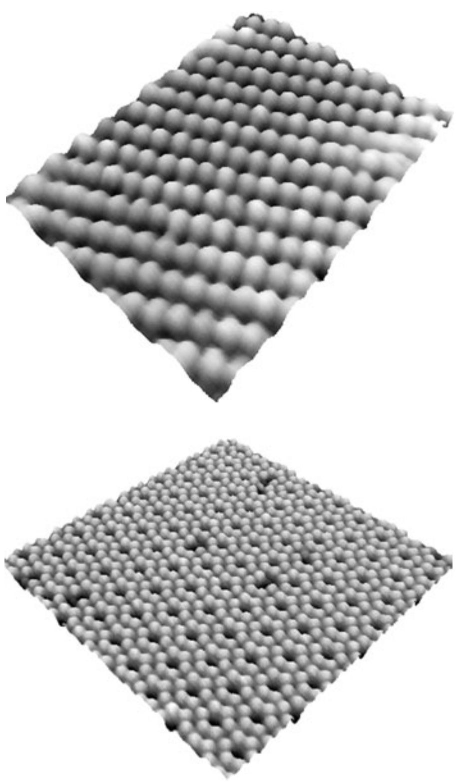


FIGURE 1-3 ■ Two different surfaces of a crystal of pure silicon.

Base standards must be both accessible and invariable. If we define the length standard as the distance between one's nose and the index finger on an outstretched arm, we certainly have an accessible standard—but it will, of course, vary from person to person. The demand for precision in science and engineering pushes us to aim first for invariability. We then exert great effort to make duplicates of the base standards that are accessible to those who need them. In the United States, the National Institute of Standards and Technology (NIST) is responsible for maintaining base standards and researching issues related to measurement.

The topics that we will investigate first, those related to the physics of forces and motion, require that we make measurements of time, length, and mass. Therefore, we begin by discussing the formal SI definitions of these quantities.

1-5 The SI Standard of Time

Time has two separate aspects that are important in physics. We may want to note at what moment an event occurred or began, or we may want to know how long the event lasted. These are two very different aspects of the measurement of time. For example, the moment at which your physics teacher walks into the room for class on a given day will be measured differently by different students because their watches will not all be synchronized. However, the measured duration of the class will not be affected by the fact that the watches are not synchronized. Thus, "*When* did it happen?" and "What is its *duration*?" are two different questions.

Any phenomenon that regularly repeats itself is a possible time standard. The Earth's rotation, which determines the length of the day, has been used in this way for centuries. Originally the second was defined as the fraction 1/86 400 of a "mean solar day." Figure 1-4 shows a two-century-old example of a time-keeping instrument used to measure the Earth's rotation in terms of a 20-hour day. A quartz clock, in which a quartz ring is made to vibrate continuously, can be calibrated against Earth's rotation via astronomical observations and used to measure time intervals in the laboratory. However, even this calibration cannot be carried out with the accuracy called for by modern scientific and engineering technology.

FIGURE 1-4 ■ When the metric system was proposed in 1792, the hour was redefined to provide a 20-hour day. The idea did not catch on. The maker of this watch wisely provided a small dial that kept both 10-hour and conventional 12-hour time. Do the two dials indicate the same time?

To meet the need for more accuracy in the measurement of time, atomic clocks have been developed that replace the use of Earth's rotation in the definition of our time standard. In 1967, the 13th General Conference on Weights and Measures adopted a standard second based on the radiation absorption characteristics of the cesium-133 atom. Like other atoms, a cesium-133 atom can absorb electromagnetic radiation that has a very precise frequency when the atom makes a transition between two of its well-defined energy states known in technical jargon as "hyperfine levels." The fixed frequency of this external radiation is used to drive a cesium clock. Such a precisely repetitive event is just what is needed for a high-precision timekeeper. Although the technical details of how a cesium clock works is beyond the scope of this text, interested readers can consult the NIST web site at http://www.nist.gov for more information about how the cesium clock is used as a time standard. (See Fig. 1-5.) This new SI standard of time defines the second as follows:

> One second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.

An atomic clock at NIST is the standard for Coordinated Universal Time (CUT) in the United States. Its time signals are available from NIST's Web site listed previously. You can also download a Java program from this site that will synchronize your computer's clock to Coordinated Universal Time so you can use your computer as a time standard by which to set other clocks.

Atomic clocks are so consistent that, in principle, two cesium clocks would have to run for 6000 years before their readings would differ by more than 1 second. This amounts to a precision better than 1 part in 10^{11}. Even such accuracy pales in comparison to that of clocks currently being developed; their precision may be as fine as 1 part in 10^{18}.

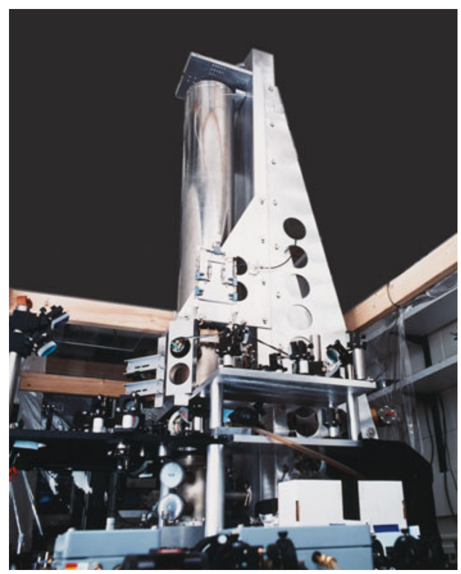


FIGURE 1-5 ■ The cesium fountain atomic frequency standard developed at the National Institute of Standards and Technology in Boulder, Colorado. It is the primary standard for the unit of time in the United States. To set your watch by it, call (303) 499-7111, or call (900) 410-8463 or http://tycho.usno.navy.mil/time.html for Naval Observatory time signals.

READING EXERCISE 1-5: (a) You and a friend are observing a storm. Each of you has your own watch. Describe under what conditions you will both measure the same time for a flash of lightning. Describe under what conditions you will both measure the same duration of time between the lightning flash and the clap of thunder. (b) Look at Fig. 1-4. Do the 10-hour and 12-hour clocks really show the same time? ■

TOUCHSTONE EXAMPLE 1-1*: Sunset

Suppose that while lying on a beach watching the Sun set over a calm ocean, you start a stopwatch just as the top of the Sun disappears. You then stand, elevating your eyes by a height $h = 1.70$ m, and stop the watch when the top of the Sun again disappears. If the elapsed time on the watch is $t = 11.1$ s, what is the radius r of Earth?

SOLUTION ■ A **Key Idea** here is that just as the Sun disappears, your line of sight to the top of the Sun is tangent to Earth's surface. Two such lines of sight are shown in Fig. 1-6. There your eyes are located at point A while you are lying, and at height h above point A while you are standing. For the latter situation, the line of sight is tangent to Earth's surface at point B. Let d represent the distance between point B and the location of your eyes when you are standing, and draw radii r as shown in Fig. 1-6. From the Pythagorean theorem, we then have

$$d^2 + r^2 = (r + h)^2 = r^2 + 2rh + h^2,$$

or

$$d^2 = 2rh + h^2. \tag{1-6}$$

Because the height h is so much smaller than Earth's radius r, the term h^2 is negligible compared to the term $2rh$, and we can rewrite Eq. 1-6 as

$$d^2 \approx 2rh. \tag{1-7}$$

In Fig. 1-6, the angle between the radii to the two tangent points A and B is θ, which is also the angle through which the Sun moves about Earth during the measured time $t = 11.1$ s. During a full day, which is approximately 24 h, the Sun moves through an angle of 360° about Earth. This allows us to write

$$\frac{\theta}{360°} = \frac{t}{24\ \text{h}},$$

which, with $t = 11.1$ s, gives us

$$\theta = \frac{(360°)(11.1\ \text{s})}{(24\ \text{h})(60\ \text{min/h})(60\ \text{s/min})} = 0.04625°.$$

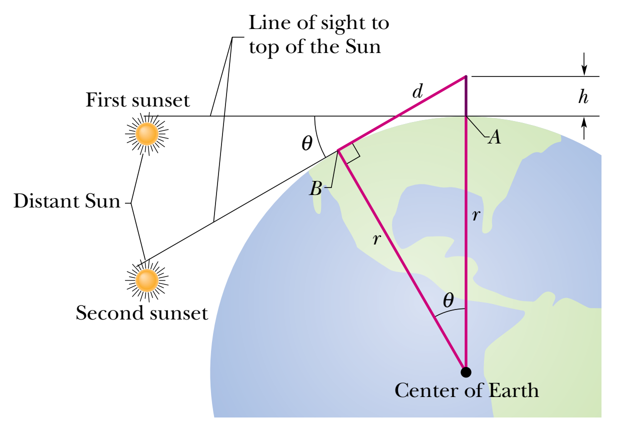


FIGURE 1-6 ■ Your line of sight to the top of the setting Sun rotates through the angle θ when you stand up at point A, and elevate your eyes by a distance h. (Angle θ and distance h are exaggerated here for clarity.)

Again in Fig. 1-6, we see that $d = r \tan \theta$. Substituting this for d in Eq. 1-7 gives us

$$r^2 \tan^2 \theta = 2rh,$$

or

$$r = \frac{2h}{\tan^2 \theta}.$$

Substituting $\theta = 0.04625°$ and $h = 1.70$ m, we find

$$r = \frac{(2)(1.70\ \text{m})}{\tan^2 (0.04625°)} = 5.22 \times 10^6\ \text{m}, \qquad \text{(Answer)}$$

which is within 20% of the accepted value (6.37×10^6 m) for the mean radius of Earth.

*Adapted from "Doubling Your Sunsets, or How Anyone Can Measure the Earth's Size with a Wristwatch and Meter Stick," by Dennis Rawlins, *American Journal of Physics*, Feb. 1979, Vol. 47, pp. 126–128. This technique works best at the equator.

1-6 The SI Standards of Length

In 1792, the newly born Republic of France established a new system of weights and measures. Its cornerstone was the meter, defined to be one ten-millionth of the distance from the North Pole to the equator. However, the first prototype of a 1-meter-long rod was short by 0.2 millimeter, because researchers miscalculated the flattening of the Earth due to its rotation. Nonetheless, this shortened length became the standard meter. For practical reasons, the meter came to be defined as the distance between two fine lines engraved near the ends of a special platinum-iridium bar, the **standard meter bar,** which was kept at the International Bureau of Weights and Measures near Paris. Accurate copies of the bar have been sent to standards laboratories throughout the world including NIST.

Eventually, modern science and technology required an even more precise standard. Today, the length standard is based on the speed of light. As you will learn in Chapter 38, one of the landmark discoveries of the 20th century was Einstein's recognition that the speed of light in a vacuum is the same for all observers. Since the speed of light can be measured to very high precision, it was adopted as a defined quantity in 1983. Time measurements with atomic clocks are also very precise, so it made sense to redefine the meter in terms of the time it takes light to travel 1 meter. By defining the speed of light c to be exactly

$$c = 299\,792\,458 \text{ m/s}, \tag{1-8}$$

light would travel 1 meter in a time period equal to 1/299 792 458 of a second. That is, if one takes this speed and multiplies by this time period, then the distance traveled by the light is exactly 1 meter. According to the 17th General Conference on Weights and Measures:

> The meter is the length of the path traveled by light in a vacuum during a time interval of 1/299 792 458 of a second.

This approach of measuring lengths in terms of a speed and time is similar to that taken by John Harrison in the 18th century when he proposed measuring longitude in terms of the angular speed of the Earth's rotation and time.

Defining the standard meter in terms of the time it takes light to travel a meter has not done away with the need for secondary standards like bars of metal with fine lines delineating the beginning and end points of a meter. We currently use the metal bar as a secondary standard against which we can easily compare other objects. Defining the meter in terms of the speed of light simply gives us a more precise way to verify that our secondary standard is correct.

1-7 SI Standards of Mass

Currently there are two accepted base units for mass—one suitable for determining large masses and the other for determining masses on an atomic scale.

The Standard Kilogram

The initial SI standard of mass is a platinum-iridium cylinder (Fig. 1-7) kept at the International Bureau of Weights and Measures near Paris. By international agreement, it is defined as a mass of 1 kilogram. Accurate replicas have been sent to standards laboratories in other countries, and the masses of other bodies can be determined by balancing them against a replica. The United States copy of the standard kilogram is housed in a vault at NIST. It is removed, no more than once a year, for the purpose of checking replicas used elsewhere. Since 1889, the U.S. replica of the standard kilogram has been taken to France twice for comparison with the primary standard.

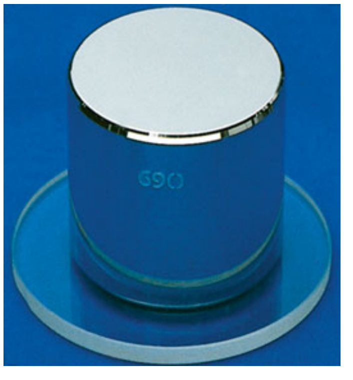


FIGURE 1-7 ■ The international 1 kg standard of mass is a cylinder 39 mm in both height and diameter.

The Atomic Mass Unit

The mass of the known universe is estimated to be 1×10^{53} kg. In contrast, the electron, which plays a vital role in chemical bonding, has a mass of 9×10^{-31} kg. Obviously, the masses of electrons and atoms can be compared with each other more precisely than they can be compared with the standard kilogram. For this reason, we have a second mass standard. It is the carbon-12 atom, which, by international agreement, has been assigned a mass of 12 **atomic mass units** (u). The relation between the atomic mass unit and the kilogram is

$$1 \text{ u} = 1.660\,538\,73 \times 10^{-27} \text{ kg}, \tag{1-9}$$

with an uncertainty of ± 13 in the last two decimal places. Scientists can determine the masses of other atoms relative to the mass of carbon-12 with much better precision than they can using a standard kilogram.

We presently lack a reliable way to extend the precision of the atomic mass unit to more common units of mass, such as the kilogram. However, it is not hard to imagine how one might do this. If we had an object made up of carbon-12 atoms and knew the exact number of atoms in the object, than we could build a precise standard kilogram based on the atomic unit. Work on this is currently underway at NIST and other similar institutions.

READING EXERCISE 1-6: Describe a procedure for determining the mass of the object that has a mass much less than 1 kilogram. Assume that you have a balance, a replica of a standard kilogram, and a big blob of clay available to you. ■

1-8 Measurement Tools for Physics Labs

Institutions like NIST and the International Bureau of Weights and Measures in Paris have many exotic instruments for performing extremely precise measurements. Traditionally, physics students use more common measuring tools in the laboratory, such as meter sticks, vernier calipers (Fig. 1-8), mechanical and electronic balances, digital stopwatches, and multimeters. With careful use, these tools provide adequate precision for studying the time durations and distances investigated in introductory physics laboratories.

FIGURE 1-8 ■ Vernier calipers are cleverly designed to make length measurements to within 1/10 of a millimeter.

In the past few years, new computer tools have become popular in introductory laboratories and in interactive lecture demonstrations. These tools greatly enhance the speed and precision of measurements while allowing students to make many measurements easily and accurately. These tools include **computer data acquisition systems** (Fig. 1-9) **and video capture and analysis tools.** Data obtained using these new computer tools will be shown throughout this text. These data will be used to provide

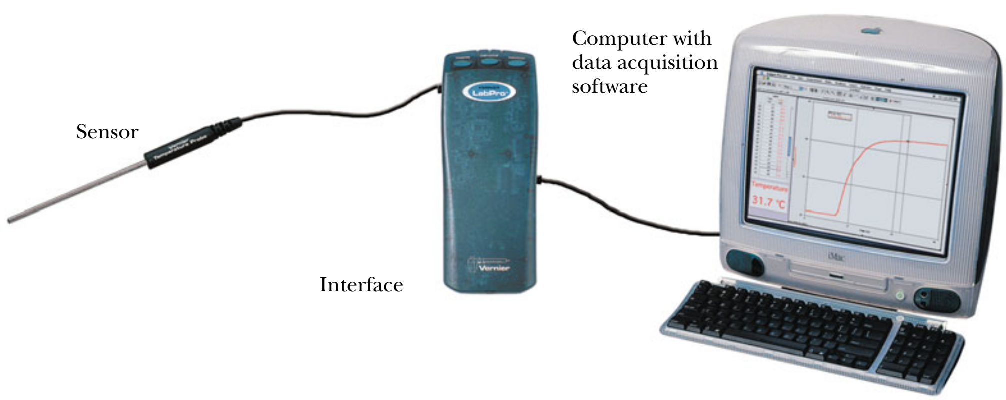


FIGURE 1-9 ■ The photo shows a computer data acquisition system consisting of a sensor, an interface, a computer, and software for real-time data collection.

experimental evidence to motivate and test various theories presented in this book. You may be replicating some of these experiments in laboratory or lecture sessions.

FIGURE 1-10 ■ An ultrasonic motion detector.

Computer Data Acquisition System

When a sensor is attached to a computer through an interface, a very powerful data collection, analysis, and display system is created.* Computers coupled with appropriate software packages are capable of analyzing signals and displaying them on the screen in easily understood formats. Using these capabilities, a graphical representation of data can be displayed in "real time."

A number of different sensors are used in contemporary introductory physics laboratories (Fig. 1-10). These include sensors for the detection of linear and rotational motion (Fig. 1-11), acceleration, force, temperature, pressure, voltage, current, and magnetic field. To determine distances, the most popular motion sensor emits pulses of ultra high frequency sound. Although these ultrasonic pulses are above the range of human hearing, the motion sensor can detect reflections of these pulses after they bounce off objects within the sensor's field of "view."

FIGURE 1-11 ■ Two electronic interfaces used in popular introductory physics computer data acquisition systems: The LabPro Interface (Vernier Software and Technology) and the Science Workshop 500 Interface (PASCO scientific).

Since the speed of ultrasound in room temperature air is known, the computer motion software can calculate the distance to an object by recording how long the pulse takes to reflect off the object and return to the sensor. This is similar to how a bat "sees," and how some auto-focus cameras determine the distance to an object. This approach to measuring a distance or length is not unlike that used by international standards organizations to define the meter in terms of the speed of light. Since ultrasonic motion detectors can send and receive short pulses up to 50 times a second, the computer software can also make rapid calculations of velocities and accelerations of slowly moving objects "on the fly," and graph them in real time. Sample graphs are shown in Fig. 1-12.

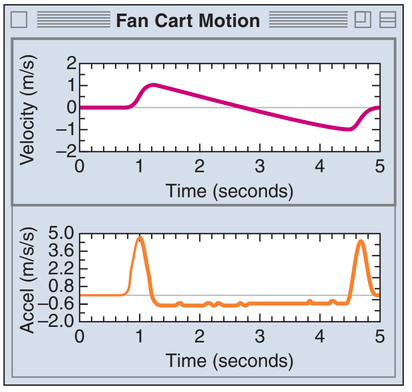


FIGURE 1-12 ■ Real-time graphs of position, velocity, or acceleration, as a function of time, can be generated by an ultrasonic motion detector.

Digital Video Capture and Analysis Tools

Software and hardware enable student investigators to digitize images from a video camera, VCR, or videodisc. Once a digital video movie is created, it can be analyzed using video analysis software. Video data are collected by locating items of interest in each frame of a movie as it is displayed on a computer screen. Video analysis is a useful tool for studying one- and two-dimensional motions, electrostatics, and digital simulations of molecular motions. Examples of digital video clips and their analysis will be presented in this text from time to time. (See Figs. 1-13 and 1-14).

* These systems go by many names, such as computer-based data collection system, e-measure, CADAA (computer-assisted data acquisition and analysis system), or MBL system (Microcomputer Based Laboratory system).

FIGURE 1-13 ■ An overlay of five digital video frames showing a ballet dancer moving toward the left while performing a grand jeté.

1-9 Changing Units

An American traveling overseas notices a road sign indicating that the distance to the next town is 32 km. She wants to get a feel for how far away the town is, and needs to convert the kilometers to the more familiar units of miles. How would she go about doing that?

We often need to change the units in which a physical quantity is expressed. A good method is called *chain-link conversion*. In this method, we multiply the original measurement by one or more conversion factors. A **conversion factor** is defined as a ratio of units that is equal to 1. For example, because 1 mile and 1.61 kilometers are identical distances, we have

$$\frac{1 \text{ mi}}{1.61 \text{ km}} = 1 \quad \text{and also} \quad \frac{1.61 \text{ km}}{1 \text{ mi}} = 1. \tag{1-10}$$

Thus, the ratios (1 mi)/(1.61 km) and (1.61 km)/(1 mi) can be used as conversion factors. This is *not* the same as writing $1/1.61 = 1$ or $1.61 = 1$; each *number* and its *unit* must be treated together. Because multiplying any quantity by one leaves it unchanged, we can introduce such conversion factors wherever we find them useful. In chain-link conversion, we use the factors to cancel unwanted units. For example, to convert 32 kilometers to miles, we have

$$32 \text{ km} = (32 \cancel{\text{km}})\left(\frac{1 \text{ mi}}{1.61 \cancel{\text{km}}}\right) = 20 \text{ mi}. \tag{1-11}$$

Suppose instead that our traveler wanted to know how many feet there are in 32 kilometers. Then two conversion factors would be needed, so that

$$32 \text{ km} = (32 \cancel{\text{km}})\left(\frac{1 \cancel{\text{mi}}}{1.61 \cancel{\text{km}}}\right)\left(\frac{5280 \text{ ft}}{1 \cancel{\text{mi}}}\right) = 1.05 \times 10^5 \text{ ft}. \tag{1-12}$$

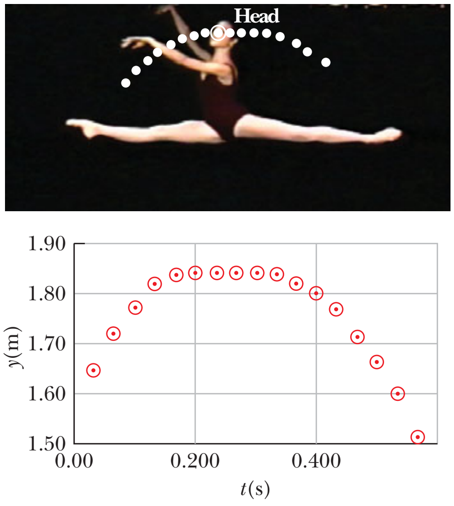


FIGURE 1-14 ■ A video analysis of the motion of the dancer reveals that while performing the grand jeté depicted in Fig. 1-13, her head is moving in a straight horizontal line between the times 0.180 s and 0.330 s. To observers following the motion of her head, the dancer appears to be floating for this short period of time. How does she accomplish this? In Chapter 8 we describe how video analysis helps us explore this question.

The number of feet is expressed in scientific notation so that the correct number of significant figures can be represented. See the next section and Appendix A for more details on how to represent significant figures properly.

Appendix D and the inside back cover give conversion factors between SI and other systems of units, including many of the non-SI units still used in the United States. However, the conversion factors are written in the style of "1 mi = 1.61 km" rather than the ratios we show here.

It is important to note that the **value of a physical quantity** is actually the product of a number and a unit. Thus, the number associated with a particular physical quantity depends on the unit in which it is expressed. For example, the distance to the traveler's town has a value of 32 km. The numerical component of its value expressed in the unit "kilometers" is 32. However, the value of the distance when expressed in miles is 20 mi, and the numerical component of its value when expressed in miles is 20. Since 20 miles is actually the *same distance* as 32 kilometers, it is meaningful to write 32 km = 20 mi. In this context the equal sign (=) signifies that 32 km is the *same distance* as 20 mi expressed in different units. However, it is totally meaningless to write 32 = 20. Thus it is extremely important to include appropriate units in all calculations.

TOUCHSTONE EXAMPLE 1-2: Marathon

When Pheidippides ran from Marathon to Athens in 490 B.C.E. to bring word of the Greek victory over the Persians, he probably ran at a speed of about 23 rides per hour (rides/h). The ride is an ancient Greek unit for length, as are the stadium and the plethron: 1 ride was defined to be 4 stadia, 1 stadium was defined to be 6 plethra, and, in terms of a modern unit, 1 plethron is 30.8 m. How fast did Pheidippides run in kilometers per second (km/s)?

SOLUTION ■ The **Key Idea** in chain-link conversions is to write the conversion factors as ratios that will eliminate unwanted units. Here we write

$$23\ \text{rides/h} = \left(23\,\frac{\cancel{\text{rides}}}{\cancel{\text{h}}}\right)\left(\frac{4\ \cancel{\text{stadia}}}{1\ \cancel{\text{ride}}}\right)\left(\frac{6\ \cancel{\text{plethra}}}{1\ \cancel{\text{stadium}}}\right)\left(\frac{30.8\ \cancel{\text{m}}}{1\ \cancel{\text{plethron}}}\right)\left(\frac{1\ \text{km}}{1000\ \cancel{\text{m}}}\right)\left(\frac{1\ \cancel{\text{h}}}{3600\ \text{s}}\right)$$
$$= 4.7227 \times 10^{-3}\ \text{km/s} \approx 4.7 \times 10^{-3}\ \text{km/s}. \quad \text{(Answer)}$$

READING EXERCISE 1-7: (a) Explain why it is correct to write 1 min/60 s = 1, but it is not correct to write 1/60 = 1. (b) Use the relevant conversion factors and the method of chain-link conversions to calculate how many seconds there are in a day. ■

1-10 Calculations with Uncertain Quantities

Issue 1: Significant Figures and Decimal Places

In July 1988, in Indianapolis, Indiana, the U.S.'s Florence Griffith Joyner set a world record in the women's 100-meter dash with an official time of 10.49 seconds (Fig. 1-15). The timing in the race is considered good to the nearest 1/100 of a second. Suppose you had been asked to report the time in minutes instead of seconds. If you used a calculator to transform the 10.49 seconds into minutes by multiplying by (1 min)/(60 s), you might report the following by copying all the digits on your display:

$$10.49\ \text{s} = (10.49\ \text{s})\left(\frac{1\ \text{min}}{60\ \text{s}}\right) = 0.174\,833\,333\ \text{min}. \quad (1\text{-}13)$$

No matter how precise a measuring instrument is, all measured quantities have uncertainties associated with them. The precision implied by the calculated time in minutes shown above is both meaningless and misleading! We should have rounded the answer to four significant digits, 0.1748 min, so as not to imply that it is more precise than the given data. The given time of 10.49 seconds consists of four digits, called **significant figures.** This tells us we should round the answer to four significant figures. In this text, final results of calculations are often rounded to match the least number of significant figures in the given data. *Significant figures* should not be confused with *decimal places*. Consider the lengths 35.6 mm, 3.56 cm, and 0.0356 m. They all have three significant figures, but they have one, two, and four decimal places, respectively.

FIGURE 1-15 ■ The late Florence Griffith Joyner set a world's record in the women's 100-meter dash in 1988.

As you work with scientific calculations in data analysis in the laboratory or complete the problems in this text, it is important to pay strict attention to reporting your answer to the same precision as the lowest precision in any of the factors used in your calculation. Information on how to keep track of significant figures and measurement uncertainties in calculations is included in Appendix A, and a table of fundamental constants that have been measured to high precision is in Appendix B.

Issue 2: Order of Magnitude

In order to make estimations, engineering and science professionals will sometimes round a number to be used in a calculation up or down to the nearest power of ten. This makes the number very easy to use in calculations. The result of this rounding procedure is known as the *order of magnitude* of a number. To determine an order of magnitude, we start by expressing the number of interest in scientific notation. Next, the mantissa is rounded up to 10 or down to 1 depending on which is closest. For example, if $A = 2.3 \times 10^4$, then the order of magnitude of A is 10^4 (ten to the fourth) since 2.3 is closer to 1 than it is to 10. On the other hand, if $B = 7.8 \times 10^4$, then the order of magnitude of B is 10^5 (ten to the fifth) since 7.8 is closer to 10 than it is to 1. Order of magnitude estimations are common when detailed or precise data are not required in a calculation or are not known.

READING EXERCISE 1-8: Using the method outlined in Appendix A, determine the number of significant figures in each of the following numbers: (a) 27 meters, (b) 27 cows, (c) 0.003 429 87 second, (d) $-1.970\,500 \times 10^{-11}$ coulombs, (e) 5280 ft/mi. (*Note:* By definition there are exactly 5280 feet in a mile.) ■

READING EXERCISE 1-9: A popular science book lists the radius of the Earth as 20 900 000 000 ft. (a) How many significant figures does this number have if you apply the method described in Appendix A for determining the number of significant figures? (b) How many significant figures did the author probably intend to report? (c) How could you rewrite this number so that it represents three significant figures? (d) What order of magnitude is the radius of the Earth in feet? ■

TOUCHSTONE EXAMPLE 1-3: Ball of String

The world's largest ball of string is about 2 m in radius. To the nearest order of magnitude, what is the total length L of the string in the ball?

SOLUTION ■ We could, of course, take the ball apart and measure the total length L, but that would take great effort and make the ball's builder most unhappy. A **Key Idea** here is that, because we want only the nearest order of magnitude, we can estimate any quantities required in the calculation.

Let us assume the ball is spherical with radius $R = 2$ m. The string in the ball is not closely packed (there are uncountable gaps between nearby sections of string). To allow for these gaps, let us somewhat overestimate the cross-sectional area of the string by assuming the cross section is square, with an edge length $d = 4$ mm. Then, with a cross-sectional area of d^2 and a length L, the string occupies a total volume of

$$V = (\text{cross-sectional area})(\text{length}) = d^2L.$$

This is approximately equal to the volume of the ball, given by $\frac{4}{3}\pi R^3$, which is about $4R^3$ because π is about 3. Thus, we have

$$d^2L = 4R^3,$$

or

$$L = \frac{4R^3}{d^2} = \frac{4(2\text{ m})^3}{(4 \times 10^{-3}\text{ m})^2} \qquad \text{(Answer)}$$
$$= 2 \times 10^6\text{ m} \approx 10^6\text{ m} = 10^3\text{ km}.$$

(Note that you do not need a calculator for such a simplified calculation.) Thus, to the nearest order of magnitude, the ball contains about 1000 km of string!

READING EXERCISE 1-10: Suppose you are to calculate the volume of a cube that is $L = 1.4$ cm on a side and you start by calculating the area, A, of a face of the cube $A = L^2$ and then calculating $V = AL$. (a) What intermediate value for A should you use in the calculation for V? (b) What is the value of the volume to the correct number of significant figures? (c) What value do you get for V if you incorrectly retain only two significant figures after you calculate A? ■

READING EXERCISE 1-11: Perform the following calculations and express the answers to the correct number of significant figures. (a) Multiply 3.4 by 7.954. (b) Add 99.3 and 98.7. (c) Subtract 98.7 from 99.3. (d) Evaluate the cosine of 3°. (e) If five railroad track segments have an average length of 2.134 meters, what is the total length of these five rails when they lie end to end? ■

READING EXERCISE 1-12: Suppose you measure a time to the nearest 1/100 of a second and get a value of 1.78 s. (a) What is the absolute precision of your measurement? (b) What is the relative precision of your measurement? ■

Problems

SEC. 1-5 ■ THE SI STANDARD OF TIME

1. Speed of Light Express the speed of light, 3.0×10^8 m/s, in (a) feet per nanosecond and (b) millimeters per picosecond.

2. Fermi Physicist Enrico Fermi once pointed out that a standard lecture period (50 min) is close to 1 microcentury. (a) How long is a microcentury in minutes? (b) Using

$$\text{percentage difference} = \left(\frac{\text{actual} - \text{approximation}}{\text{actual}}\right) 100,$$

find the percentage difference from Fermi's approximation.

3. Five Clocks Five clocks are being tested in a laboratory. Exactly at noon, as determined by the WWV time signal, on successive days of a week the clocks read as in the following table. Rank the five clocks according to their relative value as good timekeepers, best to worst. Justify your choice.

Clock	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
A	12:36:40	12:36:56	12:37:12	12:37:27	12:37:44	12:37:59	12:38:14
B	11:59:59	12:00:02	11:59:57	12:00:07	12:00:02	11:59:56	12:00:03
C	15:50:45	15:51:43	15:52:41	15:53:39	15:54:37	15:55:35	15:56:33
D	12:03:59	12:02:52	12:01:45	12:00:38	11:59:31	11:58:24	11:57:17
E	12:03:59	12:02:49	12:01:54	12:01:52	12:01:32	12:01:22	12:01:12

4. The Shake A unit of time sometimes used in microscopic physics is the *shake*. One shake equals 10^{-8} s. (a) Are there more shakes in a second than there are seconds in a year? (b) Humans have existed for about 10^6 years, whereas the universe is about 10^{10} years old. If the age of the universe now is taken to be 1 "universe day," for how many "universe seconds" have humans existed?

5. Astronomical Units An astronomical unit (AU) is the average distance of Earth from the Sun, approximately 1.50×10^8 km. The speed of light is about 3.0×10^8 m/s. Express the speed of light in terms of astronomical units per minute.

6. Digital Clocks Three digital clocks A, B, and C run at different rates and do not have simultaneous readings of zero. Figure 1-16 shows simultaneous readings on pairs of the clocks for four occasions. (At the earliest occasion, for example, B reads 25.0 s and C reads 92.0 s.) If two events are 600 s apart on clock A, how far apart are they on (a) clock B and (b) clock C? (c) When clock A reads 400 s, what does clock B read? (d) When clock C reads 15.0 s, what does clock B read? (Assume negative readings for prezero times.)

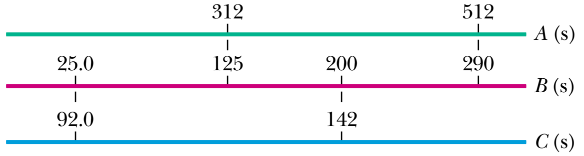


FIGURE 1-16 ■ Problem 6.

7. Length of Day Assuming the length of the day uniformly increases by 0.0010 s per century, calculate the cumulative effect on the measure of time over 20 centuries. (Such slowing of Earth's rotation is indicated by observations of the occurrences of solar eclipses during this period.)

8. Time Zones Until 1883, every city and town in the United States kept its own local time. Today, travelers reset their watches only when the time change equals 1.0 h. How far, on the average, must you travel in degrees of longitude until your watch must be reset by 1.0 h? (*Hint:* Earth rotates 360° in about 24 h.)

9. A Fortnight A fortnight is a charming English measure of time equal to 2.0 weeks (the word is a contraction of "fourteen nights"). That is a nice amount of time in pleasant company but perhaps a painful string of microseconds in unpleasant company. How many microseconds are in a fortnight?

10. Time Standards Time standards are now based on atomic clocks. A promising second standard is based on *pulsars*, which are rotating neutron stars (highly compact stars consisting only of neutrons). Some rotate at a rate that is highly stable, sending out a radio beacon that sweeps briefly across Earth once with each rotation, like a lighthouse beacon. Pulsar PSR 1937 + 21 is an example; it rotates once every 1.557 806 448 872 75 ± 3 ms, where the trailing ±3 indicates the uncertainty in the last decimal place (it does *not* mean ±3 ms). (a) How many times does PSR 1937 + 21 rotate in 7.00 days? (b) How much time does the pulsar take to rotate 1.0×10^6 times, and (c) what is the associated uncertainty?

SEC. 1-6 ■ THE SI STANDARDS OF LENGTH

11. Furlongs Horses are to race over a certain English meadow for a distance of 4.0 furlongs. What is the race distance in units of (a) rods and (b) chains? (1 furlong = 201.168 m, 1 rod = 5.0292 m, and 1 chain = 20.117 m.)

12. Types of Barrels Two types of *barrel* units were in use in the 1920s in the United States. The apple barrel had a legally set volume of 7056 cubic inches; the cranberry barrel, 5826 cubic inches. If a merchant sells 20 cranberry barrels of goods to a customer who thinks he is receiving apple barrels, what is the discrepancy in the shipment volume in liters?

13. The Earth Earth is approximately a sphere of radius 6.37×10^6 m. What are (a) its circumference in kilometers, (b) its surface area in square kilometers, and (c) its volume in cubic kilometers?

14. Points and Picas Spacing in this book was generally done in units of points and picas: 12 points = 1 pica, and 6 picas = 1 inch. If a figure was misplaced in the page proofs by 0.80 cm, what was the misplacement in (a) points and (b) picas?

15. Antarctica Antarctica is roughly semicircular, with a radius of 2000 km (Fig. 1-17). The average thickness of its ice cover is 3000 m. How many cubic centimeters of ice does Antarctica contain? (Ignore the curvature of Earth.)

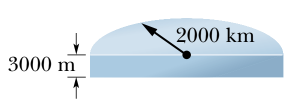


FIGURE 1-17 ■ Problem 15.

16. Roods and Perches An old manuscript reveals that a landowner in the time of King Arthur held 3.00 acres of plowed land plus a livestock area of 25.0 perches by 4.00 perches. What was the total area in (a) the old unit of roods and (b) the more modern unit of square meters? Here, 1 acre is an area of 40 perches by 4 perches, 1 rood is 40 perches by 1 perch, and 1 perch is 16.5 ft.

17. The Acre-Foot Hydraulic engineers in the United States often use, as a unit of volume of water, the *acre-foot*, defined as the volume of water that will cover 1 acre of land to a depth of 1 ft. A severe thunderstorm dumped 2.0 in. of rain in 30 min on a town of area 26 km². What volume of water, in acre-feet, fell on the town?

18. A Doll House In the United States, a doll house has the scale of 1:12 of a real house (that is, each length of the doll house is $\frac{1}{12}$ that of the real house) and a miniature house (a doll house to fit within a doll house) has the scale of 1:144 of a real house. Suppose a real house (Fig. 1-18) has a front length of 20 m, a depth of 12 m, a height of 6.0 m, and a standard sloped roof (vertical triangular faces on the ends) of height 3.0 m. In cubic meters, what are the volumes of the corresponding (a) doll house and (b) miniature house?

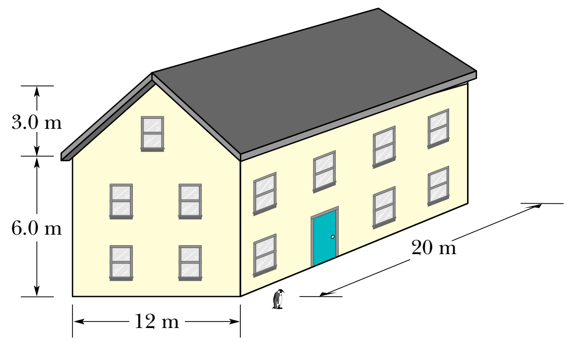


FIGURE 1-18 ■ Problem 18.

SEC. 1-7 ■ THE SI STANDARDS OF MASS

19. Earth's Mass Earth has a mass of 5.98×10^{24} kg. The average mass of the atoms that make up Earth is 40 u. How many atoms are there in Earth?

20. Gold Gold, which has a mass of 19.32 g for each cubic centimeter of volume, is the most ductile metal and can be pressed into a thin leaf or drawn out into a long fiber. (a) If 1.000 oz of gold, with a mass of 27.63 g, is pressed into a leaf of 1.000 μm thickness, what is the area of the leaf? (b) If, instead, the gold is drawn out into a cylindrical fiber of radius 2.500 μm, what is the length of the fiber?

21. Mass of Water (a) Assuming that each cubic centimeter of water has a mass of exactly 1 g, find the mass of one cubic meter of water in kilograms. (b) Suppose that it takes 10.0 h to drain a container of 5700 m³ of water. What is the "mass flow rate," in kilograms per second, of water from the container?

22. The Thunderstorm What mass of water fell on the town in Problem 17 during the thunderstorm? One cubic meter of water has a mass of 10^3 kg.

23. Iron Iron has a mass of 7.87 g per cubic centimeter of volume, and the mass of an iron atom is 9.27×10^{-26} kg. If the atoms are spherical and tightly packed, (a) what is the volume of an iron atom and (b) what is the distance between the centers of adjacent atoms?

24. Grains of Sand Grains of fine California beach sand are approximately spheres with an average radius of 50 μm and are made of silicon dioxide. A solid cube of silicon dioxide with a volume of 1.00 m³ has a mass of 2600 kg. What mass of sand grains would have a total surface area (the total area of all the individual spheres) equal to the surface area of a cube 1 m on an edge?

SEC. 1-9 ■ CHANGING UNITS

25. A Diet A person on a diet might lose 2.3 kg per week. Express the mass loss rate in milligrams per second, as if the dieter could sense the second-by-second loss.

26. Cats and Moles A mole of atoms is 6.02×10^{23} atoms. To the nearest order of magnitude, how many moles of atoms are in a large domestic cat? The masses of a hydrogen atom, an oxygen atom, and a carbon atom are 1.0 u, 16 u, and 12 u, respectively. (*Hint:* Cats are sometimes known to kill moles.)

27. Sugar Cube A typical sugar cube has an edge length of 1 cm. If you had a cubical box that contained a mole of sugar cubes, what would its edge length be? (One mole = 6.02×10^{23} units.)

28. Micrometer The micrometer (1 μm) is often called the *micron*. (a) How many microns make up 1.0 km? (b) What fraction of a centimeter equals 1.0 μm? (c) How many microns are in 1.0 yd?

29. Hydrogen Using conversions and data in the chapter, determine the number of hydrogen atoms required to obtain 1.0 kg of hydrogen. A hydrogen atom has a mass of 1.0 u.

30. A Gry A *gry* is an old English measure for length, defined as 1/10 of a line, where *line* is another old English measure for length, defined as 1/12 inch. A common measure for length in the publishing business is a *point,* defined as 1/72 inch. What is an area of 0.50 gry^2 in terms of points squared (points^2)?

Additional Problems

31. Harvard Bridge Harvard Bridge, which connects MIT with its fraternities across the Charles River, has a length of 364.4 Smoots plus one ear. The unit of one Smoot is based on the length of Oliver Reed Smoot, Jr., class of 1962, who was carried or dragged length by length across the bridge so that other pledge members of the Lambda Chi Alpha fraternity could mark off (with paint) 1-Smoot lengths along the bridge. The marks have been repainted biannually by fraternity pledges since the initial measurement, usually during times of traffic congestion so that the police could not easily interfere. (Presumably, the police were originally upset because a Smoot is not an SI base unit, but these days they seem to have accepted the unit.) Figure 1-19 shows three parallel paths, measured in Smoots (S), Willies (W), and Zeldas (Z). What is the length of 50.0 Smoots in (a) Willies and (b) Zeldas?

FIGURE 1-19 ■ Problem 31.

32. Little Miss Muffet An old English children's rhyme states, "Little Miss Muffet sat on her tuffet, eating her curds and whey, when along came a spider who sat down beside her. . . ." The spider sat down not because of the curds and whey but because Miss Muffet had a stash of 11 tuffets of dried flies. The volume measure of a tuffet is given by 1 tuffet = 2 pecks = 0.50 bushel, where 1 Imperial (British) bushel = 36.3687 liters (L). What was Miss Muffet's stash in (a) pecks, (b) bushels, and (c) liters?

33. Noctilucent Clouds During the summers at high latitudes, ghostly, silver-blue clouds occasionally appear after sunset when common clouds are in Earth's shadow and are no longer visible. The ghostly clouds have been called *noctilucent clouds* (NLC), which means "luminous night clouds," but now are often called *mesospheric clouds*, after the *mesosphere*, the name of the atmosphere at the altitude of the clouds.

These clouds were first seen in June 1885, after dust and water from the massive 1883 volcanic explosion of Krakatoa Island (near Java in the Southeast Pacific) reached the high altitudes in the Northern Hemisphere. In the low temperatures of the mesosphere, the water collected and froze on the volcanic dust (and perhaps on comet and meteor dust already present there) to form the particles that made up the first clouds. Since then, mesospheric clouds have generally increased in occurrence and brightness, probably because of the increased production of methane by industries, rice paddies, landfills, and livestock flatulence. The methane works its way into the upper atmosphere, undergoes chemical changes, and results in an increase of water molecules there, and also in bits of ice for the mesospheric clouds.

If mesospheric clouds are spotted 38 min after sunset and then quickly dim, what is their altitude if they are directly over the observer?

34. Staircase A standard interior staircase has steps each with a rise (height) of 19 cm and a run (horizontal depth) of 23 cm. Research suggests that the stairs would be safer for descent if the run were, instead, 28 cm. For a particular staircase of total height 4.57 m, how much farther would the staircase extend into the room at the foot of the stairs if this change in run were made?

35. Large and Small As a contrast between the old and the modern and between the large and the small, consider the following: In old rural England 1 hide (between 100 and 120 acres) was the area of land needed to sustain one family with a single plough for one year. (An area of 1 acre is equal to 4047 m^2.) Also, 1 wapentake was the area of land needed by 100 such families. In quantum physics, the cross-sectional area of a nucleus (defined in terms of the chance of a particle hitting and being absorbed by it) is measured in units of barns, where 1 barn is 1×10^{-28} m^2. (In nuclear physics jargon, if a nucleus is "large," then shooting a particle at it is like shooting a bullet at a barn door, which can hardly be missed.) What is the ratio of 25 wapentakes to 11 barns?

36. Cumulus Cloud A cubic centimeter in a typical cumulus cloud contains 50 to 500 water droplets, which have a typical radius of 10 μm. (a) How many cubic meters of water are in a cylindrical cumulus cloud of height 3.0 km and radius 1.0 km? (b) How many 1-liter pop bottles would that water fill? (c) Water has a mass per unit volume (or density) of 1000 kg/m^3. How much mass does the water in the cloud have?

37. Oysters In purchasing food for a political rally, you erroneously order shucked medium-size Pacific oysters (which come 8 to 12 per U.S. pint) instead of shucked medium-size Atlantic oysters (which come 26 to 38 per U.S. pint). The filled oyster container delivered to you has the interior measure of 1.0 m $\times$ 12 cm $\times$ 20 cm, and a U.S. pint is equivalent to 0.4732 liter. By how many oysters is the order short of your anticipated count?

38. U.K. Gallons A tourist purchases a car in England and ships it home to the United States. The car sticker advertised that the car's fuel consumption was at the rate of 40 miles per gallon on the open road. The tourist does not realize that the U.K. gallon differs from the U.S. gallon:

$$1 \text{ U.K. gallon} = 4.545\,963\,1 \text{ liters}$$
$$1 \text{ U.S. gallon} = 3.785\,306\,0 \text{ liters.}$$

For a trip of 750 miles (in the United States), how many gallons of fuel does (a) the mistaken tourist believe she needs and (b) the car actually require?

39. Types of Tons A ton is a measure of volume frequently used in shipping, but that use requires some care because there are at least three types of tons: A *displacement ton* is equal to 7 barrels bulk, a *freight ton* is equal to 8 barrels bulk, and a *register ton* is equal to 20 barrels bulk. A *barrel bulk* is another measure of volume: 1 barrel bulk = 0.1415 m^3. Suppose you spot a shipping order for "73 tons" of M&M candies, and you are certain that the client who sent the order intended "ton" to refer to volume (instead of weight or mass, as discussed in Chapter 6). If the client actually meant displacement tons, how many extra U.S. bushels of the candies will you erroneously ship to the client if you interpret the order as (a) 73 freight tons and (b) 73 register tons? One cubic meter is equivalent to 28.378 U.S bushels.

40. Wine Bottles The wine for a large European wedding reception is to be served in a stunning cut-glass receptacle with the interior dimensions of 40 cm × 40 cm × 30 cm (height). The receptacle is to be initially filled to the top. The wine can be purchased in bottles of the sizes given in the following table, where the volumes of the larger bottles are given in terms of the volume of a standard wine bottle. Purchasing a larger bottle instead of multiple smaller bottles decreases the overall cost of the wine. To minimize that overall cost, (a) which bottle sizes should be purchased and how many of each should be purchased, and (b) how much wine is left over once the receptacle is filled?

1 standard
1 magnum = 2 standard
1 jeroboam = 4 standard
1 rehoboam = 6 standard
1 methuselah = 8 standard
1 salmanazar = 12 standard
1 balthazar = 16 standard = 11.356 L
1 nebuchadnezzar = 20 standard

41. The Corn–Hog Ratio The *corn-hog ratio* is a financial term commonly used in the pig market and presumably is related to the cost of feeding a pig until it is large enough for market. It is defined as the ratio of the market price of a pig with a mass of 1460 slugs to the market price of a U.S. bushel of corn. The slug is the unit of mass in the English system. (The word "slug" is derived from an old German word that means "to hit"; we have the same meaning for "slug" as a verb in modern English.) A U.S. bushel is equal to 35.238 L. If the corn–hog ratio is listed as 5.7 on the market exchange, what is it in the metric units of

$$\frac{\text{price of 1 kilogram of pig}}{\text{price of 1 liter of corn}}?$$

(*Hint:* See the Mass table in Appendix D.)

42. Volume Measures in Spain You can easily convert common units and measures electronically, but you still should be able to use a conversion table, such as those in Appendix D. Table 1-3 is part of a conversion table for a system of volume measures once common in Spain; a volume of 1 fanega is equivalent to 55.501 dm^3 (cubic decimeters). (a) Complete the table, using three significant figures. Then express 7.00 almude in terms of (b) medio, (c) cahiz, and (d) cubic centimeters (cm^3).

TABLE 1-3
Problem 42

	cahiz	fanega	cuartilla	almude	medio
1 cahiz =	1	12	48	144	288
1 fanega =		1	4	12	24
1 cuartilla =			1	3	6
1 almude =				1	2
1 medio =					1

43. Pirate Ship You receive orders to sail due east for 24.5 mi to put your salvage ship directly over a sunken pirate ship. However, when your divers probe the ocean floor at that location and find no evidence of a ship, you radio back to your source of information, only to discover that the sailing distance was supposed to be 24.5 *nautical miles,* not regular miles. Use the Length table in Appendix D to calculate how far horizontally you are from the pirate ship in kilometers.

44. The French Revolution For about 10 years after the French revolution, the French government attempted to base measures of time on multiples of ten: One week consisted of 10 days, 1 day consisted of 10 hours, 1 hour consisted of 100 minutes, and 1 minute consisted of 100 seconds. What are the ratios of (a) the French decimal week to the standard week and (b) the French decimal second to the standard second?

45. Heavy Rain During heavy rain, a rectangular section of a mountainside measuring 2.5 km wide (horizontally), 0.80 km long (up along the slope), and 2.0 m deep suddenly slips into a valley in a mud slide. Assume that the mud ends up uniformly distributed over a valley section measuring 0.40 km × 0.40 km and that the mass of a cubic meter of mud is 1900 kg. What is the mass of the mud sitting above an area of 4.0 m^2 in that section?

46. Liquid Volume Prior to adopting metric systems of measurement, the United Kingdom employed some challenging measures of liquid volume. A few are shown in Table 1-4. (a) Complete the table, using three significant figures. (b) The volume of 1 bag is equivalent to a volume of 0.1091 m^3. If an old British story has a witch cooking up some vile liquid in a cauldron with a volume of 1.5 chaldrons, what is the volume in terms of cubic meters?

TABLE 1-4
Problem 46

	wey	chaldron	bag	pottle	gill
1 wey =	1	10/9	40/3	640	120 240
1 chaldron =					
1 bag =					
1 pottle =					
1 gill =					

47. The Dbug Traditional units of time have been based on astronomical measurements, such as the length of the day or year. However, one human-based measure of time can be found in Tibet, where the *dbug* is the average time between exhaled breaths. Estimate the number of dbugs in a day.

48. Tower of Pisa The following photograph of the Leaning Tower of Pisa was taken from an advertisement found in a 1994 airline magazine. Assume that the photo of the man talking on the telephone to the left has been dubbed in and is not part of the original photograph.

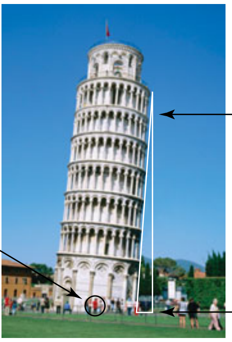


FIGURE 1-20 ■ Problem 48.

(a) Examine the photograph. Take the measurements in centimeters that are needed to find a scale factor that enables you to estimate the length of the tower in meters (i.e., its height if it were standing up straight.) Use only the evidence in the photograph—no other data are allowed. Then estimate the tower length in meters.
(b) According to data published in Sir Bannester Fletcher's *A History of Architecture* (U. of London Athlone Press, 1975, p. 470) the diameter of the lower part of the tower is 16.0 m. Using these data, find another scale factor for estimating the length of the tower, and then re-estimate the length of the tower using this new scale factor.
(c) Which of the scale factors (a) or (b) do you think will give the best estimate of the length of the tower? Explain the reasons for your answer.
(d) Using the scale factor you found in part (b), what is the length of the tower without the belfry or narrow top segment (i.e., just consider the bottom 7 stories)?

49. Mexican Food You are to fix dinners for 400 people at a convention of Mexican food fans. Your recipe calls for 2 jalapeño peppers per serving (one serving per person). However, you have only habanero peppers on hand. The spiciness of peppers is measured in terms of the *scoville heat unit* (SHU). On average, one jalapeño pepper has a spiciness of 4000 SHU and one habanero pepper has a spiciness of 300 000 SHU. To salvage the situation, how many (total) habanero peppers should you substitute for the jalapeño peppers in the recipe for the convention?

50. Big or Small? Discuss the question: "Is 500 feet big or small?" Before you do so, carry out the following estimates.

(a) You are on the top floor of a 500-ft-tall building. A fire breaks out in the building and the elevator stops working. You have to walk down to the ground floor. Estimate how long this would take you. (Your stairwell is on the other side of the building from the fire.)
(b) You are hiking the Appalachian Trail on a beautiful fall morning as part of a 10 mi hike with a group of friends. You are walking along a well-tended, level part of the trail. Estimate how long it would take you to walk 500 ft.
(c) You are driving on the New Jersey Turnpike at 65 mi/hr. You pass a sign that says "Lane ends 500 feet." How much time do you have in order to change lanes?

51. Doubling System Historically the English had a doubling system when measuring volumes; 2 mouthfuls equal 1 jigger, 2 jiggers equal 1 jack (also called a jackpot); 2 jacks equal 1 jill; 2 jills = 1 cup; 2 cups = 1 pint; 2 pints = 1 quart; 2 quarts = 1 pottle; 2 pottles = 1 gallon; 2 gallons = 1 pail. (The nursery rhyme "Jack and Jill" refers to these units and was a protest against King Charles I of England for his taxes on the jacks of liquor sold in the tavern. (See A. Kline, *The World of Measurement,* New York: Simon and Schuster, 1975, pp. 32–39.) American and British cooks today use teaspoons, tablespoons, and cups; 3 teaspoons = 1 tablespoon; 4 tablespoons = 1/4 cup. Assume that you find an old English recipe requiring 3 jiggers of milk. How many cups does this represent? How many tablespoons? You can assume that the cups in the two systems represent the same volume.

52. Fuel Efficiency In America, we measure fuel efficiency of our cars by citing the number of miles you can drive on 1 gallon of gas (miles/gallon). In Europe, the same information is given by quoting how many liters of gas it takes to go 100 kilometers (liter/100 kilometers).

(a) My current car gets 21 miles/gallon in highway travel. What number (in liter/100 kilometers) should I give to my Swedish friend so that he can compare it to the mileage for his Volvo?
(b) The car I drove in England last summer needed 6 liters of gas to go 100 kilometers. How many miles/gallon did it get?
(c) If my car has a fuel efficiency, *f*, in miles/gallon, what is its European efficiency, *e*, in liters/100 kilometers? (Write an equation that would permit an easy conversion.)

53. Pizza Sale Two terrapins decide to go to Jerry's for a pizza. When they get there they find that Jerry's is having a special:

SPECIAL TODAY:	one 20″ pizza	\$15
REGULAR PRICE	one 10″ pizza	\$5
	one 20″ pizza	\$18

Raphael: "Great! Let's get a large one."

Donatello: "Don't be dumb. Let's get three of the small ones for the same price. That'll give us more pizza and be cheaper."

Raphael: "Why would it be a special if it's more than we could get for the regular price? Let's get the large."

Who's right? Which would you buy? What would the difference be if you were buying them at Ledo's (square pizzas)?

54. Dollar and Penny A student makes the following argument: "I can prove a dollar equals a penny. Since a dime (10 cents) is one-tenth of a dollar, I can write:

$$10\,¢ = \$0.1.$$

Square both sides of the equation. Since squares of equals are equal,

$$100\,¢ = \$0.1.$$

Since 100 ¢ = \$1 and \$0.01 = 1 ¢, it follows that \$1 = 1 ¢."
What's wrong with the argument?

55. Scaling Up Here are two related problems—one precise, one an estimation.

(a) A sculptor builds a model for a statue of a terrapin to replace Testudo.* She discovers that to cast her small scale model she needs 2 kg of bronze. When she is done, she finds that she can give it two coats of finishing polyurethane varnish using exactly one small can of varnish. The final statue is supposed to be 5 times as large as the model in each dimension. How much bronze will she need? How much varnish should she buy? (*Hint*: If this seems difficult, you might start by writing a simpler question that is easier to work on before tackling this one.)

FIGURE 1-21 ■ Problem 55.

(b) The human brain has 1000 times the surface area of a mouse's brain. The human brain is convoluted, the mouse's is not. How much of this factor is due just to size (the human brain is bigger)? How sensitive is your result to your estimations of the approximate dimensions of a human brain and a mouse brain?

56. Finding the Right Dose We know from our dimensional analysis that if an object maintains its shape but changes its size, its area changes as the square of its length and its volume changes as the cube of its length. Suppose you are a parent and your child is sick and has to take some medicine. You have taken this medicine previously and you know its dose for you. You are 5′10″ tall and weigh 180 lb, and your child is 2′11″ tall and weighs 30 lb. Estimate an appropriate dosage for your child's medicine in the following cases. Be sure to discuss your reasoning.

(a) The medicine is one that will enter the child's bloodstream and reach every cell in the body. Your dose is 250 mg.
(b) The medicine is one that is meant to coat the child's throat. Your dose is 15 ml.

57. Ping-Pong Ball Packing Estimate how many Ping-Pong balls it would take to fill your classroom (assuming all the doors and windows are closed).

58. Feeding the Cougar When visiting the Como Park Zoo in St. Paul, Minnesota, with my young grandson, we encountered the sign shown at the right on the cage of the mountain lion. The detailed numbers surprised me. The amount of food given to the cat was specified to the tenth of a gram and the average cat's weight was specified to within 10 grams—about 1/3 of an ounce. This seemed to be overly precise. Can you figure out what they were trying to say and what a plausible accuracy might be for those two numbers—the amount of food given and the average cat's weight?

COUGAR
North America

Natural Diet:	Hoofed animals, small animals
Zoo diet:	1.3608 kg. commercially prepared diet for large cats, six days a week
Average Weight:	90.72 kg.
Average Lifespan:	20 years

The cougar is also called mountain lion or puma.
It is the only large cat at Como Zoo that purrs.
Cougars are very solitary animals. They are seldom seen by humans.

FIGURE 1-22 ■ Problem 58.

59. Blowing Off the Units. Throughout your physics course, your instructor will expect you to be careful with the units in your calculations. Yet, some students tend to neglect them and just trust that they always work out properly. Maybe this real-world example will keep you from such a sloppy habit.

On July 23, 1983, Air Canada Flight 143 was being readied for its long trip from Montreal to Edmonton when the flight crew asked the ground crew to determine how much fuel was already onboard the airplane. The flight crew knew that they needed to begin the trip with 22 300 kg of fuel. They knew that amount in kilograms because Canada had recently switched to the metric system: previously fuel had been measured in pounds. The ground crew could measure the onboard fuel only in liters, which they reported as 7 682 L. Thus, to determine how much fuel was onboard and how much additional fuel must be added, the flight crew asked the ground crew for the conversion factor from liters to kilograms of fuel. The response was 1.77, which the flight crew used (1.77 kg corresponds to 1 L). (a) How many kilograms of fuel did the flight crew think they had? (In this problem, take all the given data as being exact.) (b) How many liters did they ask to be added to the airplane?

Unfortunately, the response from the ground crew was based on pre-metric habits—the number 1.77 was actually the conversion factor from liters to pounds of fuel (1.77 lb corresponds to 1 L). (c) How many kilograms of fuel were actually onboard? (Except for the given 1.77, use four significant figures for other conversion factors.) (d) How many liters of additional fuel were actually needed? (e) When the airplane left Montreal, what percentage of the required fuel did it actually have?

On route to Edmonton, at an altitude of 7.9 km, the airplane ran out of fuel and began to fall. Although the airplane then had no power, the pilot somehow managed to put it into a downward glide. However, the nearest working airport was too far to reach by only gliding, so the pilot somehow angled the glide toward an old nonworking airport.

Unfortunately, the runway at that airport had been converted to a track for race cars, and a steel barrier had been constructed across it. Fortunately, as the airplane hit the runway, the front landing gear collapsed, dropping the nose of the airplane onto the runway. The skidding slowed the airplane so that it stopped just short of the steel barrier, with stunned race drivers and fans looking on. All on board the airplane emerged safely. The point here is this: Take care of the units.

* Testudo is the statue of a terrapin (the university mascot) in front of the main library on the University of Maryland campus.

APPENDIX A — The International System of Units (SI)*

1 SI Base Units

1. The SI Base Units

Quantity	Name	Symbol	Definition
length	meter	m	". . . the length of the path traveled by light in vacuum in 1/299 792 458 of a second." (1983)
mass	kilogram	kg	". . . this prototype [a certain platinum–iridium cylinder] shall henceforth be considered to be the unit of mass." (1889)
time	second	s	". . . the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom." (1967)
electric current	ampere	A	". . . that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length." (1946)
thermodynamic temperature	kelvin	K	". . . the fraction 1/273.16 of the thermodynamic temperature of the triple point of water." (1967)
amount of substance	mole	mol	". . . the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12." (1971)
luminous intensity	candela	cd	". . . the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian." (1979)

2 The SI Supplementary Units

2. The SI Supplementary Units

Quantity	Name of Unit	Symbol
plane angle	radian	rad
solid angle	steradian	sr

*Adapted from "The International System of Units (SI)," National Bureau of Standards Special Publication 330, 2001 edition. The definitions above were adopted by the General Conference of Weights and Measures, an international body, on the dates shown. In this book we do not use the candela.

3 Some SI Derivations

3. Some SI Derived Units

Quantity	Name of Unit	Symbol	In Terms of other SI Units
area	square meter	m^2	
volume	cubic meter	m^3	
frequency	hertz	Hz	s^{-1}
mass density (density)	kilogram per cubic meter	kg/m^3	
speed, velocity	meter per second	m/s	
rotational velocity	radian per second	rad/s	
acceleration	meter per second per second	m/s^2	
rotational acceleration	radian per second per second	rad/s^2	
force	newton	N	$kg \cdot m/s^2$
pressure	pascal	Pa	N/m^2
work, energy, quantity of heat	joule	J	$N \cdot m$
power	watt	W	J/s
quantity of electric charge	coulomb	C	$A \cdot s$
potential difference, electromotive force	volt	V	W/A
electric field strength	volt per meter (or newton per coulomb)	V/m	N/C
electric resistance	ohm	Ω	V/A
capacitance	farad	F	$A \cdot s/V$
magnetic flux	weber	Wb	$V \cdot s$
inductance	henry	H	$V \cdot s/A$
magnetic flux density	tesla	T	Wb/m^2
magnetic field strength	ampere per meter	A/m	
entropy	joule per kelvin	J/K	
specific heat	joule per kilogram kelvin	$J/(kg \cdot K)$	
thermal conductivity	watt per meter kelvin	$W/(m \cdot K)$	
radiant intensity	watt per steradian	W/sr	

4 Mathematical Notation

Poorly chosen mathematical notation can be a source of considerable confusion to those trying to learn and to do physics. For example, ambiguity in the meaning of a mathematical symbol can prevent a reader from understanding the meaning of a crucial relationship. It is also difficult to solve problems when the symbols used ot represent different quantities are not distinctive. In this text we have taken special care to use mathematical notation in ways that allow important distinctions to be easily visible both on the printed page and in handwritten work.

An excellent starting point for clear mathematical notation is the U.S. National Institute of Standard and Technology's Special Publication 811 (SP 811), *Guide for the Use of the International System of Units (SI)*, available at http://physics.nist.gov/cuu/Units/bibliography.html. In addition to following the National Institute guidelines, we have made a number of systematic choices to facilitate the translation of printed notation into handwritten mathematics. For example:

- Instead of making vectors bold, vector quantities (even in one dimension) are denoted by an arrow above the symbol. So printed equations look like handwritten equations. Example: $\vec{v}$ rather than $\boldsymbol{v}$ is used to denote an instantaneous velocity.

- In general, each vector component has an explicit subscript denoting that it represents the component along a chosen coordinate axis. The one exception is the position vector, $\vec{r}$, whose components are simply written as x, y, and z. For example, $\vec{r} = x\hat{\imath} + y\hat{\jmath} + z\hat{k}$, whereas, $\vec{v} = v_x\hat{\imath} + v_y\hat{\jmath} + v_z\hat{k}$.
- To emphasize the distinction between a vector's components and its magnitude, we write the magnitude of a vector, such as $\vec{F}$, as $|\vec{F}|$. However, when it is obvious that a magnitude is being described, we use the plain symbol (such as F with no coordinate subscript) to denote a vector's magnitude.
- We often choose to spell out the names of objects that are associated with mathematical variables—writing, for example, $\vec{v}_{\text{ball}}$ and not $\vec{v}_{\text{b}}$ for the velocity of a ball.
- Numerical subscripts most commonly denote sequential times, positions, velocities, and so on. For example, x_1 is the x-component of the position of some object at time t_1, whereas x_2 is the value of that parameter at some later time t_2. We have avoided using the subscript zero to denote initial values, as in x_0 to denote "the initial position along the x axis," to emphasize that *any* time can be chosen as the initial time for consideration of the subsequent time evolution of a system.
- To avoid confusing the numerical time sequence labels with object labels, we prefer to use capital letters as object labels. For example, we would label two particles A and B rather than 1 and 2. Thus, $\vec{p}_{\text{A}\,1}$ and $\vec{p}_{\text{B}\,1}$ would represent the translational momenta of two particles before a collision whereas $\vec{p}_{\text{A}\,2}$ and $\vec{p}_{\text{B}\,2}$ would be their momenta after a collision.
- To avoid excessively long strings of subscripts, we have made the unconventional choice to write all adjectival labels as *super*scripts. Thus, Newton's Second Law is written $\vec{F}^{\text{net}} = m\vec{a}$ whereas the sum of the forces acting on a certain object might be written as $\vec{F}^{\text{net}} = \vec{F}^{\text{grav}} + \vec{F}^{\text{app}}$. To avoid confusion with mathematical exponents, an adjectival label is never a single letter.
- Following a usage common in contemporary physics, the time average of a variable $\vec{v}$ is denoted as $\langle \vec{v} \rangle$ and not as $\vec{v}_{\text{avg}}$.
- Physical constants such as e, c, g, G, are all **positive** scalar quantities.

5 Significant Figures and the Precision of Numerical Results

Quoting the result of a calculation or a measurement to the correct number of significant figures is merely a way of telling your reader roughly how precise you believe the result to be. Quoting too many significant figures overstates the precision of your result and quoting too few implies less precision than the result may actually possess. So how many significant figures should you quote when reporting your result.

Determining Significant Figures

Before answering the question of how many significant figures to quote, we need to have a clear method for determining how many significant figures a reported number has. The standard method is quite simple:

> **METHOD FOR COUNTING SIGNIFICANT FIGURES:** Read the number from left to right, and count the first nonzero digit and all the digits (zero or not) to the right of it as significant.

Using this rule, 350 mm, 0.000350 km, and 0.350 m each has *three* significant figures. In fact, each of these numbers merely represents the same distance, expressed in different units. As you can see from this example, the number of *decimal places* that a number has is *not* the same as its number of *significant figures*. The first of these distances has zero decimal places, the second has six decimal places, and the third has three, yet all three of these numbers have three significant figures.

One consequence of this method is especially worth noting. Trailing zeros count as significant figures. For example, 2700 m/s has four significant figures. If you really meant it to have only three significant figures, you would have to write it either as 2.70 km/s (changing the unit) or 2.70×10^3 m/s (using scientific notation.)

A Simple Rule for Reporting Significant Figures in a Calculated Result

Now that you know how to count significant figures, how many should the result of a calculation have? A simple rule that will work in most calculations is:

> **SIGNIFICANT FIGURES IN A CALCULATED RESULT:** The common practice is to quote the result of a calculation to the number of significant figures of the *least* precise number used in the calculation.

Although this simple rule will often either understate or (less frequently) overstate the precision of a result, it still serves as a good rule-of-thumb for everyday numerical work. In introductory physics you will only rarely encounter data that are known to better than two, three, or four significant figures. This simple rule then tells you that you can't go very far wrong if you round off all your final results to three significant figures.

There are two situations in which the simple rule should *not* be applied to a calculation. One is when an exact number is involved in the calculation and another is when a calculation is done in parts so that intermediate results are used.

1. ***Using Exact Data*** There are some obvious situations in which a number used in a calculation is exact. Numbers based on counting items are exact. For example, if you are told that there are 5 people on an elevator, there are exactly 5 people, not 4.7 or 5.1. Another situation arises when a number is exact by definition. For example, the conversion factor 2.54 cm/inch does *not* have three significant figures because the inch is *defined* to be exactly 2.5400000 . . . cm. *Data that are known exactly should not be included when deciding which of the original data has the fewest significant figures*.
2. ***Significant Figures in Intermediate Results*** Only the final result at the end of your calculation should be rounded using the simple rule. Intermediate results should never be rounded. Spreadsheet software takes care of this for you, as does your calculator if you store your intermediate results in its memory rather than writing them down and then rekeying them. If you must write down intermediate results, keep a few more significant figures than your final result will have.

Understanding and Refining the Simple Significant Figure Rule

Quoting the result of a calculation or measurement to the correct number of significant figures is a way of indicating its precision. You need to understand what limits the precision of data before you fully understand how to use the simple rule or its exceptions.

Absolute Precision There are two ways of talking about precision. First there is *absolute precision*, which tells you explicitly the smallest scale division of the measurement. It's always quoted in the same units as the measured quantity. For example, saying "I measured the length of the table to the nearest centimeter" states the absolute precision of the measurement. The absolute precision tells you how many *decimal places* the measurement has; it alone does not determine the number of significant figures. Example: if a table is 235 cm long, then 1 cm of absolute precision translates into three significant figures. On the other hand, if a table is for a doll's house and is only 8 cm long, then the same 1 cm of absolute precision has only one significant figure.

Relative Precision Because of this problem with absolute precision, scientists often prefer to describe the precision of data *relative* to the size of the quantity being measured. To use the previous examples, the *relative precision* of the length of the real table in the previous example is 1 cm out of 235 cm. This is usually stated as a ratio (1 part in 235) or as a percentage ($1/235 = 0.004255 \approx 0.4\%$). In the case of the toy table, the same 1 cm of absolute precision yields a relative precision of only 1 part in 8 or $1/8 = 0.125 = 12.5\%$.

Inconsistencies between Significant Figures and Relative Precision There is an inconsistency that goes with using a certain number of significant figures to express relative precision. Quoted to the same number of significant figures, the relative precision of results can be quite different. For example, 13 cm and 94 cm both have two significant figures. Yet the first is specified to only 1 part in 13 or $1/13 \approx 10\%$, whereas the second is known to 1 part in 94 or $1/94 \approx 1\%$. This bias toward greater relative precision for results with larger first significant figures is one weakness of using significant figures to track the precision of calculated results. You can partially address this problem, by including one more significant figure than the simple rule suggests, when the final result of a calculation has a 1 as its first significant figure.

Multiplying and Dividing When multiplying or dividing numbers, the *relative* precision of the result cannot exceed that of the least precise number used. Since the number of significant figures in the result tells us its relative precision, the simple rule is all that you need when you multiply or divide. For example, the area of a strip of paper of measured size is 280 cm by 2.5 cm would be correctly reported, according to the simple rule, as 7.0×10^2 cm^2. This result has only two significant figures since the less precise measurement, 2.5 cm, that went into the calculation had only two significant figures. Reporting this result as 700 cm^2 would not be correct since this result has three significant figures, exceeding the relative precision of the 2.5 cm measurement.

Addition and Subtraction When adding or subtracting, you line up the decimal points before you add or subtract. This means that it's the *absolute* precision of the least precise number that limits the precision of the sum or the difference. This can lead to some exceptions to the simple rule. For example, adding 957 cm and 878 cm yields 1835 cm. Here the result is reliable to an absolute precision of about 1 cm since both of the original distances had this reliability. But the result then has four significant figures whereas each of the original numbers had only three. If, on the other hand, you take the difference between these two distances you get 79 cm. The difference is still reliable to about 1 cm, but that absolute precision now translates into only two significant figures worth of relative precision. So, you should be careful when adding or subtracting, since addition can actually increase the relative precision of your result and, more important, subtraction can reduce it.

Evaluating Functions What about the evaluation of functions? For example, how many significant figures does the $\sin(88.2°)$ have? You can use your calculator to answer this question. First use your calculator to note that $\sin(88.2°) = 0.999506$. Now add 1 to the least significant decimal place of the argument of the function and evaluate it again. Here this gives $\sin(88.3°) = 0.999559$. Take the last significant figure in the result to be *the first one from the left that changed* when you repeated the calculation. In this example the first digit that changed was the 0; it became a 5 (the second 5) in the recalculation. So, using the empirical approach gives you five significant figures.

APPENDIX B

Some Fundamental Constants of Physics*

Constant	Symbol	Computational Value	Best (1998) Value	
			Value[a]	Uncertainty[b]
Speed of light in a vacuum	c	3.00×10^{8} m/s	2.997 924 58	exact
Elementary charge	e	1.60×10^{-19} C	1.602 176 462	0.039
Gravitational constant	G	6.67×10^{-11} m^3/s$^2 \cdot$ kg	6.673	1500
Universal gas constant	R	8.31 J/mol $\cdot$ K	8.314 472	1.7
Avogadro constant	N_A	6.02×10^{23} mol^{-1}	6.022 141 99	0.079
Boltzmann constant	k_B	1.38×10^{-23} J/K	1.380 650 3	1.7
Stefan–Boltzmann constant	σ	5.67×10^{-8} W/m$^2 \cdot$ K^4	5.670 400	7.0
Molar volume of ideal gas at STP[d]	V_m	2.27×10^{-2} m^3/mol	2.271 098 1	1.7
Electric constant (permittivity)	ϵ_0	8.85×10^{-12} C^2/N $\cdot$ m^2	8.854 187 817 62	exact
Coulomb constant	$k = 1/4\pi\epsilon_0$	8.99×10^{9} N $\cdot$ m^2/C^2	8.987 551 787	5×10^{-10}
Magnetic constant (permeability)	μ_0	1.26×10^{-6} N/A^2	1.256 637 061 43	exact
Planck constant	h	6.63×10^{-34} J $\cdot$ s	6.626 068 76	0.078
Electron mass[c]	m_e	9.11×10^{-31} kg	9.109 381 88	0.079
		5.49×10^{-4} u	5.485 799 110	0.0021
Proton mass[c]	m_p	1.67×10^{-27} kg	1.672 621 58	0.079
		1.0073 u	1.007 276 466 88	$1.3 \times .10^{-4}$
Ratio of proton mass to electron mass	m_p/m_e	1840	1836.152 667 5	0.0021
Electron charge-to-mass ratio	e/m_e	1.76×10^{11} C/kg	1.758 820 174	0.040
Neutron mass[c]	m_n	1.68×10^{-27} kg	1.674 927 16	0.079
		1.0087 u	1.008 664 915 78	5.4×10^{-4}
Hydrogen atom mass[c]	m_{1H}	1.0078 u	1.007 825 031 6	0.0005
Deuterium atom mass[c]	m_{2H}	2.0141 u	2.014 101 777 9	0.0005
Helium atom mass[c]	m_{4He}	4.0026 u	4.002 603 2	0.067
Muon mass	m_μ	1.88×10^{-28} kg	1.883 531 09	0.084
Electron magnetic moment	μ_e	9.28×10^{-24} J/T	9.284 763 62	0.040
Proton magnetic moment	μ_p	1.41×10^{-26} J/T	1.410 606 663	0.041
Bohr magneton	μ_B	9.27×10^{-24} J/T	9.274 008 99	0.040
Nuclear magneton	μ_N	5.05×10^{-27} J/T	5.050 783 17	0.040
Bohr radius	r_B	5.29×10^{-11} m	5.291 772 083	0.0037
Rydberg constant	R	1.10×10^{7} m^{-1}	1.097 373 156 854 8	7.6×10^{-6}
Electron Compton wavelength	λ_C	2.43×10^{-12} m	2.426 310 215	0.0073

[a] Values given in this column should be given the same unit and power of 10 as the computational value.
[b] Parts per million.
[c] Masses given in u are in unified atomic mass units, where $1 \text{ u} = 1.660\,538\,73 \times 10^{-27}$ kg.
[d] STP means standard temperature and pressure: 0°C and 1.0 atm (0.1 MPa).

*The values in this table were selected from the 1998 CODATA recommended values (www.physics.nist.gov).

APPENDIX C

Some Astronomical Data

Some Distances from Earth			
To the Moon*	3.82×10^8 m	To the center of our galaxy	2.2×10^{20} m
To the Sun*	1.50×10^{11} m	To the Andromeda Galaxy	2.1×10^{22} m
To the nearest star (Proxima Centauri)	4.04×10^{16} m	To the edge of the observable universe	$\sim 10^{26}$ m

* Mean distance.

The Sun, Earth, and the Moon

Property	Unit	Sun		Earth	Moon
Mass	kg	1.99×10^{30}		5.98×10^{24}	7.36×10^{22}
Mean radius	m	6.96×10^8		6.37×10^6	1.74×10^6
Mean density	kg/m^3	1410		5520	3340
Free-fall acceleration at the surface	m/s^2	274		9.81	1.67
Escape velocity	km/s	618		11.2	2.38
Period of rotation[a]	—	37 d at poles[b]	26 d at equator[b]	23 h 56 min	27.3 d
Radiation power[c]	W	3.90×10^{26}			

[a] Measured with respect to the distant stars, [b] The Sun, a ball of gas, does not rotate as a rigid body; [c] Just outside Earth's atmosphere solar energy is received, assuming normal incidence, at the rate of 1340 W/m^2.

Some Properties of the Planets

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Mean distance from Sun, 10^6 km	57.9	108	150	228	778	1430	2870	4500	5900
Period of revolution, y	0.241	0.615	1.00	1.88	11.9	29.5	84.0	165	248
Period of rotation,[a] d	58.7	-243[b]	0.997	1.03	0.409	0.426	-0.451[b]	0.658	6.39
Orbital speed, km/s	47.9	35.0	29.8	24.1	13.1	9.64	6.81	5.43	4.74
Equatorial diameter, km	4880	12 100	12 800	6790	143 000	120 000	51 800	49 500	2300
Mass (Earth = 1)	0.0558	0.815	1.000	0.107	318	95.1	14.5	17.2	0.002
Surface value of g,[c] m/s^2	3.78	8.60	9.78	3.72	22.9	9.05	7.77	11.0	0.5
Escape velocity,[c] km/s	4.3	10.3	11.2	5.0	59.5	35.6	21.2	23.6	1.1

[a] Measured with respect to the distant stars.
[b] Venus and Uranus rotate opposite their orbital motion.
[c] Gravitational acceleration measured at the planet's equator.

APPENDIX D

Conversion Factors

Conversion factors may be read directly from these tables. For example, 1 degree $= 2.778 \times 10^{-3}$ revolutions, so $16.7° = 16.7 \times 2.778 \times 10^{-3}$ rev. The SI units are fully capitalized. Adapted in part from G. Shortley and D. Williams, *Elements of Physics*, 1971, Prentice-Hall, Englewood Cliffs, N.J.

Solid Angle

1 sphere $= 4\pi$ steradians $= 12.57$ steradians

Plane Angle

	°	′	″	RADIAN	rev
1 degree =	1	60	3600	1.745×10^{-2}	2.778×10^{-3}
1 minute =	1.667×10^{-2}	1	60	2.909×10^{-4}	4.630×10^{-5}
1 second =	2.778×10^{-4}	1.667×10^{-2}	1	4.848×10^{-6}	7.716×10^{-7}
1 RADIAN =	57.30	3438	2.063×10^{5}	1	0.1592
1 revolution =	360	2.16×10^{4}	1.296×10^{6}	6.283	1

Length

	cm	METER	km	in.	ft	mi
1 centimeter =	1	10^{-2}	10^{-5}	0.3937	3.281×10^{-2}	6.214×10^{-6}
1 METER =	100	1	10^{-3}	39.37	3.281	6.214×10^{-4}
1 kilometer =	10^{5}	1000	1	3.937×10^{4}	3281	0.6214
1 inch =	2.540	2.540×10^{-2}	2.540×10^{-5}	1	8.333×10^{-2}	1.578×10^{-5}
1 foot =	30.48	0.3048	3.048×10^{-4}	12	1	1.894×10^{-4}
1 mile =	1.609×10^{5}	1609	1.609	6.336×10^{4}	5280	1

1 angström $= 10^{-10}$ m
1 nautical mile $= 1852$ m $= 1.151$ miles $= 6076$ ft
1 fermi $= 10^{-15}$ m
1 light-year $= 9.460 \times 10^{12}$ km
1 parsec $= 3.084 \times 10^{13}$ km
1 fathom $= 6$ ft
1 Bohr radius $= 5.292 \times 10^{-11}$ m
1 yard $= 3$ ft
1 rod $= 16.5$ ft
1 mil $= 10^{-3}$ in.
1 nm $= 10^{-9}$ m

Area

	METER²	cm²	ft²	in.²
1 SQUARE METER =	1	10^{4}	10.76	1550
1 square centimeter =	10^{-4}	1	1.076×10^{-3}	0.1550
1 square foot =	9.290×10^{-2}	929.0	1	144
1 square inch =	6.452×10^{-4}	6.452	6.944×10^{-3}	1

key: 1 square mile $= 2.788 \times 10^{7}$ ft² $=$ 640 acres; 1 barn $= 10^{-28}$ m²; 1 acre $= 43\,560$ ft²; 1 hectare $= 10^{4}$ m² $= 2.471$ acres.

Volume

	METER³	cm³	L	ft³	in.³
1 CUBIC METER =	1	10^{6}	1000	35.31	6.102×10^{4}
1 cubic centimeter =	10^{-6}	1	1.000×10^{-3}	3.531×10^{-5}	6.102×10^{-2}
1 liter =	1.000×10^{-3}	1000	1	3.531×10^{-2}	61.02
1 cubic foot =	2.832×10^{-2}	2.832×10^{4}	28.32	1	1728
1 cubic inch =	1.639×10^{-5}	16.39	1.639×10^{-2}	5.787×10^{-4}	1

key: 1 U.S. fluid gallon $=$ 4 U.S. fluid quarts $=$ 8 U.S. pints $=$ 128 U.S. fluid ounces $=$ 231 in.³ 1 British imperial gallon $= 277.4$ in.³ $= 1.201$ U.S. fluid gallons.

Mass

Quantities in the colored areas are not mass units but are often used as such. When we write, for example, 1 kg "=" 2.205 lb, this means that a kilogram is a *mass* that *weighs* 2.205 pounds at a location where *g* has the standard value of 9.80665 m/s^2.

g	KILOGRAM	slug	u	oz	lb	ton
1 gram = 1	0.001	6.852×10^{-5}	6.022×10^{23}	3.527×10^{-2}	2.205×10^{-3}	1.102×10^{-6}
1 KILOGRAM = 1000	1	6.852×10^{-2}	6.022×10^{26}	35.27	2.205	1.102×10^{-3}
1 slug = 1.459×10^{4}	14.59	1	8.786×10^{27}	514.8	32.17	1.609×10^{-2}
1 atomic mass unit = 1.661×10^{-24}	1.661×10^{-27}	1.138×10^{-28}	1	5.857×10^{-26}	3.662×10^{-27}	1.830×10^{-30}
1 ounce = 28.35	2.835×10^{-2}	1.943×10^{-3}	1.718×10^{25}	1	6.250×10^{-2}	3.125×10^{-5}
1 pound = 453.6	0.4536	3.108×10^{-2}	2.732×10^{26}	16	1	0.0005
1 ton = 9.072×10^{5}	907.2	62.16	5.463×10^{29}	3.2×10^{4}	2000	1

1 metric ton = 1000 kg

Time

y	d	h	min	SECOND
1 year = 1	365.25	8.766×10^{3}	5.259×10^{5}	3.156×10^{7}
1 day = 2.738×10^{-3}	1	24	1440	8.640×10^{4}
1 hour = 1.141×10^{-4}	4.167×10^{-2}	1	60	3600
1 minute = 1.901×10^{-6}	6.944×10^{-4}	1.667×10^{-2}	1	60
1 SECOND = 3.169×10^{-8}	1.157×10^{-5}	2.778×10^{-4}	1.667×10^{-2}	1

Speed

ft/s	km/h	METER/SECOND	mi/h	cm/s
1 foot per second = 1	1.097	0.3048	0.6818	30.48
1 kilometer per hour = 0.9113	1	0.2778	0.6214	27.78
1 METER per SECOND = 3.281	3.6	1	2.237	100
1 mile per hour = 1.467	1.609	0.4470	1	44.70
1 centimeter per second = 3.281×10^{-2}	3.6×10^{-2}	0.01	2.237×10^{-2}	1

1 knot = 1 nautical mi/h = 1.688 ft/s   1 mi/min = 88.00 ft/s = 60.00 mi/h

Force

dyne	NEWTON	lb	pdl
1 dyne = 1	10^{-5}	2.248×10^{-6}	7.233×10^{-5}
1 NEWTON = 10^{5}	1	0.2248	7.233
1 pound = 4.448×10^{5}	4.448	1	32.17
1 poundal = 1.383×10^{4}	0.1383	3.108×10^{-2}	1

1 ton = 2000 lb

Pressure

atm	dyne/cm^2	inch of water	cm Hg	PASCAL	lb/in.^{2}	lb/ft^2
1 atmosphere = 1	1.013×10^6	406.8	76	1.013×10^5	14.70	2116
1 dyne per centimeter^2 = 9.869×10^{-7}	1	4.015×10^{-4}	7.501×10^{-5}	0.1	1.405×10^{-5}	2.089×10^{-3}
1 inch of water[a] at 4°C = 2.458×10^{-3}	2491	1	0.1868	249.1	3.613×10^{-2}	5.202
1 centimeter of mercury[a] at 0°C = 1.316×10^{-2}	1.333×10^4	5.353	1	1333	0.1934	27.85
1 PASCAL = 9.869×10^{-6}	10	4.015×10^{-3}	7.501×10^{-4}	1	1.450×10^{-4}	2.089×10^{-2}
1 pound per inch^2 = 6.805×10^{-2}	6.895×10^4	27.68	5.171	6.895×10^3	1	144
1 pound per foot^2 = 4.725×10^{-4}	478.8	0.1922	3.591×10^{-2}	47.88	6.944×10^{-3}	1

[a] Where the acceleration of gravity has the standard value of 9.80665 m/s^2.

1 bar = 10^6 dyne/cm^2 = 0.1 MPa   1 millibar = 10^3 dyne/cm^2 = 10^2 Pa   1 torr = 1 mm Hg

Energy, Work, Heat

	Btu	erg	ft · lb	hp · h	JOULE	cal	kW · h	eV	MeV
1 British thermal unit =	1	1.055×10^{10}	777.9	3.929×10^{-4}	1055	252.0	2.930×10^{-4}	6.585×10^{21}	6.585×10^{15}
1 erg =	9.481×10^{-11}	1	7.376×10^{-8}	3.725×10^{-14}	10^{-7}	2.389×10^{-8}	2.778×10^{-14}	6.242×10^{11}	6.242×10^5
1 foot-pound =	1.285×10^{-3}	1.356×10^7	1	5.051×10^{-7}	1.356	0.3238	3.766×10^{-7}	8.464×10^{18}	8.464×10^{12}
1 horsepower-hour =	2545	2.685×10^{13}	1.980×10^6	1	2.685×10^6	6.413×10^5	0.7457	1.676×10^{25}	1.676×10^{19}
1 JOULE =	9.481×10^{-4}	10^7	0.7376	3.725×10^{-7}	1	0.2389	2.778×10^{-7}	6.242×10^{18}	6.242×10^{12}
1 calorie =	3.969×10^{-3}	4.186×10^7	3.088	1.560×10^{-6}	4.186	1	1.163×10^{-6}	2.613×10^{19}	2.613×10^{13}
1 kilowatt hour =	3413	3.600×10^{13}	2.655×10^6	1.341	3.600×10^6	8.600×10^5	1	2.247×10^{25}	2.247×10^{19}
1 electron-volt =	1.519×10^{-22}	1.602×10^{-12}	1.182×10^{-19}	5.967×10^{-26}	1.602×10^{-19}	3.827×10^{-20}	4.450×10^{-26}	1	10^{-6}
1 million electron-volts =	1.519×10^{-16}	1.602×10^{-6}	1.182×10^{-13}	5.967×10^{-20}	1.602×10^{-13}	3.827×10^{-14}	4.450×10^{-20}	10^{-6}	1

Power

Btu/h	ft · lb/s	hp	cal/s	kW	WATT
1 British thermal unit per hour = 1	0.2161	3.929×10^{-4}	6.998×10^{-2}	2.930×10^{-4}	0.2930
1 foot-pound per second = 4.628	1	1.818×10^{-3}	0.3239	1.356×10^{-3}	1.356
1 horsepower = 2545	550	1	178.1	0.7457	745.7
1 calorie per second = 14.29	3.088	5.615×10^{-3}	1	4.186×10^{-3}	4.186
1 kilowatt = 3413	737.6	1.341	238.9	1	1000
1 WATT = 3.413	0.7376	1.341×10^{-3}	0.2389	0.001	1

Magnetic Field

gauss	TESLA	milligauss
1 gauss = 1	10^{-4}	1000
1 TESLA = 10^4	1	10^7
1 milligauss = 0.001	10^{-7}	1

1 tesla = 1 weber/meter^2

Magnetic Flux

maxwell	WEBER
1 maxwell = 1	10^{-8}
1 WEBER = 10^8	1

APPENDIX E

Mathematical Formulas

Geometry

Circle of radius r: circumference $= 2\pi r$; area $= \pi r^2$.

Sphere of radius r: area $= 4\pi r^2$; volume $= \frac{4}{3}\pi r^3$.

Right circular cylinder of radius r and height h:
area $= 2\pi r^2 + 2\pi rh$; volume $= \pi r^2 h$.

Triangle of base a and altitude h: area $= \frac{1}{2}ah$.

Quadratic Formula

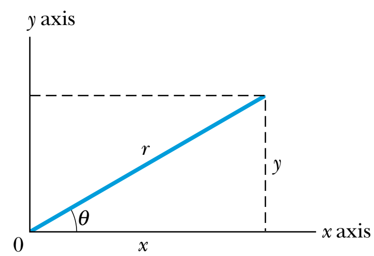
If $ax^2 + bx + c = 0$, then $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$.

Trigonometric Functions of Angle θ

$$\sin\theta = \frac{y}{r} \qquad \cos\theta = \frac{x}{r}$$

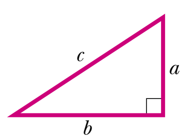
$$\tan\theta = \frac{y}{x} \qquad \cot\theta = \frac{x}{y}$$

$$\sec\theta = \frac{r}{x} \qquad \csc\theta = \frac{r}{y}$$



Pythagorean Theorem

In this right triangle,
$a^2 + b^2 = c^2$



Triangles

Angles are A, B, C

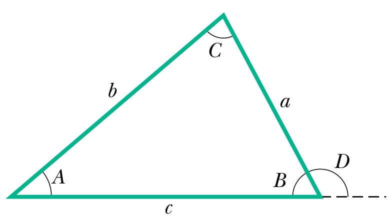
Opposite sides are a, b, c

Angles $A + B + C = 180°$

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$$

$c^2 = a^2 + b^2 - 2ab\cos C$

Exterior angle $D = A + C$



Mathematical Signs and Symbols

$=$ equals

$\approx$ equals approximately

$\sim$ is the order of magnitude of

$\neq$ is not equal to

$\equiv$ is identical to, is defined as

$>$ is greater than ($\gg$ is much greater than)

$<$ is less than ($\ll$ is much less than)

$\geq$ is greater than or equal to (or, is no less than)

$\leq$ is less than or equal to (or, is no more than)

$\pm$ plus or minus

$\propto$ is proportional to

Σ the sum of

$\langle x \rangle$ the average value of x

Trigonometric Identities

$\sin(90° - \theta) = \cos\theta$

$\cos(90° - \theta) = \sin\theta$

$\sin\theta/\cos\theta = \tan\theta$

$\sin^2\theta + \cos^2\theta = 1$

$\sec^2\theta - \tan^2\theta = 1$

$\csc^2\theta - \cot^2\theta = 1$

$\sin 2\theta = 2\sin\theta\cos\theta$

$\cos 2\theta = \cos^2\theta - \sin^2\theta = 2\cos^2\theta - 1 = 1 - 2\sin^2\theta$

$\sin(\alpha \pm \beta) = \sin\alpha\cos\beta \pm \cos\alpha\sin\beta$

$\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta$

$$\tan(\alpha \pm \beta) = \frac{\tan\alpha \pm \tan\beta}{1 \mp \tan\alpha\tan\beta}$$

$\sin\alpha \pm \sin\beta = 2\sin\frac{1}{2}(\alpha \pm \beta)\cos\frac{1}{2}(\alpha \mp \beta)$

$\cos\alpha + \cos\beta = 2\cos\frac{1}{2}(\alpha + \beta)\cos\frac{1}{2}(\alpha - \beta)$

$\cos\alpha - \cos\beta = -2\sin\frac{1}{2}(\alpha + \beta)\sin\frac{1}{2}(\alpha - \beta)$

Binomial Theorem

$$(1 + x)^n = 1 + \frac{nx}{1!} + \frac{n(n-1)x^2}{2!} + \cdots \qquad (x^2 < 1)$$

Exponential Expansion

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$$

Logarithmic Expansion

$$\ln(1 + x) = x - \tfrac{1}{2}x^2 + \tfrac{1}{3}x^3 - \cdots \qquad (|x| < 1)$$

Trigonometric Expansions (θ in radians)

$$\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \cdots$$

$$\cos\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \cdots$$

$$\tan\theta = \theta + \frac{\theta^3}{3} + \frac{2\theta^5}{15} + \cdots$$

Cramer's Rule

Two simultaneous equations in unknowns x and y,

$$a_1x + b_1y = c_1 \quad \text{and} \quad a_2x + b_2y = c_2,$$

have the solutions

$$x = \frac{\begin{vmatrix} c_1 & b_1 \\ c_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{c_1b_2 - c_2b_1}{a_1b_2 - a_2b_1}$$

and

$$y = \frac{\begin{vmatrix} a_1 & c_1 \\ a_2 & c_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{a_1c_2 - a_2c_1}{a_1b_2 - a_2b_1}.$$

Products of Vectors

Let $\hat{\mathrm{i}}$, $\hat{\mathrm{j}}$, and $\hat{\mathrm{k}}$ and be unit vectors in the x, y, and z directions. Then

$$\hat{\mathrm{i}} \cdot \hat{\mathrm{i}} = \hat{\mathrm{j}} \cdot \hat{\mathrm{j}} = \hat{\mathrm{k}} \cdot \hat{\mathrm{k}} = 1, \qquad \hat{\mathrm{i}} \cdot \hat{\mathrm{j}} = \hat{\mathrm{j}} \cdot \hat{\mathrm{k}} = \hat{\mathrm{k}} \cdot \hat{\mathrm{i}} = 0,$$
$$\hat{\mathrm{i}} \times \hat{\mathrm{i}} = \hat{\mathrm{j}} \times \hat{\mathrm{j}} = \hat{\mathrm{k}} \times \hat{\mathrm{k}} = 0,$$
$$\hat{\mathrm{i}} \times \hat{\mathrm{j}} = \hat{\mathrm{k}}, \qquad \hat{\mathrm{j}} \times \hat{\mathrm{k}} = \hat{\mathrm{i}}, \qquad \hat{\mathrm{k}} \times \hat{\mathrm{i}} = \hat{\mathrm{j}}.$$

Any vector $\vec{a}$ with components a_x, a_y, and a_z along the x, y, and z axes can be written as

$$\vec{a} = a_x\hat{\mathrm{i}} + a_y\hat{\mathrm{j}} + a_z\hat{\mathrm{k}}.$$

Let $\vec{a}$, $\vec{b}$, and $\vec{c}$ be arbitrary vectors with magnitudes a, b, and c. Then

$$\vec{a} \times (\vec{b} + \vec{c}) = (\vec{a} \times \vec{b}) + (\vec{a} \times \vec{c})$$
$$(s\vec{a}) \times \vec{b} = \vec{a} \times (s\vec{b}) = s(\vec{a} \times \vec{b}) \quad (s = \text{a scalar}).$$

Let θ be the smaller of the two angles between $\vec{a}$ and $\vec{b}$. Then

$$\vec{a} \cdot \vec{b} = \vec{b} \cdot \vec{a} = a_xb_x + a_yb_y + a_zb_z = ab\cos\theta$$

$$\vec{a} \times \vec{b} = -\vec{b} \times \vec{a} = \begin{vmatrix} \hat{\mathrm{i}} & \hat{\mathrm{j}} & \hat{\mathrm{k}} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$
$$= \hat{\mathrm{i}}\begin{vmatrix} a_y & a_z \\ b_y & b_z \end{vmatrix} - \hat{\mathrm{j}}\begin{vmatrix} a_x & a_z \\ b_x & b_z \end{vmatrix} + \hat{\mathrm{k}}\begin{vmatrix} a_x & a_y \\ b_x & b_y \end{vmatrix}$$
$$= (a_yb_z - b_ya_z)\hat{\mathrm{i}} + (a_zb_x - b_za_x)\hat{\mathrm{j}} + (a_xb_y - b_xa_y)\hat{\mathrm{k}}$$
$$|\vec{a} \times \vec{b}| = ab\sin\theta$$
$$\vec{a} \cdot (\vec{b} \times \vec{c}) = \vec{b} \cdot (\vec{c} \times \vec{a}) = \vec{c} \cdot (\vec{a} \times \vec{b})$$
$$\vec{a} \times (\vec{b} \times \vec{c}) = (\vec{a} \cdot \vec{c})\vec{b} - (\vec{a} \cdot \vec{b})\vec{c}$$

Derivatives and Integrals

In what follows, the letters u and v stand for any functions of x, and a and m are constants. To each of the indefinite integrals should be added an arbitrary constant of integration. The *Handbook of Chemistry and Physics* (CRC Press Inc.) gives a more extensive tabulation.

Derivatives

1. $\dfrac{dx}{dx} = 1$

2. $\dfrac{d}{dx}(au) = a\dfrac{du}{dx}$

3. $\dfrac{d}{dx}(u + v) = \dfrac{du}{dx} + \dfrac{dv}{dx}$

4. $\dfrac{d}{dx}x^m = mx^{m-1}$

5. $\dfrac{d}{dx}\ln x = \dfrac{1}{x}$

6. $\dfrac{d}{dx}(uv) = u\dfrac{dv}{dx} + v\dfrac{du}{dx}$

7. $\dfrac{d}{dx}e^x = e^x$

8. $\dfrac{d}{dx}\sin x = \cos x$

9. $\dfrac{d}{dx}\cos x = -\sin x$

10. $\dfrac{d}{dx}\tan x = \sec^2 x$

11. $\dfrac{d}{dx}\cot x = -\csc^2 x$

12. $\dfrac{d}{dx}\sec x = \tan x \sec x$

13. $\dfrac{d}{dx}\csc x = -\cot x \csc x$

14. $\dfrac{d}{dx}e^u = e^u\dfrac{du}{dx}$

15. $\dfrac{d}{dx}\sin u = \cos u\dfrac{du}{dx}$

16. $\dfrac{d}{dx}\cos u = -\sin u\dfrac{du}{dx}$

Integrals

1. $\int dx = x$

2. $\int au\, dx = a\int u\, dx$

3. $\int (u + v)\, dx = \int u\, dx + \int v\, dx$

4. $\int x^m dx = \dfrac{x^{m+1}}{m+1} \quad (m \neq -1)$

5. $\int \dfrac{dx}{x} = \ln|x|$

6. $\int u \dfrac{dv}{dx}\, dx = uv - \int v \dfrac{du}{dx}\, dx$

7. $\int e^x\, dx = e^x$

8. $\int \sin x\, dx = -\cos x$

9. $\int \cos x\, dx = \sin x$

10. $\int \tan x\, dx = \ln|\sec x|$

11. $\int \sin^2 x\, dx = \frac{1}{2}x - \frac{1}{4}\sin 2x$

12. $\int e^{-ax}\, dx = -\dfrac{1}{a} e^{-ax}$

13. $\int xe^{-ax}\, dx = -\dfrac{1}{a^2}(ax + 1)e^{-ax}$

14. $\int x^2 e^{-ax}\, dx = -\dfrac{1}{a^3}(a^2x^2 + 2ax + 2)e^{-ax}$

15. $\int_0^\infty x^n e^{-ax}\, dx = \dfrac{n!}{a^{n+1}}$

16. $\int_0^\infty x^{2n} e^{-ax^2}\, dx = \dfrac{1 \cdot 3 \cdot 5 \cdots (2n-1)}{2^{n+1}a^n}\sqrt{\dfrac{\pi}{a}}$

17. $\int \dfrac{dx}{\sqrt{x^2 + a^2}} = \ln(x + \sqrt{x^2 + a^2})$

18. $\int \dfrac{x\, dx}{(x^2 + a^2)^{3/2}} = -\dfrac{1}{(x^2 + a^2)^{1/2}}$

19. $\int \dfrac{dx}{(x^2 + a^2)^{3/2}} = \dfrac{x}{a^2(x^2 + a^2)^{1/2}}$

20. $\int_0^\infty x^{2n+1} e^{-ax^2}\, dx = \dfrac{n!}{2a^{n+1}} \quad (a > 0)$

21. $\int \dfrac{x\, dx}{x + d} = x - d\ln(x + d)$

APPENDIX F

Properties of Common Elements

All physical properties are for a pressure of 1 atm unless otherwise specified.

Element	Symbol	Atomic Number Z	Molar Mass, g/mol	Density, g/cm^3 at 20°C	Melting Point, °C	Boiling Point, °C	Specific Heat, J/(g · °C) at 25°C
Aluminum	Al	13	26.9815	2.699	660	2450	0.900
Antimony	Sb	51	121.75	6.691	630.5	1380	0.205
Argon	Ar	18	39.948	1.6626×10^{-3}	−189.4	−185.8	0.523
Arsenic	As	33	74.9216	5.78	817 (28 atm)	613	0.331
Barium	Ba	56	137.34	3.594	729	1640	0.205
Beryllium	Be	4	9.0122	1.848	1287	2770	1.83
Bismuth	Bi	83	208.980	9.747	271.37	1560	0.122
Boron	B	5	10.811	2.34	2030	—	1.11
Bromine	Br	35	79.909	3.12 (liquid)	−7.2	58	0.293
Cadmium	Cd	48	112.40	8.65	321.03	765	0.226
Calcium	Ca	20	40.08	1.55	838	1440	0.624
Carbon	C	6	12.01115	2.26	3727	4830	0.691
Cesium	Cs	55	132.905	1.873	28.40	690	0.243
Chlorine	Cl	17	35.453	3.214×10^{-3} (0°C)	−101	−34.7	0.486
Chromium	Cr	24	51.996	7.19	1857	2665	0.448
Cobalt	Co	27	58.9332	8.85	1495	2900	0.423
Copper	Cu	29	63.54	8.96	1083.40	2595	0.385
Fluorine	F	9	18.9984	1.696×10^{-3}(0°C)	−219.6	−188.2	0.753
Gadolinium	Gd	64	157.25	7.90	1312	2730	0.234
Gallium	Ga	31	69.72	5.907	29.75	2237	0.377
Germanium	Ge	32	72.59	5.323	937.25	2830	0.322
Gold	Au	79	196.967	19.32	1064.43	2970	0.131
Hafnium	Hf	72	178.49	13.31	2227	5400	0.144
Helium	He	2	4.0026	0.1664×10^{-3}	−269.7	−268.9	5.23
Hydrogen	H	1	1.00797	0.08375×10^{-3}	−259.19	−252.7	14.4
Indium	In	49	114.82	7.31	156.634	2000	0.233
Iodine	I	53	126.9044	4.93	113.7	183	0.218
Iridium	Ir	77	192.2	22.5	2447	(5300)	0.130
Iron	Fe	26	55.847	7.874	1536.5	3000	0.447
Krypton	Kr	36	83.80	3.488×10^{-3}	−157.37	−152	0.247
Lanthanum	La	57	138.91	6.189	920	3470	0.195
Lead	Pb	82	207.19	11.35	327.45	1725	0.129
Lithium	Li	3	6.939	0.534	180.55	1300	3.58
Magnesium	Mg	12	24.312	1.738	650	1107	1.03
Manganese	Mn	25	54.9380	7.44	1244	2150	0.481
Mercury	Hg	80	200.59	13.55	−38.87	357	0.138
Molybdenum	Mo	42	95.94	10.22	2617	5560	0.251
Neodymium	Nd	60	144.24	7.007	1016	3180	0.188

Element	**Symbol**	**Atomic Number Z**	**Molar Mass, g/mol**	**Density, g/cm^3 at 20°C**	**Melting Point, °C**	**Boiling Point, °C**	**Specific Heat, J/(g·°C) at 25°C**
Neon	Ne	10	20.183	0.8387×10^{-3}	−248.597	−246.0	1.03
Nickel	Ni	28	58.71	8.902	1453	2730	0.444
Niobium	Nb	41	92.906	8.57	2468	4927	0.264
Nitrogen	N	7	14.0067	1.1649×10^{-3}	−210	−195.8	1.03
Osmium	Os	76	190.2	22.59	3027	5500	0.130
Oxygen	O	8	15.9994	1.3318×10^{-3}	−218.80	−183.0	0.913
Palladium	Pd	46	106.4	12.02	1552	3980	0.243
Phosphorus	P	15	30.9738	1.83	44.25	280	0.741
Platinum	Pt	78	195.09	21.45	1769	4530	0.134
Plutonium	Pu	94	(244)	19.8	640	3235	0.130
Polonium	Po	84	(210)	9.32	254	—	—
Potassium	K	19	39.102	0.862	63.20	760	0.758
Radium	Ra	88	(226)	5.0	700	—	—
Radon	Rn	86	(222)	9.96×10^{-3} (0°C)	(−71)	−61.8	0.092
Rhenium	Re	75	186.2	21.02	3180	5900	0.134
Rubidium	Rb	37	85.47	1.532	39.49	688	0.364
Scandium	Sc	21	44.956	2.99	1539	2730	0.569
Selenium	Se	34	78.96	4.79	221	685	0.318
Silicon	Si	14	28.086	2.33	1412	2680	0.712
Silver	Ag	47	107.870	10.49	960.8	2210	0.234
Sodium	Na	11	22.9898	0.9712	97.85	892	1.23
Strontium	Sr	38	87.62	2.54	768	1380	0.737
Sulfur	S	16	32.064	2.07	119.0	444.6	0.707
Tantalum	Ta	73	180.948	16.6	3014	5425	0.138
Tellurium	Te	52	127.60	6.24	449.5	990	0.201
Thallium	Tl	81	204.37	11.85	304	1457	0.130
Thorium	Th	90	(232)	11.72	1755	(3850)	0.117
Tin	Sn	50	118.69	7.2984	231.868	2270	0.226
Titanium	Ti	22	47.90	4.54	1670	3260	0.523
Tungsten	W	74	183.85	19.3	3380	5930	0.134
Uranium	U	92	(238)	18.95	1132	3818	0.117
Vanadium	V	23	50.942	6.11	1902	3400	0.490
Xenon	Xe	54	131.30	5.495×10^{-3}	−111.79	−108	0.159
Ytterbium	Yb	70	173.04	6.965	824	1530	0.155
Yttrium	Y	39	88.905	4.469	1526	3030	0.297
Zinc	Zn	30	65.37	7.133	419.58	906	0.389
Zirconium	Zr	40	91.22	6.506	1852	3580	0.276

The values in parentheses in the column of molar masses are the mass numbers of the longest-lived isotopes of those elements that are radioactive. Melting points and boiling points in parentheses are uncertain. The data for gases are valid only when these are in their usual molecular state, such as H_2, He, O_2, Ne, etc. The specific heats of the gases are the values at constant pressure. *Primary source*: Adapted fron J. Emsley, *The Elements*, 3rd ed., 1998, Clarendon Press, Oxford (www.webelements.com). Data on newest elements are current.

APPENDIX G

Periodic Table of the Elements

Metals

Metalloids

Nonmetals

Alkali metals IA; Noble gases 0; Transition metals; Inner transition metals

THE HORIZONTAL PERIODS

Period	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57-71 *	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89-103 †	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Uua	112 Uub	113	114 Uuq	115	116	117	118

Inner transition metals

Lanthanide series *	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinide series †	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

The names of elements 104 through 109 (Rutherfordium, Dubnium, Seaborgium, Bohrium, Hassium, and Meitnerium, respectively) were adopted by the International Union of Pure and Applied Chemistry (IUPAC) in 1997. As of early 2004, the discovery of elements 110 through 115 have been reported in scientific journals. See www.webelements.com for the latest information and newest elements.

Answers to Reading Exercises and Odd-Numbered Problems

(Answers that involve a proof, graph, or otherwise lengthy solution are not included.)

Chapter 1

RE 1-1: Examples include second or hour, meter or inch, and gram or kilogram.

RE 1-2: A 12-inch ruler would more likely change less over time than your foot, especially if you are still growing.

RE 1-3: The length of one day or the time it takes for the earth to rotate 360° about its own axis is not constant, because the speed of the earth's rotation is slowly decreasing with time.

RE 1-4: (a) Since 24 h of time occurs for each 360° of rotation or 4 min for each degree of longitude or 240 s for each degree of longitude, 20 min and 13 s will relate to a rotation or longitude change of (1213 s)/(240 s/deg) = 5.05 degrees of longitude change. (b) If the clock is off by 2 min or 120 s, the longitude will be off by (120 s)/(240 s/degree) = 0.5 degrees of longitude. (c) 360° or one revolution relates to one circumference of length. Therefore $0.5°/360° = x/(24\,000$ nautical miles), or $x = 33.3$ nautical miles off course. Sailor beware!

RE 1-5: (a) If your watches are synchronized, you should measure the same time for the flash. For the same duration of time between the flash and thunder you both should have accurate watches and be located close to one another. (b) No, the 12 h (smaller) clock shows a time of 7:44 or a total elapsed time of 464 min since 12 o'clock. This is 464 min/(1440 min/day) = .322 day elapsed. The 10 h (larger) clock shows a time of 8.23 hours elapsed since 10 o'clock (12 o'clock on the other scale) or 8.23/(20 hr/day) = .412 day elapsed.

RE 1-6: One of many possible procedures would be to use the balance to determine the amount of clay equal to 1 kg. Divide the clay into 1000 equal volume pieces. Assuming the density of the clay is uniform, each clay piece now has a mass of 1 gram. Use these pieces with the balance and the object whose mass is to be determined to find its mass.

RE 1-7: (a) It is correct to write 1 min/60 s = 1 because 1 minute and 60 seconds are the same *length* of time. It is meaningless to say 1/60 = 1 when no units are specified. These numbers are not the same in the absence of the context of the units. (b) In terms of conversion factors and chain-link conversions, the number of minutes in a day is given by

$$1\text{ d} = (1\text{ d})\left(\frac{24\text{ h}}{1\text{ d}}\right)\left(\frac{60\text{ min}}{1\text{ h}}\right) = 1440\text{ m}.$$

RE 1-8: (a) 2. (b) Exact, if the cows were counted. (c) 6. Remember that the leading zeros don't count. (d) 7. Trailing zeros do count. (e) Exact, by definition.

RE 1-9: (a) 11. (b) Probably 3, we can't be sure. (c) 2.09×10^{10} ft. (d) 10^{10} ft (ten to the tenth feet).

RE 1-10: (a) You should keep all digits for intermediate results; thus you should use $A = 1.96\text{ cm}^2$ for calculating V. (b) 2.7 cm³; in this situation the answer can be to no more significant figures than the original data. (c) 2.8 cm³.

RE 1-11: (a) 27; (b) 198.0; (c) 0.6; (d) 0.9986, see *Evaluating Functions* in Appendix A, Section 5. (e) Since five is an exact number, the four significant numbers in the average length limits the answer to 10.67 m.

RE 1-12: (a) 0.01 s; (b) .01 s out of 1.78 s or .01/1.78 = 0.00562, or about 0.6%.

Problems

1. (a) 0.98 ft/ns; (b) 0.30 mm/ps. **3.** C, D, A, B, E; the important criterion is the constancy of the daily variation, not its magnitude. **5.** 0.12 AU/min **7.** 2.1 h. **9.** 1.21×10^{12} μs. **11.** (a) 160 rods; (b) 40 chains. **13.** (a) 4.00×10^4 km; (b) 5.10×10^8 km²; (c) 1.08×10^{12} km³. **15.** 1.9×10^{22} cm³. **17.** 1.1×10^3 acre-feet. **19.** 9.0×10^{49}. **21.** (a) 10^3 kg; (b) 158 kg/s. **23.** (a) 1.18×10^{-29} m³. **25.** 3.8 mg/s. **27.** 8×10^2 km. **29.** 6.0×10^{26}. **31.** (a) 60.8 W; (b) 43.3 Z. **33.** 89 km. **35.** $\approx 1 \times 10^{36}$. **37.** 700 to 1500. **39.** (a) 293 U.S. bushels; (b) 3.81×10^3 U.S. bushels. **41.** 9.4×10^{-3}. **43.** 5.95 km. **45.** 1.9×10^5 kg. **47.** 2×10^4 to 4×10^4. **49.** 10.7. **59.** (a) 13 597 kg; (b) 4917 L; (c) 6172 kg; (d) 20 075 L; (e) 45%

Chapter 2

RE 2-1: (b), (c), and (d).

RE 2-2: Correct order: (c), (b), and (a).

RE 2-3: Yes, the displacement can be positive as long as the particle moves to a less negative position.

RE 2-4: (a) Average velocity is the displacement divided by the total time $\langle v_x \rangle = 10$ mi/30 min = 0.33 mi/min due east. (b) Average speed is the total distance traveled divided by the total time $\langle s \rangle = 30$ mi/30 min = 1 mi/min. (c) The answers are different because the displacement is different from the total distance traveled in the 30 minute time period.

RE 2-5: Instantaneous speed. The speedometer only tells you the speed at which you are currently driving, not your acceleration or direction.

RE 2-6: (a) Remember that the velocity is the time derivative of the position equation. The velocity will be constant if it has no time dependence. Position equations 1 and 4 give a constant velocity. (b) The velocity is negative in equations 2 and 3.

RE 2-7: In returning to x_1 the total displacement $\Delta x = x_1 - x_1$ is zero. Since $\langle v_x \rangle = \Delta x/\Delta t$, the average velocity is also zero.

RE 2-8: (a) +, (b) −, (c) −, (d) +; remember that $\vec{a}$ will have the same direction as $\Delta\vec{v}$ or $\vec{v}_2 - \vec{v}_1$.

RE 2-9: The equations of Table 2-1 apply when a_x is constant. Take the second derivative of x with respect to t to find a_x. Only equations 1, 3 and 4 give a constant a_x ($a_x = 0$ is a constant).

Problems

1. 414 ms. **3.** (a) +40 km/h; (b) 40 km/h. **5.** (a) 73 km/h; (b) 68 km/h; (c) 70 km/h; (d) 0. **7.** (a) 0, −2, 0, 12 m; (b) +12 m; (c) +7 m/s. **9.** 1.4 m. **11.** (a) −6 m/s; (b) negative x direction; (c) 6 m/s; (d) first smaller, then zero, and then larger; (e) yes (t = 2s); (f) no. **13.** 100 m. **15.** (a) velocity squared; (b) acceleration; (c) m^2/s^2, m/s^2. **17.** 20 m/s^2, in the direction opposite to its initial velocity. **19.** (a) m/s^2, m/s^3; (b) 1.0 s; (c) 82 m; (d) −80 m; (e) 0, −12, −36, −72 m/s; (f) −6, −18, −30, −42 m/s^2. **21.** 0.10 m. **23.** (a) 1.6 m/s; (b) 18 m/s. **25.** (a) 3.1×10^6 s = 1.2 months; (b) 4.6×10^{13} m. **27.** 1.62×10^{15} m/s^2. **29.** 2.5 s. **31.** (a) 3.56 m/s^2; (b) 8.43 m/s. **33.** (a) 5.00 m/s; (b) 1.67 m/s^2; (c) 7.50 m. **35.** (a) 0.74 s; (b) −6.2 m/s^2. **37.** (a) 10.6 m; (b) 41.5 s. **39.** (a) 30 s; (b) 300 m. **41.** (a) 54 m, 18 m/s, −12 m/s^2; (b) 64 m at t = 4.0 s; (c) 24 m/s at t = 2.0 s; (d) −24 m/s^2; (e) 18 m/s. **49.** (a) 0.75 s; (b) 50 m. **57.** Since there is some latitude in what might be considered "the right answer" here, we have elected to mention some Web sites (current as of May 2002) where graphs for model rocket kinematics are shown: http://www.rocket-roar.com/rap/alt.html; http://mks.niobrara.com/altitude.html; http://www.boilerbay.com/rockets/; **59.** 40 m.

Chapter 3

RE 3-1: (a) The velocity of the cart on the carpet goes to zero at t = 1.1 s. (b) The velocity of the cart on the track at t = 1.1 s is approximately 0.65 m/s, so it still has (0.65 m/s/0.80 m/s) or 81% of its initial speed.

RE 3-2: (a) An elevator or car starting or stopping, or a merry-go-round moving at a constant speed. (b) The person feels heavy during startup and light during stopping. Objects, such as a marble, start to move with no apparent reason on the merry-go-round floor.

RE 3-3: (a) No acceleration: Sliding a block along a table with a small steady force or shoving on a huge object like a desk or car, etc., can result in either constant velocity motion or an inability to move the object (desk or car). (b) Acceleration: Pushing hard on a sliding block, pushing on a rolling ball, pushing or pulling someone on a vehicle with wheels, etc.

RE 3-4: You would attach one end of the rubber band to a post and hook the other end of the rubber band to a calibrated spring scale. Then you would record the unstretched length of the rubber band and the fact that the force on it is 0 N. Next you would pull on the rubber band with the spring scale until it reads 1 N and record the new length of the rubber band. Then you would repeat the process as the spring scale reads 2 N, 3 N, etc., recording the rubber-band length each time. In that way you can generate either a look-up table or a graph of force vs. rubber-band length. If greater precision is needed, you could take data for many more force-scale readings.

RE 3-5: (a) $\vec{F} = (-26\text{ N})\hat{\text{i}}$, $\vec{a} = (-0.42\text{ m/s}^2)\hat{\text{i}}$; (b) $m = F/a = 62$ kg; (c) 62 kg

RE 3-6: (a) The mass measurement in part (b) above uses the ratio of the force to acceleration and hence is the inertial mass. (b) We assumed that the student is on the surface of planet Earth and that the bathroom scale was calibrated for the same planet.

RE 3-7: In both cases (a) and (b) the acceleration is zero, therefore the net force must also be zero. This will require all three forces to add to zero as vectors. (a) This requires $\vec{F}_C$ to point to the left in the diagram with a magnitude of 2 N so $\vec{F}_C = (-2\text{ N})\hat{\text{i}}$. (b) Since the acceleration is also zero in this case, we still have $\vec{F}_C = (-2\text{ N})\hat{\text{i}}$.

RE 3-8: (a) Bottom right cart has a net force of −5 N, top left has +4 N, top right has −1 N, and bottom left has a net force of zero. (b) Since the acceleration and net force are directly proportional, the accelerations rank in the same order.

RE 3-9: In the chosen coordinate system, all the accelerations in the v vs. t graphs shown is Fig. 3-2 are negative since the slopes are negative. (a) The box on carpet acceleration is about −3.9 m/s^2 as determined by calculating the slope of the v vs. t graph. Slope = (0.00 − 0.90)(m/s)/(0.23 − 0.00)(s). (b) The cart on track acceleration is about −0.15 m/s^2 as determined by calculating the slope of the v vs. t graph. Slope = (0.62 − 0.80)(m/s)/(1.2 − 0.0)(s).

RE 3-10: (a) There appear to be no other horizontal forces on the moving objects except friction. Thus, we can assume that the net force on each object is due to a friction force. This friction force seems to be constant since the acceleration is constant and we assume that $F_x^{\text{net}} = ma_x$. (b) Box on carpet $F_x^{\text{fric}} = ma_x = 0.5\text{ kg} \times (-3.9\text{ m/s}^2) = -2$ N. It points to the left. (c) Cart on track $F_x^{\text{fric}} = ma_x = 0.5\text{ kg} \times (-0.15\text{ m/s}^2) = -0.08$ N. It also points to the left.

RE 3-11: (a) A tossed object is changing its velocity at all times. Just before it reaches the top of its flight it has a positive velocity and just after it has a negative velocity. Since acceleration is rate of change of velocity over time, even the instantaneous acceleration doesn't go to zero over an infinitesimal time interval. (b) The Fig. 3-22 graph of velocity vs. time is linear with a constant negative slope. Since slope of a v_y vs. t graph represents the acceleration component a_y, then a_y = constant so $\vec{a} = a_y\hat{\text{j}}$ is constant.

RE 3-12: Change every x in the two equations in Table 2-1 to a y. Then replace a_y (previously a_x) with $-g$.

RE 3-13: (a) The unmagnetized paperclip will be attracted to the magnet and, in turn, the magnet will be attracted toward the paperclip. Newton's Third Law tells us that these attractive forces will be equal in magnitude to one another but opposite in direction; the force on the magnet will be to the left and the force on the paperclip will be to the right. (b) Newton's Third Law applies to all forces of interaction of which this is just one example.

Problems

1. 16 N. **3.** (a) 0.02 m/s^2; (b) 8×10^4 km; (c) 2×10^3 m/s. **5.** 1.2×10^5 N. **7.** (a) 4.9×10^5 N; (b) 1.5×10^6 N. **9.** (a) 245 m/s^2; (b) 20.4 kN. **11.** (a) 8.0 m/s; (b) $+x$ direction. **13.** 8.0 cm/s^2. **15.** 1.8×10^4 N. **17.** (a) 31.3 kN; (b) 24.4 kN. **19.** $2Ma/(a + g)$. **21.** 2.4 N. **23.** (a) 1.23 N; (b) 2.46 N; (c) 3.69 N; (d) 4.92 N; (e) 6.15 N; (f) 0.25 N. **25.** (a) 3.2 s; (b) 1.3 s. **27.** (a) 3.70 m/s; (b) 1.74 m/s; (c) 0.154 m. **29.**

4.0 m/s. **31.** 22 cm and 89 cm below the nozzle. **33.** (a) 5.4 s; (b) 41 m/s. **35.** (a) 1.23 cm; (b) 4 times, 9 times, 16 times, 25 times. **37.** (a) 29.4 m; (b) 2.45 s. **39.** (a) 3260 N (b) 2.7×10^3 kg; (c) 1.2 m/s **41.** (a) 17 s; (b) 290 m. **43.** (a) 11 N; (b) 2.2 kg; (c) 0; (d) 2.2 kg. **45.** (a) 494 N, up; (b) 494 N, down. **47.** (a) 1.1 N. **49.** 5.1 m/s. **51.** (a) 466 N; (b) 527 N.

Chapter 4

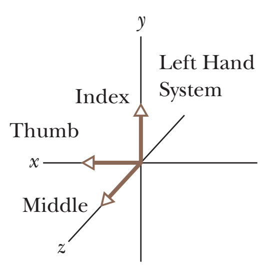
RE 4-1: Displacement (1) is identical as the ball ends up going a net distance of 6 meters north and 3 meters west. Displacement (2) is different. It actually has an equal magnitude but the ball has moved in the opposite direction. *Note*: Displacement does not depend on where something starts or ends, but only on how much and in what direction its position has changed relative to where it started.

RE 4-2: (a) The maximum magnitude occurs when the two vectors point in the same direction. This gives a magnitude for vector $\vec{c}$ of 3 m + 4 m = 7 m. (This answer is not correct without a unit attached.) (b) The minimum magnitude occurs when the two vectors point in the opposite directions. This gives a magnitude for vector $\vec{c}$ of 4 m − 3 m = 1 m.

RE 4-3: Methods (c), (d), and (f) work since the parallelogram methods (c) and (d) show that the same correct resultant can be obtained regardless of the order in which components are added. Method (f) shows an equivalent construction using components. All the other vectors point in the wrong directions.

RE 4-4: The vectors in figures (b) and (d) have the same components as the standard vector.

RE 4-5: Compare Figs 4-12 and 4-13.



RE 4-6: (a & b). The x- and y-components of $\vec{d}_1$ are both positive. The x-component of $\vec{d}_2$ is positive but the y-component points down in a negative direction. (c) Using the parallelogram method to get the vector sum of $\vec{d}_1$ and $\vec{d}_2$ results in a vector that has both x- and y-components that are positive.

RE 4-7: This is a kind of artificial question since units of force and acceleration are different as are units of displacement and velocity. However, if the scalars (mass and time respectively) act as compressors or stretchers, then the simplistic answers would be (a) The force vector would point in the same direction as the acceleration vector but be three times as long. (b) The velocity vector would point off in the same direction as the displacement vector and be twice as long since the displacement was divided by 0.5 s.

RE 4-8:

(a) $\vec{F} = m\vec{a} = 3.0\ \text{kg}[(1.8\ \text{m/s}^2)\hat{\imath} + (1.0\ \text{m/s}^2)\hat{\jmath}] = (5.4\ \text{N})\hat{\imath} + (3.0\ \text{N})\hat{\jmath}$.

(b) $\langle\vec{v}\rangle = \dfrac{\Delta\vec{r}}{\Delta t} = \dfrac{(3.2\ \text{m})\hat{\imath} + (-0.8\ \text{m})\hat{\jmath}}{0.5\ \text{s}} = (6.4\ \text{m/s})\hat{\imath} + (-1.6\ \text{m/s})\hat{\jmath}$.

Problems

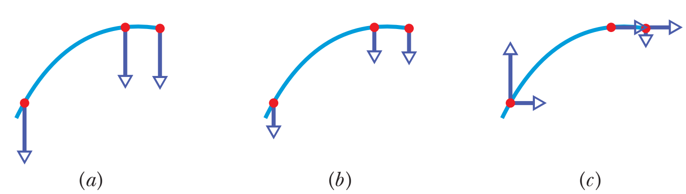
1. The displacements should be (a) parallel, (b) antiparallel, (c) perpendicular. **3.** (a) 5; (b) 1; (c) 7. **5.** (a) −2.5 m; (b) −6.9 m. **7.** (a) 47.2 m; (b) 122°. **9.** (a) 168 cm; (b) 32.5° above the floor. **11.** (a) 6.42 m; (b) no; (c) yes; (d) yes; (e) a possible answer: $(4.30\ \text{m})\hat{\imath} + (3.70\ \text{m})\hat{\jmath} + (3.00\ \text{m})\hat{k}$; (f) 7.96 m. **13.** (a) 370 m; (b) 36° north of east; (c) 425 m; (d) the distance. **15.** (a) $(-9\ \text{m})\hat{\imath} + (10\ \text{m})\hat{\jmath}$; (b) 13 m; (c) + 132°. **17.** (a) 4.2 m; (b) 40° east of north; (c) 8.0 m; (d) 24° north of west. **19.** (a) $(3.0\ \text{m})\hat{\imath} - (2.0\ \text{m})\hat{\jmath} + (5.0\ \text{m})\hat{k}$; (b) $(5.0\ \text{m})\hat{\imath} - (4.0\ \text{m})\hat{\jmath} - (3.0\ \text{m})\hat{k}$; (c) $(-5.0\ \text{m})\hat{\imath} + (4.0\ \text{m})\hat{\jmath} + (3.0\ \text{m})\hat{k}$. **21.** (a) 38 m; (b) 320°; (c) 130 m; (d) 1.2°; (e) 62 m; (f) 130°. **23.** (a) 1.59 m; (b) 12.1 m; (c) 12.2 m; (d) 82.5°. **29.** (a) Put axes along cube edges, with the origin at one corner. Diagonals are $a\hat{\imath} + a\hat{\jmath} + a\hat{k}$, $a\hat{\imath} + a\hat{\jmath} - a\hat{k}$, $a\hat{\imath} - a\hat{\jmath} - a\hat{k}$, $a\hat{\imath} - a\hat{\jmath} + a\hat{k}$; (b) 54.7°; (c) $\sqrt{3}\,a$. **31.** 4.1. **33.** (a) 103 km; (b) 60.9° north of due west. **35.** (a) 15 m; (b) south; (c) 6.0 m; (d) north. **37.** 5.0 km, 4.3° south of due west. **39.** 5.39 m at 21.8° left of forward. **41.** (a) 4.28 m; (b) 11.7 m. **43.** (a) −80 m; (b) 110 m; (c) 143 m; (d) +168° (counterclockwise). **45.** 3.6 m. **47.** (a) 1.84 m; (b) 69° north of east. **49.** (a) 9.51 m; (b) 14.1 m; (c) 13.4 m; (d) 10.5 m. **51.** (a) $9.19\hat{\imath} + 7.71\hat{\jmath}$; (b) $14.0\hat{\imath} + 3.41\hat{\jmath}$

Chapter 5

RE 5-1: (a) No, because in Fig. 5-5 the vertical positions of the ball on the right are the same as those of the ball on the left. (b) No. The horizontal positions of the ball on the right are equally spaced, indicating that horizontal velocity of the ball is constant and unaffected by the falling.

RE 5-2: The skateboarder's vertical motion is independent of his horizontal velocity. This is why the skateboarder lands back on his skateboard after his jump.

RE 5-3: (a) At each of the three points, the force vector points straight down and has a constant magnitude and (b) the same is true for the three acceleration vectors. (c) The horizontal component of each of the three velocity vectors points to the right and has a constant size. The vertical component of the velocity at the left point is directed straight upward and is slightly larger than the common size of the horizontal velocity components. The vertical component of the velocity at the center point is zero, while at the right point it is directed downward and is smaller in size than the horizontal velocity component.

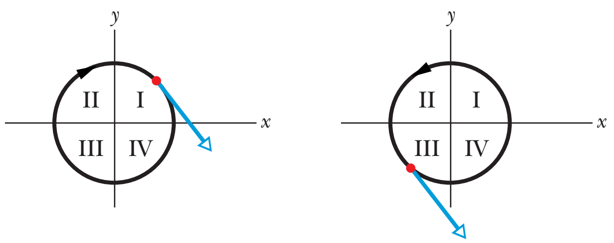


RE 5-4: (a) The x-component of velocity is not changing and is the slope of Fig. 5-9. From the data in the figures, the slope is about 2.3 m/s. The initial y-component of velocity is the initial slope of Fig 5-10, which is about 3.5 m/s. The launch angle will be the inverse tangent of 3.5/2.3 or about 57°. (b) Using a protractor about 57°, too.

RE 5-5: (a) The horizontal component of velocity remains constant. (b) The vertical component of velocity is changing constantly as there is a vertical acceleration. (c) The horizontal component of its acceleration is zero. The only force (gravity) acting is in the vertical direction. (d) The vertical component of its acceleration is constant (9.8 m/s^2 downward).

RE 5-6: (a) Using Eq. 5-15 and noting that $\Delta x = 8$ m and $\Delta y = -6$ m gives a displacement of $\Delta\vec{r} = (8\text{ m})\hat{\text{i}} + (-6\text{ m})\hat{\text{j}}$. (b) No, since it has components along both axes.

RE 5-7: (a) When traveling clockwise, the x-component of the particle's velocity is positive when it is in the I and II quadrant, and its y-component is negative in the I quadrant, so the particle is now in the I quadrant. (b) When traveling counterclockwise, the x-component of the particle's velocity is positive when it is in the III and IV quadrant, and it's y-component is negative in the III quadrant, so the particle is then in the III quadrant.



(a) Quadrant I (b) Quadrant II

RE 5-8: Remember that the x-component of acceleration will be in the direction of the change in the x-component of velocity and the y-component of acceleration will be in the direction of the change in the y-component of velocity. Just knowing the trajectory or path of the particle does not give you the direction of the acceleration. You also need to know how the velocity is changing as the particle travels along its trajectory. Therefore, if the change in the velocity vector is in the direction of the path of the particle, $\vec{a}$ will be tangent to the trajectory. However, you will study other situations (Section 5-7) where $\vec{a}$ is actually perpendicular to the trajectory, that is, the change in the velocity is perpendicular to the trajectory.

RE 5-9: The centripetal force is always inward toward the center of the curve. According to Newton's First Law, the passenger wants to travel in a straight line unless acted upon by a force. The centripetal force acts on the passenger through the friction between the passenger and the car seat. If that frictional force is not strong enough, the passenger tends to travel in a straight line and slides to the outside edge of the seat, where both the seat and the side of the car can provide the centripetal force needed to move your body in a curved path.

Problems

1. (a) 62 ms; (b) 480 m/s. **3.** (a) 0.205 s; (b) 0.205 s; (c) 20.5 cm; (d) 61.5 cm. **5.** (a) 2.00 ns; (b) 2.00 mm; (c) 1.00×10^7 m/s; (d) 2.00×10^6 m/s. **7.** (a) 16.9 m; (b) 8.21 m; (c) 27.6 m; (d) 7.26 m; (e) 40.2 m; (f) 0. **9.** 4.8 cm. **13.** (a) 11 m; (b) 23 m; (c). 17 m/s; (d) 63° below the horizontal. **15.** (a) 24 m/s; (b) 65° above the horizontal. **17.** (a) 10 s; (b) 897 m. **19.** the third. **21.** (a) 202 m/s; (b) 806 m; (c) 161 m/s; (d) −171 m/s. **23.** (a) yes; (b) 2.56 m. **25.** between the angles 31° and 63° above the horizontal. **27.** (a) $(-5.0\text{ m})\hat{\text{i}} + (8.0\text{ m})\hat{\text{j}}$; (b) 9.4 m; (c) 122°; (e) $(8\text{ m})\hat{\text{i}} + (-8\text{ m})\hat{\text{j}}$; (f) 11 m; (g) −45°. **29.** (a) $(-7.0\text{ m})\hat{\text{i}} + (12\text{ m})\hat{\text{j}}$; (b) x axis. **31.** 8.43 m at −129°. **33.** 7.59 km/h, 22.5° east of north; **35.** (a) $(3.00\text{ m/s})\hat{\text{i}} + (-8.00\text{ m/s}^2)t\,\hat{\text{j}}$; (b) $(3.00\text{ m/s})\hat{\text{i}} + (-16.00\text{ m/s})\hat{\text{j}}$; (c) 16.3 m/s; (d) −79.4° **37.** 0.421 m/s at 3.1° west of due north. **39.** (a) $(6.00\text{ m})\hat{\text{i}} + (-106\text{ m})\hat{\text{j}}$; (b) $(19.0\text{ m/s})\hat{\text{i}} + (-224\text{ m/s})\hat{\text{j}}$; (c) $(24.0\text{ m/s}^2)\hat{\text{i}} + (-336\text{ m/s}^2)\hat{\text{j}}$; (d) −85.2° to $+x$. **41.** (a) $(-1.5\text{ m/s})\hat{\text{j}}$; (b) $(4.5\text{ m})\hat{\text{i}} + (-2.25\text{ m})\hat{\text{j}}$. **43.** (a). 45 m; (b) 22 m/s. **45.** (a) $(8\text{ m/s}^2)t\,\hat{\text{j}}$; (b) $(8\text{ m/s}^2)\hat{\text{j}}$. **47.** (a) 22 m; (b) 15 s. **49.** (a) 7.49 km/s; (b) 8.00 m/s². **51.** (a) 19 m/s; (b) 35 rev/min; (c) 1.7 s. **53.** (a) 0.034 m/s²; (b) 84 min. **55.** (a) 12 s; (b) 4.1 m/s², down; (c) 4.1 m/s², up. **57.** 160 m/s². **59.** (4.00 m, 6.00 m)

Chapter 6

RE 6-1: If you gather the tails of the three vectors shown in the helicopter diagram, you get the free-body diagram shown in (c).

RE 6-2: Use the balance in Fig. 3-9 and place one object on the left pan and the other object on the right pan. If the two objects have the same mass they will balance one another. They would have the same weight if they both gave the same reading on the spring scale. Also you could realize that if they have the same mass, they have the same weight since $W =$ mg and g is a constant. The weight and mass are not the same. The weight is a force, and the mass is mass. Yes, since the weight and mass are proportional, the ratios are the same.

RE 6-3: It's true that the planet is yanking down on the patient but this is a force equal to his weight. However, since the normal force from the floor is equal and opposite, there is no net force and hence no acceleration.

RE 6-4: (a) In this case, at constant speed a equals zero and thus the net force must equal zero, requiring $\vec{N}$ and $\vec{F}^{\text{grav}}$ to be equal in magnitude and opposite in direction. (b) Since the only two forces acting on the block are $\vec{N}$ and $\vec{F}^{\text{grav}}$, to have an upward acceleration we must have a net upward force, meaning that the magnitude of $\vec{N}$ is now larger than that of $\vec{F}^{\text{grav}}$. (c) Slowing down means an acceleration or net force in the downward direction, requiring the magnitude of $\vec{F}^{\text{grav}}$ to be larger than that of $\vec{N}$. What do you think would happen to $\vec{N}$ if the elevator cable broke and the block fell freely with $a = g$?

RE 6-5: In both answers to follow we are assuming the only forces acting on the block in the horizontal direction are the friction force and the pull of the cord, which is what the force sensor is measuring. Since in both cases there is no acceleration, these two forces must be equal and opposite, allowing us to equate the force sensor reading to the frictional force. (a) From the graph it looks like the block breaks free when the force is about 9.5 N. The total mass is 0.7956 kg, and the normal force that equals the weight is mg; therefore using Eq. 6-11, we find $\mu^{\text{stat}} = 9.5/(0.7956 \times 9.8) = 1.22$. Notice that the coefficient of friction has no units. (b) From the graph, the force needed to keep the block moving at a constant speed is about 3.0 N. Using Eq. 6-10, $\mu^{\text{kin}} = 3.0/(0.7956 \times 9.8) = 0.38$.

RE 6-6: (a) Zero; (b) 5 N; (c) No; (d) Yes, there is now a net force of 2 N on the block causing it to accelerate; (e) 8 N.

RE 6-7: It is true that friction has both a bad side and a good side. Friction always tries to retard motion. If you desire that motion then friction is bad—for example, the pistons in your car engine—and we do everything we can (lubricants) to eliminate it. However, there are other times when we don't want motion (slippage) to occur, as when we are walking or riding a bike, and the force of friction allows us to do these activities.

RE 6-8: Think of the cord as an object with a mass you are trying to accelerate with only two forces—the one at one end from the hand and the other at the other end from the block. We will assume that the length of the cord hanging down on each side is the same so we can ignore the force of gravity on the cord. (a) If the cord is not accelerating then the magnitudes of the two forces are equal and cancel. (b) If the block is accelerating then so is the cord and the force of the hand on the cord is greater than that of the block. (c). In this case the acceleration is opposite to b and the pull force of the hand is less than the pull force due to the block.

RE 6-9: Look at Eq. 6-25. The only things in this equation that will change with the size of the drops are the mass, m, and the cross-sectional area A. So for this exercise v_t^2 is proportional to m/A. How will this ratio change with the size of the drops? A changes as r^2 and m changes as (ρ_{water})(volume) and since volume goes as r^3, we finally determine that m/A and hence v_t^2 goes as r. Therefore, large drops have greater speeds than small drops.

Problems

1. (a) $F_x = 1.88$ N; (b) $F_y = 0.684$ N; (c) $(1.88\text{ N})\hat{\imath} + (0.684\text{ N})\hat{\jmath}$. **3.** 2.9 m/s^2. **5.** $(3\text{ N})\hat{\imath} + (-11\text{ N})\hat{\jmath}$. **7.** (a) $(-32\text{ N})\hat{\imath} + (-21\text{ N})\hat{\jmath}$; (b) 38 N; (c) 213° from $+x$. **9.** (a) 108 N; (b) 108 N; (c) 108 N. **11.** (a) 200 N; (b) 120 N. **13.** 0.61. **15.** (a) 190 N; (b) 0.56 m/s^2. **17.** (a) 0.13 N; (b) 0.12. **19.** (a) no; (b) $(-12\text{ N})\hat{\imath} + (5\text{ N})\hat{\jmath}$. **23.** (a) 300 N; (b) 1.3 m/s^2. **25.** (a) 66 N; (b) 2.3 m/s^2. **27.** (b) 3.0×10^7 N. **29.** 100 N. **31.** (a) 0; (b) 3.9 m/s^2 down the incline; (c) 1.0 m/s^2 down the incline. **33.** (a) 3.5 m/s^2; (b) 0.21 N; (c) blocks move independently. **35.** 490 N **37.** (a) 6.1 m/s^2, leftward; (b) 0.98 m/s^2, leftward. **39.** $g(\sin\theta - \sqrt{2}\,\mu^{\text{kin}}\cos\theta)$. **41.** 9.9 s. **43.** 6200 N. **45.** 2.3. **47.** 1.5 mm. **49.** (a) 68 N (b) 73 N. **51.** (a) 2.2×10^{-3} N; (b) 3.7×10^{-3} N. **53.** (a) 4.6×10^3 N for each bolt; (b) 5.8×10^3 N. **55.** (a) 180 N; (b) 640 N. **57.** (a) 3.1 N; (b) 14.7 N. **59.** (a) 6.8×10^3 N (b) $-21°$ or 159°. **61.** (b) $F/(m+M)$; (c) $MF/(m+M)$; (d) $F(m+2M)/2\ (m+M)$. **63.** 1.8×10^4 N. **65.** about 48 km/h. **67.** 21 m. **69.** $\sqrt{Mgr/m}$. **71.** (a) light; (b) 778 N; (c) 223 N. **73.** 2.2 km. **75.** (b) 8.74 N; (c) 37.9 N, radially inward; (d) 6.45 m/s. **77.** (a) $\sqrt{Rg\tan(\theta + \tan^{-1}(\mu^{\text{stat}}))}$; (b) graph; (c) 41.3 m/s; (d) 21.2 m/s. **81.** (a) 3.0 N, up the incline; (b) 3.0 N, up the incline; (c) 1.6 N, up the incline; (d) 4.4 N, up the incline; (e) 1.0 N, down the incline. **83.** 0.54

Chapter 7

RE 7-1: (a) The 60 s encounter between the *Titanic* and an iceberg was a collision. (b) A tennis ball encountering a racket for 2 s is not a collision.

RE 7-2: (a) $|\vec{F}_1| > |\vec{F}_3| > |\vec{F}_2| = |\vec{F}_4| = 0$. Since the slopes represent $\Delta\vec{p}/\Delta t$ the magnitude is greatest where the slope is steepest. Thus, ranking is by steepness of slope. (b) Since the momentum is initially positive, the particle speeds up in region 1, drifts in region 2, and *slows down in region 3,* where its momentum is becoming less positive (and hence more negative).

RE 7-3: The change in the egg's momentum is $m\vec{v}_2 - m\vec{v}_1$, and since $\vec{v}_2$ is zero the change is just $m\vec{v}_1$. The time you take in catching the egg does not affect the momentum change since the initial and final velocities are still the same. However the time taken in the catch will affect the average force the egg experiences. Since the change in momentum equals the impulse, which equals the average force times the time the force acts, making the time of the catch longer makes the average force on the egg less and hence a greater likelihood of a successful catch. In order to make Δt as large as possible, you move your hands and body backwards once the catch is made in order to bring the egg to zero speed over the largest time interval possible.

RE 7-4: (a) p_{1x} is to the right and $+$, p_{2x} is to the left and $-$, therefore Δp_x is $-$. Remember that Δ is always final minus initial, and here we have a negative number minus a positive number giving a negative result. (b) Δp_y is zero since the y component of the momentum does not change in the bounce. (c) The direction of $\Delta\vec{p}$ is left. To see this, draw the two momentum vectors and subtract the initial from the final. Remember: To subtract vectors add the negative of the second to the first.

RE 7-5: (1) Assuming the carts are frictionless, the system consisting of the firecracker and the two carts is an isolated system and momentum should be conserved. In fact, if the firecracker is initially at rest and explodes symmetrically, then the carts should move off at the same speed in opposite directions. (2) Assuming the carts are not frictionless, then the track and the table and the Earth become part of the system. We might not see the carts come off with the same speeds in opposite directions. Instead the Earth might move (imperceptibly) to make up the difference. However, momentum is always conserved, so it should be so for our new system.

RE 7-6: (a) Zero, since no external forces are acting and hence the total momentum is conserved. (b) No, since the y-component of momentum must also be conserved. (c) The second piece must be moving in the negative direction on the x axis so that the total momentum after the explosion is zero.

RE 7-7: We need a mass for the grapefruit—let's say 1.0 kg. The grapefruit's momentum starts at zero and goes to (1 kg)(2 m/s) = 2 kg · m/s, therefore $\Delta p = 2$ kg · m/s. The change in the Earth's momentum will be equal and opposite, therefore the change in the Earth's speed will be 2 kg · m/s divided by the mass of the Earth. If you look at the inside front cover of this text, you find $m_{\text{Earth}} = 5.98 \times 10^{24}$ kg. Dividing, you get $v_{\text{Earth}} = 3.3 \times 10^{-25}$ m/s. Did you feel the Earth move?

Problems

1. 24 km/h. **3.** (a) $(-4.0 \times 10^4\text{ kg}\cdot\text{m/s})\,\hat{\imath}$; (b) west. **5.** (a) 30°; (b) $(-0.572\text{ kg}\cdot\text{m/s})\,\hat{\jmath}$. **7.** 2.5 m/s. **9.** 3000 N. **11.** 67 m/s, in opposite direction. **13.** (a) 42 N · s; (b) 2100 N. **15.** (a) $(7.4 \times 10^3\text{ N}\cdot\text{s})\hat{\imath} + (-7.4 \times 10^3\text{ N}\cdot\text{s})\hat{\jmath}$; (b) $(-7.4 \times 10^3\text{ N}\cdot\text{s})\hat{\imath}$; (c) 2.3×10^3 N; (d) 2.1×10^4 N; (e) $-45°$. **17.** 10 m/s. **19.** (a) 1.0 kg · m/s; (b) 10 N; (c) 1700 N; (d) the answer for (b) includes time between pellet collisions. **21.** 41.7 cm/s. **23.** (a) 46 N; (b) none. **25.** ≈ 2 mm/y. **27.** 3.0 mm/s, away from the stone. **29.** (a) 4.6 m/s; (b) 3.9 m/s; (c) 7.5 m/s. **31.** increases by 4.4 m/s. **33.** 190 m/s. **35.** (a) $\{m_A/(m_A + m_B)\}v_{A\,1}$. **37.** (a) 7290 m/s; (b) 8200 m/s. **39.** 4400 km/h. **41.** 8.1 m/s at 38° south of east. **43.** (a) 11.4 m/s; (b) 95.1° clockwise from $+x$. **45.** (a) 61.7 km/h; (b) 63.4° south of west. **47.** (a) 2.5 m/s. **49.** 1.0 m/s north. **51.** (a) 1.4×10^{-22} kg · m/s; (b) 150°; (c) 120°. **53.** 14 m/s, 135° from the other pieces. **55.** 3.0 m/s. **57.** 120°. **59.** (a) 4.15×10^5 m/s; (b) 4.84×10^5 m/s. **61.** (a) 41°; (b) 4.76 m/s; (c) no. **63.** 2.0 m/s, $-x$ direction. **65.** 108 m/s. **67.** (a) 1.57×10^6 N; (b) 1.35×10^5 kg; (c) 2.08 km/s. **69.** 2.2×10^{-3}

Chapter 8

RE 8-1: (a) At the center; (b) in the lower right quadrant; (c) on the negative y axis; (d) at the center; (e) in the lower left quadrant; (f) at the center

RE 8-2: (a) The spacing between successive halfway points is the same, which suggests that the velocity represented by these points is constant.

(b) $v = |\Delta\vec{r}|/\Delta t = 0.41\text{ m}/[(12/15)\text{s}] = 0.51$ m/s

RE 8-3: Since there are no outside forces on the system, the center of mass of the system will not change. Thus, the skaters will end up meeting at the origin of the original coordinate system in all three situations (a), (b), and (c). The only difference is that in case (a) Ethel will be holding one end of the "massless" pole at the end, in case (b) Fred will be holding an end of the "massless" pole, and in case (c) one-third of the "massless" pole will be sticking out behind Fred and two-thirds will be sticking out behind Ethel.

Problems

1. (a) -4.5 m; (b) -5.5 m. **3.** (a) 4600 km; (b) $0.73R_e$. **5.** (a) 1.1 m; (b) 1.3 m; (c) shifts toward topmost particle. **7.** (a) -0.25 m; (b) 0. **9.** 6.8×10^{-12} m from the nitrogen atom, along axis of symmetry. **11.** (a) $H/2$; (b) $H/2$; (c) descends to lowest point and then ascends to $H/2$; (d) $\frac{HM}{m}\left(\sqrt{1+\frac{m}{M}}-1\right)$. **13.** $x_{com} = B/2$ and $y_{com} = H/3$. **15.** $x_{com} = B/2$ and $y_{com} = 4R/(3\pi)$. **17.** (a) 0,0; (b) 0. **19.** (-1.50 m, -1.43 m). **21.** 29 m. **23.** 72 km/h. **25.** (a) 28 cm; (b) 2.3 m/s. **27.** 53 m. **29.** (a) halfway between the containers; (b) 26 mm toward the heavier container; (c) down; (d) -1.6×10^{-2} m/s^2. **31.** 4.2 m. **33.** 1.2 m/s, 132° counterclockwise from east. **37.** (a) 33 m/s; (b) 8.7 m/s. **39.** (a) 540 m/s; (b) 40.4°. **41.** (a) $0.2000v^{rel}$; (b) $0.2103v^{rel}$; (c) $0.2095v^{rel}$. **43.** (a) 1.0 m/s north; (b) 3 m north

Chapter 9

RE 9-1: (a) Decreases. (b) Remains the same. Remember that the kinetic energy is a scalar and depends on the velocity squared, so -2 m/s and 2 m/s give the same kinetic energy. (c) Negative for situation (a) and zero for situation (b). Situation (b) is interesting. How can the net work done be zero? Try breaking the velocity change into two changes: first from -2 m/s to zero, then from zero to 2 m/s. For the first change the work is negative and for the second change the work is positive. When we add the two works together, we get zero for the total.

RE 9-2: $c > a > b = d$

RE 9-3: Use Eq. 9-19: (a) positive; (b) negative; (c) zero. Think through your calculated answers. Do they make sense? For example, in (a) as the block moves from -3 cm to the origin, the spring force and displacement are in the same direction giving a positive work; from the origin to 2 cm the spring force and displacement are in opposite directions giving a negative work, but the positive work is larger because the displacement is larger giving a net positive work.

RE 9-4: $d > c > b > a$

RE 9-5: The power is zero at all times since $\vec{F}$ and $\vec{v}$ are always perpendicular in uniform circular motion.

Problems

1. 1.2×10^6 m/s. **3.** (a) 3610 J; (b) 1900 J; (c) 1.1×10^{10} J. **5.** (a) 2.9×10^7 m/s; (b) 2.1×10^{-13} J. **7.** (a) 7.5×10^4 J; (b) 3.8×10^4 kg · m/s; (c) 38° south of east. **9.** 1.18×10^4 kg. **11.** (a) 3.7 m/s; (b) 1.3 N·s; (c) 1.8×10^2 N. **13.** (a) 42 J; (b) 30 J; (c) 12 J; (d) 6.48 m/s, positive direction of x axis; (e) 5.48 m/s, positive direction of x axis; (f) 3.46 m/s, positive direction of x axis. **15.** AB: +, BC: 0, CD: −, DE: +. **17.** (a) 170 N; (b) 340 m; (c) -5.8×10^4 J; (d) 340 N; (e) 170 m; (f) -5.8×10^4 J. **19.** 800 J. **21.** (a) 98 N; (b) 4.0 cm; (c) 3.9 J; (d) -3.9 J. **23.** 0, by both methods. **25.** (a) -0.043 J; (b) -0.13 J. **27.** (a) 6.0 N; (b) $-$ 2.5 N; (c) 15 N **29.** 15.3 J. **31.** (a) 590 J; (b) 0; (c) 0; (d) 590 J. **33.** 6.8 J. **35.** (a) 1.20 J; (b) 1.10 m/s. **37.** (a) 1.50 J; (b) increases. **39.** (a) 1.2×10^4 J; (b) $-$ 1.1×10^4 J; (c) 1100 J; (d) 5.4 m/s. **41.** (a) $-3Mgd/4$; (b) Mgd; (c) $Mgd/4$; (d) $\sqrt{gd/2}$. **43.** 20 J. **45.** (a) 8.84×10^3 ; (b) 7.84×10^3 J; (c) 6.84×10^3 J. **47.** (a) 2.3 J; (b) 2.6 J. **49.** 490 W. **51.** (a) 0.83 J; (b) 2.5 J; (c) 4.2 J; (d) 5.0 W. **53.** 740 W. **55.** 68 kW. **57.** (a) 1.8×10^5 ft · lb; (b) 0.55 hp. **59.** (a) 8.8 m/s; (b) 2600 J; (c) 1.6 kW. **61.** 24 W **63.** (a) 2.1×10^6 kg; (b) $\sqrt{100 + 1.5t}$ m/s; (c) $(1.5 \times 10^6)/\sqrt{100 + 1.5t}$ N; (d) 6.7 km **65.** (a) $\approx 1 \times 10^5$ megatons; (b) $\approx$ ten million bombs

Chapter 10

RE 10-1: No, for the force to be conservative the work done in going between two points must not depend on the path taken. Also, if you go from 2 to 1 instead of 1 to 2 the work will change sign. Therefore, for the force in the exercise to be conservative the work for the bottom path should have a negative sign.

RE 10-2: A Hot Wheels® car that traverses path b should lose more kinetic energy than one that traverses path a. This is because path b is longer so the friction forces have more distance to act on path b.

RE 10-3: The kinetic energy of the barbell is zero before the lift and zero after the lift, as evidenced by the fact that y vs. t is a constant at $t = 0.0$ s and at $t = 2.0$ s. Since the kinetic energy change $\Delta K = 0.0$ J, then the net work on the barbells should be zero. An examination of graph 10-10b shows that the positive work is approximately given by the area under the F^{net} vs. y curve. W^+ = area under the positive portion of the curve = (0.5)(116 N)(.15 m) = +8.7 J and W^- = area under the negative portion of the curve (0.5)(58 J)(.45 − .15) m = −8.7 J. So $W^{net} = W^+ + W^- = 0.0$ J.

RE 10-4: Use Eq. 10-13. Note that the change in the potential energy is the negative of the area under the curves in the figure. The most positive will be (3) and the least positive (2).

RE 10-5: Without friction, the decrease in the potential energy will equal the increase in the kinetic energy. (a) Therefore, since all four blocks are losing the same amount of potential energy, they will all have the same kinetic energy at point B. (b) Since the kinetic energies are the same, the speeds are the same.

RE 10-6: Use the equation $F_x^{int}(x) = -dU(x)/dx$. The force is the negative of the slope of the U vs. x curve. (a) Ranking *magnitudes* with the greatest first: CD, AB, BC. (b) The slope is negative, hence the force is in the positive x direction.

RE 10-7: $b > a > c$ as determined by the equation $\Delta E^{thermal} = f_x^{kin}\Delta x$.

RE 10-8: (a) 4 kg · m/s; (b) 8 kg · m/s; (c) assuming an elastic collision, 3 J.

RE 10-9: (a) 2 kg · m/s. (b) Since the initial y-component is zero, the final must be zero. Therefore, the final y-component of momentum for the target is 3 kg · m/s.

Problems

1. 89 N/cm. **3.** (a) 4.31 mJ; (b) -4.31 mJ; (c) 4.31 mJ; (d) -4.31 mJ; (e) all increase. **5.** (a) mgL; (b) $-mgL$; (c) 0; (d) $-mgL$; (e) mgL; (f) 0; (g) same. **7.** (a) 184 J; (b) -184 J; (c) -184 J. **9.** -320 J **11.** (a) 2.08 m/s; (b) 2.08 m/s; (c) increase. **13.** (a) $\sqrt{2gL}$; (b) $2\sqrt{gL}$; (c) $\sqrt{2gL}$; (d) all the same. **15.** (a) 260 m; (b) same; (c) decrease. **17.** (a) 21.0 m/s; (b) 21.0 m/s; (c) 21.0 m/s. **19.** (a) 0.98 J; (b) -0.98 J; (c) 3.1 N/cm. **21.** (a) 39.2 J; (b) 39.2 J; (c) 4.00 m. **23.** (a) 35 cm; (b) 1.7 m/s. **25.** 10 cm. **27.** 1.25 cm. **31.** (a) $2\sqrt{gL}$; (b) $5mg$; (c) 71°. **33.** $mgL/32$. **37.** (a) $1.12(A/B)^{1/6}$; (b) repulsive; (c) attractive. **39.** (a) -3.7 J; (c) 1.29 m; (d) 9.12 m; (e) 2.16 J ; (f) 4.0 m; (g) $(4 - x)e^{-x/4}$ N; (h) 4 m. **41.** (a) 30.1 J; (b) 30.1 J; (c) 0.22. **43.** (a) 5.6 J; (b) 3.5 J. **45.** 11 kJ. **47.** 20 ft · lb. **49.** (a) 1.5 MJ; (b) 0.51 MJ; (c) 1.0 MJ; (d) 63 m/s. **51.** (a) 67 J;

(b) 67 J; (c) 46 cm. **53.** (a) 31.0 J; (b) 5.35 m/s; (c) conservative. **55.** (a) 44 m/s; (b) 0.036. **57.** (a) -0.90 J; (b) 0.46 J; (c) 1.0 m/s. **59.** 1.2 m. **63.** in the center of the flat part. **65.** (a) 216 J; (b) 1180 N; (c) 432 J; (d) motor also supplies thermal energy to crate and belt. **67.** (a) 0.2 to 0.3 MJ; (b) same amount. **69.** (a) 860 N; (b) 2.4 m/s. **71.** (a) $mR(\sqrt{2gh} + gt)$; (b) 5.06 kg. **73.** (a) $mv_1/(m + M)$; (b) $M/(m + M)$. **75.** 25 cm. **79.** (a) 41°; (b) 4.76 m/s; (c) no. **81.** (a) 6.9 m/s, 30° to $+x$ direction; (b) 6.9 m/s, $-30°$ to $+x$ direction; (c) 2.0 m/s, $-x$ direction. **83.** (a) 99 g; (b) 1.9 m/s; (c) 0.93 m/s. **85.** 7.8%. **87.** (a) 1.2 kg; (b) 2.5 m/s. **89.** (a) 100 g; (b) 1.0 m/s. **91.** (a) 1.9 m/s, to the right; (b) yes; (c) no, total kinetic energy would have increased. **93.** (a) 1/3; (b) $4h$. **95.** 1.0 kg. **97.** (c) 11%; (d) 10%; (e) 79%

Chapter 11

RE 11-1: (a) Positive, since θ is increasing. (b) Negative, since θ is decreasing.

RE 11-2: (a) Positive; (b) negative; (c) negative; (d) positive

RE 11-3: Find the angular acceleration, α, by taking the second derivative of θ with respect to t. The accelerations for (a) and (d) do not depend on t and are therefore constant, and hence the equations of Table 11-1 apply.

RE 11-4: Since the speeds are being squared, v^2 and ω^2 will always be positive quantities.

RE 11-5: (a) Yes, the centripetal acceleration; (b) no, since α is zero; (c) yes; (d) yes, since α is no longer zero.

RE 11-6: Calculate mr^2 for each, and you'll find they are all the same.

RE 11-7: (1) > (2) > (4) > (3). Remember that I depends not only on the mass but also on how far that mass is from the chosen axis.

RE 11-8: $I_a = I_d = mr^2$, $I_b = \frac{1}{2}mr^2$, $I_c = \frac{5}{8}mr^2$, so $a = d > c > b$.

RE 11-9: $A = C > D > B = E =$ zero. For A and C, ϕ is 90°; for D, ϕ is between zero and 90°; for E, ϕ is zero; and for C, r is zero.

RE 11-10: (a) Same direction. (b) Less.

Problems

1. (a) $a + 3bt^2 - 4ct^3$; (b) $6bt - 12ct^2$. **3.** (a) 5.5×10^{15} s; (b) 26. **5.** (a) 2 rad; (b) 0; (c) 130 rad/s; (d) 32 rad/s^2; (e) no. **7.** 11 rad/s. **9.** (a) -67 rev/min^2; (b) 8.3 rev. **11.** 200 rev/min. **13.** 8.0 s. **15.** (a) 44 rad; (b) 5.5 s, 32 s; (c) -2.1 s, 40 s. **17.** (a) 340 s; (b) -4.5×10^{-3} rad/s^2; (c) 98 s. **19.** 1.8 m/s^2, toward the center. **21.** 0.13 rad/s. **23.** (a) 3.0 rad/s; (b) 30 m/s; (c) 6.0 m/s^2; (d) 90 m/s^2. **25.** (a) 3.8×10^3 rad/s; (b) 190 m/s. **27.** (a) 7.3×10^{-5} rad/s; (b) 350 m/s; (c) 7.3×10^{-5} rad/s; (d) 460 m/s. **29.** 16 s. **31.** (a) -2.3×10^{-9} rad/s^2; (b) 2600 y; (c) 24 ms. **33.** 12.3 kg · m^2. **35.** (a) 1100 J; (b) 9700 J. **37.** (a) $5md^2 + 8/3Md^2$; (b) $(5/2m + 4/3M)d^2\omega^2$. **39.** 0.097 kg · m^2. **41.** $^1/_3M(a^2 + b^2)$. **45.** 4.6 N · m. **47.** (a) $r_1F_A \sin\theta_1 - r_2F_B \sin\theta_2$; (b) -3.8 N · m. **49.** (a) 28.2 rad/s^2; (b) 338 N · m. **51.** (a) 155 kg · m^2; (b) 64.4 kg. **53.** 130 N. **55.** (a) 6.00 cm/s^2; (b) 4.87 N; (c) 4.54 N; (d) 1.20 rad/s^2; (e) 0.0138 kg · m^2. **57.** (a) 1.73 m/s^2; (b) 6.92 m/s^2. **59.** 396 N · m. **61.** (a) $mL^2\omega^2/6$; (b) $L^2\omega^2/6g$. **63.** 5.42 m/s **65.** $\frac{3}{2}\sqrt{\frac{g}{L}}$. **67.** (a) $[(3g/H)(1 - \cos\theta)]^{0.5}$; (b) $3g(1 - \cos\theta)$; (c) $3/2g \sin\theta$; (d) 41.8°. **69.** (a) $0.083519ML^2 \approx 0.084ML^2$; (b) low by (only) 0.22%

Chapter 12

RE 12-1: (a) When is the sin of the angle between the vectors zero? Sin is zero for 0° and 180°. (b) Here the sin needs to equal ±1. This occurs at 90° and 270°. (c) Here $|\vec{c}\,||\vec{d}\,| \sin\phi = 3 \cdot 4 \sin\phi = 6$ so $\phi = \sin^{-1}(6/12)$ so $\phi = 30°$ or 150°.

RE 12-2: The time rate of change of the rotational momentum is equal to the net torque. 3 > 1 > 2 = 4 = zero.

RE 12-3: (a) 1 = 3 > 2 = 4 > 5 = zero, since $r_\perp$ is 4 m for both 1 and 3 and 2 m for both 2 and 4 and zero for 5. (b) Particles 2 and 3 have negative rotational momentum about o, since $\vec{\ell} = \vec{r} \times \vec{p}$ points into the page for each of them.

RE 12-4: (a) Since the rate of change of the rotational momentum is equal to the applied torque, which is the same for all three cases, all three objects increase their rotational momentum at the same rate; and assuming all three started from rest, they will all have the same rotational momentum at any given time. (b) Look at Table 11-2 (Some Rotational Inertias). Note that $I_{hoop} > I_{disk} > I_{sphere}$. Since $L = I\omega$ and they all have the same L, the object with the biggest I will have the smallest ω; $\omega_{sphere} > \omega_{disk} > \omega_{hoop}$.

RE 12-5: (a) Decrease, since although the total mass of the system has not changed, it is distributed closer to the axis of rotation. (b) Remain the same, since there is no net external torque. (c) If I decreases and L is constant, then ω must increase.

Problems

1. (a) 59.3 rad/s; (b) 9.31 rad/s^2; (c) 70.7 m. **3.** -3.15 J. **5.** 1/50 **7.** (a) 8.0°; (b) more. **9.** (a) 13 cm/s^2; (b) 4.4 s; (c) 55 cm/s; (d) 1.8×10^{-2} J; (e) 1.4 J; (f) 27 rev/s. **11.** (a) 10 s; (b) 897 m. **13.** the third. **17.** (a) 10 N · m, parallel to yz plane, at 53° to $+y$; (b) 22 N · m, $-x$. **19.** (a) (50 N · m)$\hat{k}$; (b) 90°. **21.** (a) (-170 kg · m^2/s)$\hat{k}$; (b) (+56 N · m)$\hat{k}$; (c) (+56 kg · m^2/s^2)$\hat{k}$. **23.** (a) 0; (b) $8t$ N · m, in $-z$ direction; (c) $2/\sqrt{t}$ N · m, $-z$; (d) $8/t^3$ N · m, $+z$. **25.** 9.8 kg · m^2/s. **27.** (a) 0; (b) (8.0 N · m)$\hat{i}$ + (8.0 N · m)$\hat{k}$. **29.** (a) mvd; (b) no; (c) 0, yes. **31.** (a) -1.47 N · m; (b) 20.4 rad; (c) -29.9 J; (d) 19.9 W. **33.** (a) $14md^2$; (b) $4md^2\omega$; (c) $14md^2\omega$. **35.** $\omega_1 R_A R_B I_A/(I_A R_B^2 + I_B R_A^2)$. **37.** (a) 3.6 rev/s; (b) 3.0; (c) in moving the bricks in, the forces on them from the man transferred energy from internal energy of the man to kinetic energy. **39.** (a) 267 rev/min; (b) $^2/_3$. **41.** (a) 149 kg · m^2; (b) 158 kg · m^2/s; (c) 0.746 rad/s **43.** $\frac{m}{M + m}\left(\frac{v}{R}\right)$ **45.** (a) $(mRv - I\omega_1)/(I + mR^2)$; (b) no, energy transferred to internal energy of cockroach. **47.** 3.4 rad/s. **49.** (a) 0.148 rad/s; (b) 0.0123; (c) 181°. **51.** The day would be longer by about 0.8 s. **53.** (a) 18 rad/s; (b) 0.92 **55.** (a) 0.24 kg · m^2; (b) 1800 m/s **57.** $\theta = \cos^{-1}\left[1 - \frac{6m^2h}{d(2m + M)(3m + M)}\right]$. **59.** 11.0 m/s **61.** (a) 0.180 m ; (b) clockwise

Chapter 13

RE 13-1: Situations (c), (e), and (f) can yield static equilibrium, since in each case both the net force and the net torque can be zero. In (a), (b), and (d) the net force can be zero but the net torque cannot.

RE 13-2: The apple's center of gravity will end up directly below the rod, since only in that position is the net torque on the apple *stably* zero. The net torque on the apple is also zero when the apple's center of gravity is directly *above* the rod, but this is an *unstable* equilibrium point and the slightest rotation will cause the apple to rotate away from this position.

RE 13-3: You are better off if there is no friction between the ladder and the wall. With no friction between the ladder and the ground, the ground cannot exert any *horizontal* force to counter the horizontal force that the wall must exert on the ladder to keep it in place.

RE 13-4: In each of these three cases, the net horizontal force is zero independent of the magnitudes of the three unknown forces. This leaves only two independent equations for equilibrium—namely, net vertical force equals zero and net torque equals zero. But we have three unknowns to solve for. Since we can't do this, each of these three situations is indeterminate.

RE 13-5: Equation 13-29 tells us that, for elastic stretching, Young's modulus is just the stress (F/A) divided by the strain ($\Delta L/L$). Relative to rod 1, rod 2 has the same stress and twice the strain, and so its Young's modulus is half that of rod 1. By the same reasoning, rod 3 also has half the Young's modulus of rod 1, and rod 4 has a Young's modulus that is four times larger than that of rod 1. So, from higher to lower Young's modulus, rod 4 is the largest, rod 1 is next, and rods 2 and 3 tie for smallest.

RE 13-6: During bending, the particles on the inside of the bend are pushed closer together while those on the outside of the bend are pulled farther apart. During a shear deformation, adjacent planes of particles shift laterally with respect to one another. While the planes remain the same distance from one another, the "springs" (bonds) between adjacent planes are each stretched by the same amount.

Problems

1. (a) 2; (b) 7 **3.** (a) $(-27\text{ N})\hat{\text{i}} + (2\text{ N})\hat{\text{j}}$; (b) 176° counterclockwise from $+x$ direction **5.** 7920 N **7.** (a) $(mg/L)\sqrt{L^2 + r^2}$; (b) mgr/L **9.** (a) 1160 N, down; (b) 1740 N, up; (c) left; (d) right **11.** 74 g **13.** (a) 280 N; (b) 880 N, 71° above the horizontal **15.** (a) 8010 N; (b) 3.65 kN; (c) 5.66 kN **17.** 71.7 N **19.** (a) 5.0 N; (b) 30 N; (c) 1.3 m **21.** $mg\sqrt{\dfrac{2rh - h^2}{r - h}}$ **23.** (a) 192 N; (b) 96.1 N; (c) 55.5 N **25.** (a) 6630 N; (b) 5740 N; (c) 5960 N **27.** 2.20 m **29.** 0.34 **31.** (a) 211 N; (b) 534 N; (c) 320 N **33.** (a) 445 N; (b)0.50; (c) 315 N **35.** (a) slides at 31°; (b) tips at 34° **37.** (a) 6.5×10^6 N/m^2; (b) 1.1×10^{-5} m **39.** (a) 867 N; (b) 143 N; (c) 0.165 **41.** 44 N

Chapter 14

RE 14-1: The ratio (relative amount) of the magnitudes of these two forces depends only on the square of the ratio of the two center-to-center distances between the Earth and the other mass.

RE 14-2: Equation 14-2 tells us that g (the acceleration of a freely falling body) is just (Gm^{Earth}/r^2) where r is the distance to the center of the Earth to the point where g is measured. This is consistent with the model that assumes that the Moon stays in its orbit simply because it is in free fall. Although the observations are consistent with this model, this does not "prove" that the model is "true." It only establishes that this model is "good enough" to account for the data at hand.

RE 14-3: Since the location of the particle lies outside each of the spheres at the same distance from the center of the sphere in each case, each of the spheres will exert exactly the *same* magnitude force on the particle.

RE 14-4: $\vec{F}^{\text{grav}}$ due to the Earth *always* points directly toward the center of the Earth. However, the object's apparent weight associated with $\vec{N}$, (the "normal" force exerted on an object "at rest" on the surface of the rotating Earth), is *not* always directed exactly *away* from the center of the Earth! In fact, $\vec{N}$ points directly away from the center of the Earth only at the Earth's poles and at its equator. Why?

RE 14-5: In each case the direction of $\vec{F}^{\text{grav}}$ would be toward the center of the Earth. Case A: The magnitude of $\vec{F}^{\text{grav}}$ would decrease as $1/r^2$ where r is the distance to the center of the Earth. Case B: The magnitude of $\vec{F}^{\text{grav}}$ would be proportional to *r, and hence decrease*. Case C: Because of the considerably higher density of the Earth's core compared with its surface crust, the magnitude of $\vec{F}^{\text{grav}}$ would increase at first but then decrease to zero as we moved toward the center of the Earth.

RE 14-6: (a) The gravitational potential energy of the ball–sphere system increases. (b) The gravitational force between the ball and the sphere is attractive (inward), and the displacement is outward. Since the force and displacement are in opposite directions, the work done by the gravitational force is negative.

Problems

1. 19 m **3.** 29 pN **5.** 1/2 **7.** 2.60×10^5 km **9.** 0.017 N, toward the 300 kg sphere **11.** 3.2×10^{-7} N **13.** $\dfrac{GmM}{d^2}\left[1 - \dfrac{1}{8(1 - R/2d)^2}\right]$ **15.** 2.6×10^6 m **17.** (b) 1.9 h **21.** (a) $0.414R$; (b) $0.5R$ **23.** (a) $(3.0 \times 10^{-7}\text{ N/kg})m$; (b) $(3.3 \times 10^{-7}\text{ N/kg})m$; (c) $(6.7 \times 10^{-7}\text{ N/kg·m})mr$ **25.** (a) 9.83 m/s^2; (b) 9.84 m/s^2; (c) 9.79 m/s^2 **27.** (a) -1.3×10^{-4} J; (b) less; (c) positive; (d) negative **29.** (a) 0.74; (b) 3.7 m/s^2; (c) 5.0 km/s **31.** (a) 5.0×10^{-11} J; (b) -5.0×10^{-11} J **35.** (a) 1700 m/s; (b) 250 km; (c) 1400 m/s **37.** (a) 82 km/s; (b) 1.8×10^4 km/s **39.** 2.5×10^4 km

Chapter 15

RE 15-1: Half the weight of the woman, (125 lb/2)(9.8 N/2.2 lb) ≈ 300 N, is supported by her two spike heels. Let's say that each heel makes contact with 1 cm^2 = 10^{-4} m^2 of the floor. Then the pressure of her heels on the floor is $P = F/A = (300\text{ N}/10^{-4}\text{ m}^2) = 3 \times 10^6$ Pa. This estimate is close to that presented in the table. This pressure is high because of the small contact area over which this otherwise modest force is applied. An automobile has a much larger contact area.

RE 15-2: If air and water are made up of molecules that are about the same size and mass, then the average distance between the molecules in air at sea level must be about $1000^{1/3} = 10$ times larger than those of the water. This suggests that there is significantly more empty space around each air molecule, allowing them to be compressed closer together by quite a bit before they fill all of the available volume.

RE 15-3: The force the air exerts on the book is about (10^5 N/m^2) $(2.54 \times 10^{-2}\text{ m/in})^2$ (2.2 lb/9.8 N) (8 in)(10 in) ≅ 1200 lb. The close fit and the flexibility of the rubber mat prevents air from leaking into the space between the mat and the smooth tabletop, holding the mat down against the table with close to the full 1200 lb of force the air exerts on the top surface of the mat. The rougher surface of the book, as well as its rigidity, let air readily leak into the space between the book and the table when you start to pick up the book. This "equalizes" the pressure on each side of the book, reducing the net force that the air exerts on the book to a negligible amount.

RE 15-4: The density of air is only about one-thousandth that of water.

RE 15-5: The pressure at a depth Δy is the *same* in each container of oil. The shape of the container does not matter.

RE 15-6: Compressible fluids, like compressible springs, can "absorb" work and store it as elastic potential energy. Increasing the pressure of the compressible fluid in the hydraulic jack will thus store some of the work done on the fluid as elastic potential energy and slightly reduce the amount of work that the fluid does on the output by that amount.

RE 15-7: The pressure at the bottom of this container is determined solely by the depth of the fluid above the bottom and the pressure that the air exerts on the surface of that fluid. In particular, the weight of the "extra" fluid that lies outside the central column is *not* carried by the horizontal bottom of the container and does *not* increase the pressure there.

RE 15-8: (a) Since the penguin floats in each of the three fluids, each fluid supplies a buoyant force exactly equal to the penguin's weight, so each fluid supplies the *same* buoyant force ($A = B = C$). (b) The penguin must displace the amount of fluid that matches her weight. Thus she *displaces* more of the least dense fluid B than of A, and even less of the most dense fluid C ($B > A > C$).

RE 15-9: You need to make sure that the weight of the canoe and its load is less than that of the water it displaces before the water starts coming in over the top edge of the hull. Although a chunk of concrete cannot displace its weight with water, a thin concrete canoe and its riders can.

RE 15-10: The net flow into (+) and out of (−) the entire system must be zero. So: $+x + (4 + 8 + 4 - 6 + 5 - 2)\ \text{cm}^3/\text{s} = 0\ \text{cm}^3/\text{s}$ or $x = -13\ \text{cm}^3/\text{s}$, so fluid flows out of the unlabeled pipe at a rate of $13\ \text{cm}^3/\text{s}$.

RE 15-11: (a) The area of face 1 is $4.0\ \text{cm}^2 = 4.0 \times 10^{-4}\ \text{m}^2$. Face 2 has an area of $5.7\ \text{cm}^2 = 5.7 \times 10^{-4}\ \text{m}^2$. Face 3 has an area of $8.0\ \text{cm}^2 = 8.0 \times 10^{-4}\ \text{m}^2$. (b) The total surface area of all 6 faces is $69.7\ \text{cm}^2 = 69.7 \times 10^{-4}\ \text{m}^2$.

RE 15-12: (a) The flux through any face is $v\ \Delta A \cos(\theta)$. Thus the flux through face 1 is $(0.5\ \text{m/s})\ (4.0 \times 10^{-4}\ \text{m}^2)\ (\cos(0)) = +2.0 \times 10^{-4}\ \text{m}^3/\text{s}$. The flux through face 2 is $(0.5\ \text{m/s})\ (5.7 \times 10^{-4}\ \text{m}^2)\ (\cos(45°)) = +2.0 \times 10^{-4}\ \text{m}^3/\text{s}$. The flux through face 3 is $(0.5\ \text{m/s})\ (8.0 \times 10^{-4}\ \text{m}^2)\ (\cos(180°)) = -4.0 \times 10^{-4}\ \text{m}^3/\text{s}$. (b) The flux through the front, back, and bottom faces is zero because $\theta = 90°$ for each of these faces and so the $\cos(\theta)$ term in the expression for the flux is zero. (c) Adding the contributions from all six faces yields zero net flux through this closed surface, as expected.

RE 15-13: (a) The volume flow rate is the *same* through each of the four sections. (b) The flow speed is largest in section 1, followed by section 2 and section 3, where it will be the same, and finally section 4 has the smallest flow speed. Recall that the flow speed is inversely proportional to the local cross-sectional area of the pipe. (c) The pressure will be greatest in section 4, less in section 3, still less in section 2, and least in section 1. The pressure difference between sections 2 and 3 is due to their difference in altitude. The pressure differences between sections at the same altitude are due to differences in the flow speed.

Problems

1. 1.1×10^5 Pa or 1.1 atm **3.** 2.9×10^4 N **5.** 0.074 **7.** (b) 26 kN **9.** 5.4×10^4 Pa **11.** (a) 5.3×10^6 N; (b) 2.8×10^5N; (c) 7.4×10^5 N; (d) no **13.** 7.2×10^5 N **15.** $\frac{1}{4}\rho g A(h_2 - h_1)^2$ **17.** 1.7 km **19.** (a) $\rho g W D^2/2$; (b) $\rho g W D^3/6$; (c) $D/3$ **21.** (a) 7.9 km; (b) 16 km **23.** 4.4 mm **25.** (a) $2.04 \times 10^{-2}\ \text{m}^3$; (b) 1570 N **27.** (a) $670\ \text{kg/m}^3$; (b) $740\ \text{kg/m}^3$ **29.** (a) 1.2 kg; (b) $1300\ \text{kg/m}^3$ **31.** 57.3 cm **33.** $0.126\ \text{m}^3$ **35.** (a) $45\ \text{m}^2$; (b) car should be over center of slab if slab is to be level **37.** (a) 9.4 N; (b) 1.6 N **39.** 8.1 m/s **41.** 66 W **43.** (a) 2.5 m/s; (b) 2.6×10^5 Pa **45.** (a) 3.9 m/s; (b) 88 kPa **47.** (a) $1.6 \times 10^{-3}\ \text{m}^3/\text{s}$; (b) 0.90 m **49.** 116 m/s **51.** (a) $6.4\ \text{m}^3$; (b) 5.4 m/s; (c) 9.8×10^4 Pa **53.** (a) 74 N; (b) $150\ \text{m}^3$ **55.** (b) $2.0 \times 10^{-2}\ \text{m}^3/\text{s}$ **57.** (b) 63.3 m/s

Chapter 16

RE 16-1: The amplitude and the angular frequency will stay the same. The initial phase will differ from ϕ_0 by 90° or $\pi/2$ since you can think of a cosine as a sine that has been shifted 90° to the left.

RE 16-2: (a) When $t = 2.00\ T$ the particle will have moved through two full oscillations and will be back where it started from—namely, at $x = -X$. (b) When $t = 3.50T$ the particle will have moved through three full oscillations and an additional half oscillation and so will be at $x = +X$. (c) When $t = 5.25T$ the particle will have moved through five full oscillations and an additional quarter oscillation and so will be at $x = 0$.

RE 16-3: Equation 16-12 tells us that the period of a mass on a given spring increases as the amount of oscillating mass increases. The fact that the mass of the spring itself oscillates along with the mass on its end suggests that some of the spring's mass should be included in the mass that appears in Eq. 16-12. Since the spring oscillates with a progressively smaller amplitude as we go from its moving end to its fixed end, only some fraction of the spring's mass needs to be included in this corrected total oscillating mass.

RE 16-4: Only (a) implies simple harmonic motion. Although (b) is a restoring type of force, it is quadratic, not linear in x. Force (c) is repulsive rather than attractive, driving the particle away from $x = 0$ rather than back toward it. Force (d) is both repulsive and nonlinear.

RE 16-5: The particle's velocity component is zero at $t = t_2$ and t_4. The particle is moving to the left at its greatest speed at $t = t_1$ and it is moving to the right at its greatest speed at $t = t_3$. Considering v_x as a mathematical function of t, we can indeed say that v_x is a minimum at t_1 and a maximum at t_3, but do remember that it is actually moving at its fastest speed when the velocity component is both a minimum and a maximum.

RE 16-6: The vertical component a_x of the acceleration is *increasing* in regions 1 and 2 and it is *decreasing* in regions 3 and 4. Note, however, that the *magnitude* of this acceleration is actually *decreasing* in regions 1 and 3 while the magnitude is *increasing* in regions 2 and 4. Pause and reflect on this!

RE 16-7: In each of these cases, the net force acting on the pendulum mass is proportional to the mass itself. Since Newton's Second Law tells us that acceleration is net force divided by mass, the mass cancels out here and so acceleration will be independent of the mass in these cases.

RE 16-8: "Same shape and size" for these three pendula means that the rotational inertia of each is simply proportional to its mass *with the same constant of proportionality in each case*. "Suspended at the same point" means the same distance from the point of suspension to the center of mass in each case. Since I/m and h are the same for each of the three, Eq. 16-26 tells us that each will have the same period.

RE 16-9: Since $K = 3$ J and $U = 2$ J at *a* given point, then the total mechanical energy of this system is $E = K + U = 5$ J *at every point* in its motion. Conservation of mechanical energy rules! (a) In particular, when the block is at $x = 0$, the system's potential energy is zero and so its kinetic energy must be 5 J. (b) At $x = -X$, the system's kinetic energy is zero so then $U = 5$ J.

RE 16-10: From Eq. 16-39 the time it takes for the mechanical energy of a damped oscillator to fall to one-fourth (or to any given fraction, for that matter) of its initial value is proportional to m/b. The ratio of m/b for set 2 is 4/6 = 2/3 that of set 1, and for set 3 it is 1/3 of that for set 1. Thus set 1 takes the longest time to lose one-fourth of its mechanical energy, followed by set 2, then by set 3. (set 1 > set 2 > set 3)

Problems

1. (a) 0.50 s; (b) 2.0 Hz; (c) 18 cm **3.** (a) 0.500 s; (b) 2.00 Hz; (c) 12.6 rad/s; (d) 79.0 N/m; (e) 4.40 m/s; (f) 27.6 N **5.** $f > 500$ Hz **7.** (a) 6.28×10^5 rad/s; (b) 1.59 mm **9.** (a) 1.0 mm; (b) 0.75 m/s; (c) 570 m/s^2 **11.** (a) 1.29×10^5 N/m; (b) 2.68 Hz **13.** 7.2 m/s **15.** 2.08 h **17.** 3.1 cm **19.** (a) 5.58 Hz; (b) 0.325 kg; (c) 0.400 m **21.** (a) 2.2 Hz; (b) 56 cm/s; (c) 0.10 kg; (d) 20.0 cm below y_i 23. (a) $0.183A$; (b) same direction **29.** (a) $(n + 1)k/n$; (b) $(n + 1)k$; (c) $\sqrt{(n + 1)/n}\,f$; (d) $\sqrt{n + 1}\,f$ **31.** (a) 39.5 rad/s; (b) 34.2 rad/s; (c) 124 rad/s^2 **33.** 99 cm **35.** 5.6 cm **37.** (a) $2\pi\sqrt{\dfrac{L^2 + 12d^2}{12gd}}$; (b) increases for $d < L/\sqrt{12}$, decreases for $d > L/\sqrt{12}$; (c) increases; (d) no change **39.** (a) 0.205 kg·m^2; (b) 47.7 cm; (c) 1.50 s **41.** $2\pi\sqrt{m/3k}$ **43.** (a) 0.35 Hz; (b) 0.39 Hz; (c) 0 **45.** (b) smaller **47.** (a) $(r/R)\sqrt{k/m}$; (b) $\sqrt{k/m}$; (c) no oscillation **49.** 37 mJ **51.** (a) 2.25 Hz; (b) 125 J; (c) 250 J; (d) 86.6 cm **53.** (a) $\frac{3}{4}$; (b) $\frac{1}{4}$; (c) $x^{\max}/\sqrt{2}$ **55.** (a) 16.7 cm; (b) 1.23% **57.** 0.39 **59.** (a) 14.3 s; (b) 5.27 **61.** (a) $F^{\max}/b\omega$; (b) $F^{\max}/b$

Chapter 17

RE 17-1: (a) None of these graphs correctly shows the displacement of the rope versus position along the rope at $t = 0$ s. Graph (b) is the closest to correct of the four but fails to show the considerable length of undisturbed rope that lies between $x = 0$ and the trailing (left) edge of the pulse at $t = 0$ s. (b) Graph (a) correctly shows the displacement of the rope versus time at $x = x_1$ as the pulse passes by.

RE 17-2: Realizing that each of these phase expressions is of the form $(kx - \omega t)$ and that the wavelength $\lambda = 2\,\pi/k$, we see that wave 1 has the smallest wavelength and thus the largest k so it must correspond to case (c). Wave 2 has the smallest k and so must go with case (a), and wave 3 has the middle value of k and so matches case (b).

RE 17-3: The velocity v_y^{string} describes the up and down (transverse) motion of a particular small segment of the string as the wave passes by that location. Typically the velocity varies rapidly between positive and negative values as the wave goes by. The magnitude of the maximum of this velocity increases with increasing amplitude of passing wave having the same wavelength and frequency. The other velocity, v_x^{wave} tells us how fast and in what direction any given *crest* of the wave itself moves along the rope. For a uniform rope its time does not vary at all and it does not depend on the amplitude of the wave. In the derivation in this section, v_x^{wave} is used to obtain the mass of the segment of string under study and v_y^{string} is used to obtain the momentum change of the segment.

RE 17-4: If you increase the frequency of the oscillations driving waves in a string, holding the tension constant, then (a) the speed of the waves remains the same and (b) the wavelength decreases. If you instead increase the tension keeping the driving frequency constant, then (c) the wave speed increases and (d) the wavelength also increases.

RE 17-5: (a) Equation (1) represents the interference of a pair of waves traveling in the positive x direction. (b) Equation (3) represents the interference of a pair of waves traveling in the negative x direction. (c) Equation (2) represents the interference of a pair of waves traveling in opposite directions.

RE 17-6: (a) The missing frequency is 75 Hz. (b) The seventh harmonic has a frequency of 7×75 Hz = 525 Hz.

Problems

1. (a) 3.49 m^{-1}; (b) 31.5 m/s **3.** (a) 0.68 s; (b) 1.47 Hz; (c) 2.06 m/s **7.** (a) $y(x, t) = 2.0 \sin 2\pi(0.10x - 400t)$, with x and y in cm and t in s; (b) 50 m/s; (c) 40 m/s **9.** (a) 11.7 cm; (b) π rad **11.** 129 m/s **13.** (a) 15 m/s; (b) 0.036 N **15.** $y(x, t) = 0.12 \sin(141x + 628t)$, with y in mm, x in m, and t in s **17.** (a) $2\pi y^{\max}/\lambda$; (b) no **19.** (a) 5.0 cm; (b) 40 cm; (c) 12 m/s; (d) 0.033 s; (e) 9.4 m/s; (f) $5.0 \sin(16x + 190t + 0.93)$, with x in m, y in cm, and t in s **21.** 2.63 m from the end of the wire from which the later pulse originates **25.** $1.4y^{\max}$ **27.** (a) 0.31 m; (b) 1.64 rad; (c) 2.2 mm **29.** (a) 140 m/s; (b) 60 cm; (c) 240 Hz **31.** (a) 82.0 m/s; (b) 16.8 m; (c) 4.88 Hz **33.** 7.91 Hz, 15.8 Hz, 23.7 Hz **35.** (a) 105 Hz; (b) 158 m/s **37.** (a) 0.25 cm; (b) 120 cm/s; (c) 3.0 cm; (d) zero **39.** (a) 50 Hz; (b) $y = 0.50 \sin[\pi(x \pm 100t)]$, with x in m, y in cm, and t in s **41.** (a) 1.3 m; (b) $y = 0.002 \sin(9.4x) \cos(3800t)$, with x and y in m and t in s **43.** (a) 2.0 Hz; (b) 200 cm; (c) 400 cm/s; (d) 50 cm, 150 cm, 250 cm, etc.; (e) 0, 100 cm, 200 cm, etc. **47.** (a) 323 Hz; (b) eight **49.** 5.0 cm

Chapter 18

RE 18-1: We express units in terms of very basic elements of length [L], mass [M] and time [T]. Since B is a force per unit area, its units are $B \sim \dfrac{[M][L]/[T^2]}{[L^2]} = $ [M]/[L][T^2]. ρ is a mass per unit volume so $\rho \sim$ [M]/[L^3]. $B/\rho \sim$ [L^2]/[T^2] and $\sqrt{B/\rho} \sim$ [L]/[T] or a "velocity" given by [m]/[s] in SI units.

RE 18-2: The measured wave speed for the round trip is $v^{\text{wave}} = (2)(2.4\ \text{m})/(.0133 - .0002)(\text{s}) = 366$ m/s, which is in reasonable agreement with the stated 343 m/s in room-temperature air.

RE 18-3: Since energy per unit time passing through a surface that faces a source of sound is just the product of the sound intensity there and the area of the surface, and since sound intensity falls off with distance from the source, (a) the intensity of the sound is the same at surfaces 1 and 2 and is smaller at surface 3, and (b) the areas of surfaces 1 and 2 are equal while that of surface 3 is larger.

RE 18-4: The second harmonic of the longer pipe B has the same frequency as the first harmonic of the shorter pipe A.

RE 18-5: (a) and (e) have greater detected frequency than emitted frequency. (b) and (f) have reduced detected frequencies. (c) and (d) are indeterminate.

Problems

1. divide the time by 3 **3.** (a) 79 m, 41 m; (b) 89 m **5.** 1900 km **7.** 40.7 m **9.** (a) 0.0762 mm; (b) 0.333 mm **11.** (a) 343 $(1 + 2m)$ Hz, with m being an integer from 0 to 28; (b) $686m$ Hz, with m being an integer from 1 to 29 **13.** (a) 143 Hz, 429 Hz, 715 Hz; (b) 286 Hz, 572 Hz, 858 Hz **15.** 17.5 cm **17.** 15.0 mW **19.** (a) 1000; (b) 32 **21.** (a) 59.7; (b) 2.81×10^{-4} **23.** (a) 5000; (b) 71; (c) 71 **25.** (a) 5200 Hz; (b) amplitude$_{SAD}$/amplitude$_{SBD}$ = 2 **27.** (a) 57.2 cm; (b) 42.9 cm **29.** (a) 405 m/s; (b) 596 N; (c) 44.0 cm; (d) 37.3 cm **31.** (a) 1129, 1506, and 1882 Hz **33.** 12.4 m **35.** (a) node; (c) 22 s **37.** 45.3 N **39.** 387 Hz **41.** 0.02 **43.** 17.5 kHz **45.** (a) 526 Hz; (b) 555 Hz **47.** (a) 1.02 kHz; (b) 1.04 kHz **49.** 155 Hz **51.** (a) 485.8 Hz; (b) 500.0 Hz; (c) 486.2 Hz; (d) 500.0 Hz **53.** (a) 598 Hz; (b) 608 Hz; (c) 589 Hz **55.** (a) 42°; (b) 11 s

Chapter 19

RE 19-1: Some properties that are measurable include mass, volume, hardness, elasticity, and breaking strength. Flavor and color, for example, are less easily quantified.

RE 19-2: For comfort we often want to maintain the temperature inside our homes significantly higher (in winter) or lower (in summer) than that of the environment outside. Thermal insulation inside the walls of our homes reduces the amount of heat energy that would otherwise flow out of the house in winter or into the house in summer, reducing the expenditure of energy needed to maintain a comfortable interior temperature.

RE 19-3: Equation 19-5 tells us that, for the same amount of heat energy added to the same mass, the temperature increase is inversely proportional to the specific heat of the material being heated. Thus object A has a greater specific heat than object B.

RE 19-4: The good news for the firefighter is that each kilogram of water sprayed on the fire can remove a relatively large amount of heat from the burning object. The bad news is that this heat can easily be transferred to the firefighter's body if the steam condenses on her skin. One gram of steam at 100 °C condensing on one gram of (water-like) flesh at 37 °C will yield two grams of water-like material at a temperature of (100 °C + 37 °C)/2 = 69 °C.

RE 19-5: For the net work done by the gas on its environment to be positive, the top curve must go from left (lower pressure) to right (higher pressure.) For maximum positive work each cycle that area on the P-V diagram enclosed by the cycle must be as large as possible. So curves c and e yield the maximum possible positive work here.

RE 19-6: (a) The change in the internal energy of the gas is the same in each case. (b) The work done by the gas is greatest for path 4, then path 3, path 2, and finally path 1. (c) The thermal energy added to the gas is also greatest for path 4, then path 3, path 2, and finally path 1.

RE 19-7: (a) For any cyclic process, $Q - W = 0$ or $Q = W$. (b) Because the net work that the gas does on its environment is negative here, that means that the net thermal energy Q transfer to the system is also negative and has the same value as the work. Thus thermal energy equal in magnitude to the work done by the system must be transferred *from the gas to the environment* each cycle.

RE 19-8: (a) Plates 2 and 3 will be tied for the largest increase in their vertical heights, followed by plate 1 and then plate 4. (b) Plate 3 will have the greatest increase in area, followed by plate 2, with plates 1 and 4 tied for last place.

RE 19-9: The hole gets larger as the plate's temperature increases, as would a circle drawn on the plate.

RE 19-10: The pressure at the base of the rod decreases, since the weight of the rod remains constant while the area of the base supporting that weight increases a bit.

RE 19-11: The greater the thermal conductivity, the smaller is the temperature difference between the two faces of samples of the same thickness. Since the temperature differences here, going from left to right, are 10 C°, 5 C°, 15 C°, and 5 C°, slabs b and d tie for greatest thermal conductivity, followed by slab a, with slab c having the smallest thermal conductivity.

Problems

1. (a) 320 °F; (b) −12.3 °F **3.** (a) Dimensions are inverse time. **5.** (a) 523 J/kg·K; (b) 26.2 J/mol·K; (c) 0.600 mole **7.** 42.7 kJ **9.** 1.9 times as great **11.** (a) 33.9 Btu; (b) 172 F° **13.** 160 s **15.** 2.8 days **17.** 742 kJ **19.** 73 kW **21.** 33 g **23.** (a) 0°C; (b) 2.5°C **25.** A: 120 J, B: 75 J, C: 30 J **27.** −30 J **29.** (a) 6.0 cal; (b) −43 cal; (c) 40 cal; (d) 18 cal, 18 cal **31.** 348 K **33.** (a) −40°; (b) 575°; (c) Celsius and Kelvin cannot give the same reading **35.** 960 μm **37.** 2.731 cm **39.** 29 cm^3 **41.** 0.26 cm^3 **43.** 360°C **47.** 0.68 s/h, fast **49.** 7.5 cm **51.** (a) 0.13 m; (b) 2.3 km **53.** 1660 J/s **55.** (a) 16 J/s; (b) 0.048 g/s **57.** 0.50 min **59.** (a) 17 kW/m^2; (b) 18 W/m^2 **61.** 0.40 cm/h

Chapter 20

RE 20-1: Processes (a), (b), (d), and (e) start and end on the same isotherm because each has $PV = 12$ units.

RE 20-2: (a) The average translational kinetic energy doubles when the temperature in kelvins of the gas doubles. (b) The average translational kinetic energy would be zero if the temperature of the gas were 0 K. However, all real gases condense into liquids before reaching 0 K.

RE 20-3: (a) The average kinetic energy of each of the three types of molecules is the same. (b) Since that is true, the rms speed of each is inversely related to its molecular mass, so type 3 has the greatest rms speed, followed by type 2, with type 1 the smallest.

RE 20-4: Since the internal energy of an ideal gas depends only on its temperature, path 5 has the greatest change in E^{int}, followed by the other four paths, all of which tie for second place.

Problems

1. 0.933 kg **3.** 6560 **5.** (a) 5.47×10^{-8} mol; (b) 3.29×10^{16} **7.** (a) 0.0388 mol; (b) 220°C **9.** (a) 106; (b) 0.892 m^3 **11.** $A(T_2 - T_1) - B(T_2^2 - T_1^2)$ **13.** 5600 J **15.** 100 cm^3 **17.** 2.0×10^5 Pa **19.** 180 m/s **21.** 9.53×10^6 m/s **23.** 1.9 kPa **25.** 3.3×10^{-20} J **27.** (a) 6.75×10^{-20} J; (b) 10.7 **31.** (a) 6×10^9 km **33.** 15 cm **35.** (a) 3.27×10^{10}; (b) 172 m **37.** (a) 6.5 km/s; (b) 7.1 km/s **39.** (a) 1.0×10^4 K; (b) 1.6×10^5 K; (c) 440 K, 7000 K; (d) hydrogen, no; oxygen, yes **41.** (a) 7.0 km/s; (b) 2.0×10^{-8} cm; (c) 3.5×10^{10} collisions/s **43.** (a) $\frac{2}{3}v_0$; (b) $N/3$; (c) $122v_0$; (d) $1.31v_0$ **45.** $RT\ \ln(V_f/V_i)$ **47.** $(n_1C_1 + n_2C_2 + n_3C_3)/(n_1 + n_2 + n_3)$ **49.** (a) 6.6×10^{-26} kg; (b) 40 g/mol **51.** 8000 J **53.** (a) 6980 J; (b) 4990 J; (c) 1990 J; (d) 2990 J **55.** (a) 14 atm; (b) 620 K **59.** 1.40 **61.** (a) In joules, in the order Q, ΔE^{int}, W: $1 \rightarrow 2$: 3740, 3740, 0; $2 \rightarrow 3$: 0, −1810, 1810; $3 \rightarrow 1$: −3220, −1930, −1290; cycle: 520, 0, 520; (b) $V_2 = 0.0246$ m^3, $p_2 = 2.00$ atm, $V_3 = 0.0373$ m^3, $p_3 = 1.00$ atm

Chapter 21

RE 21-1: As the putty falls to the floor, gravitational potential energy is converted into translational kinetic energy. When the putty hits the floor it looks at first as if all the mechanical energy is somehow destroyed. But a closer look at the putty after the fall reveals that the putty and the floor beneath it have warmed up a bit. How so? As the putty collides with the floor, the floor does work on the putty. Since the putty doesn't bounce back, the work done on the putty system serves to raise its internal energy. Now the putty's temperature rises and it begins transferring microscopic thermal energy to its surroundings (air and floor) until thermal equilibrium is achieved. Even more careful observations show, in fact, that all of the mechanical energy present in the system before the fall is still there after the putty hits the floor, just in other forms, primarily as thermal energy.

RE 21-2: Driving a nail into a board, letting your hot coffee cool, and saying hello to your friend are all examples of irreversible processes in the sense that if you saw a movie of them running backward you would know something was wrong.

RE 21-3: Process (c) and (b) involve the same amount of heat energy transfer to the water, while (a) adds twice as much heat to the water. Process (a) also happens at the lowest average temperature, so it involves the greatest entropy change of the water, followed by (b) and then (c).

RE 21-4: Equation 21-11 relates the efficiency of a Carnot engine to the two thermodynamic temperatures between which it operates. Applying this to these three cases yields Carnot efficiencies of (a) 0.20, (b) 0.25, and (c) 0.33, so ranking the efficiencies, greatest first, yields (c), then (b), then (a).

RE 21-5: (a) Raising the lower temperature T_L by (δT) increases the numerator of Eq. 21-14 by (δT) and simultaneously decreases the denominator by the same amount. This yields the *greatest increase* in the coefficient of performance of the refrigerator. (b) Lowering the lower temperature T_L by (δT) decreases the numerator of Eq. 21-14 by (δT) and simultaneously decreases the denominator by the same amount. This yields the *greatest decrease* in the coefficient of performance of the refrigerator. (c) Increasing the higher temperature T_H by (δT) makes the denominator bigger by (δT) with no change in the numerator, decreasing the coefficient of performance of the refrigerator, but not as much as in (b). (d) Decreasing the higher temperature T_H by (δT) makes the denominator smaller by (δT) with no change in the numerator, increasing the coefficient of performance of the refrigerator, but not as much as in (a). So, from greatest to least, the changes in the coefficient of performance of the refrigerator are (a), (d), (c), and finally (b).

RE 21-6: If we had, say, 6 molecules, then the number of microstates corresponding to 3 molecules in each half of the box would be $6!/(3!)^2 = 20$. Generalizing Eq. 21-18 to three bins in the box with 2 molecules in each bin would have $6!/(2!)^3 = 90$. In this case a greater number of microstates is associated with dividing the box up into a larger number of equally populated equal subvolumes. This remains true as the number of molecules is increased, so (b) has more microstates than (a).

Problems

1. 14.4 J/K **3.** (a) 9220 J; (b) 23.0 J/K; (c) 0 **5.** (a) 5.79×10^4 J; (b) 173 J/K **7.** (a) 14.6 J/K; (b) 30.2 J/K **9.** (a) 57.0°C; (b) −22.1 J/K; (c) +24.9 J/K; (d) +2.8 J/K **13.** (a) 320 K; (b) 0; (c) +1.72 J/K **15.** +0.75 J/K **17.** (a) −943 J/K; (b) +943 J/K; (c) yes **19.** (a) $3p_0V_0$; (b) $\Delta E^{\text{int}} = 6RT_0$, $\Delta S = \frac{3}{2}R \ln 2$; (c) both are zero **21.** (a) 31%; (b) 16 kJ **23.** (a) 23.6%; (b) 1.49×10^4 J **25.** 266 K and 341 K **27.** (a) 1470 J; (b) 554 J; (c) 918 J; (d) 62.4% **29.** (a) 2270 J; (b) 14800 J; (c) 15.4% (d) 75.0%, greater **31.** (a) 78%; (b) 81 kg/s **33.** (a) $T_2 = 3T_1$, $T_3 = 3T_1/4^{\gamma-1}$, $T_4 = T_1/4^{\gamma-1}$, $p_2 = 3p_1$, $p_3 = 3p_1/4^\gamma$, $p_4 = p_1/4^\gamma$; (b) $1 - 4^{1-\gamma}$ **35.** 21 J **37.** 440 W **39.** 0.25 hp **41.** $[1 - (T_2/T_1)]/[1 - (T_4/T_3)]$ **45.** (a) $W = N!/(n_1!n_2!n_3!)$; (b) $[(N/2)!\,(N/2)!]/[(N/3)!\,(N/3)!\,(N/3)!]$; (c) 4.2×10^{16}

Chapter 22

RE 22-1: Electric stove, microwave, lights, car starter motor, toothbrush, computer, tape recorder, CD player, FM radio, amplifier, etc.

RE 22-2: (a) Since the two tapes have identical histories, they should have like charges and repel. (b) The observations were consistent with my predictions. The two tapes repelled each other.

RE 22-3: (a) If woodolin was a new type of charge then two wooden rods charged with linen would repel each other. A wooden rod would have to attract *both* the charged amber (or plastic) rod *and* the charged glass rod. (b) According to the text statements, this observation has never been made. It has always been the case that a suspected new type of charge (such as woodolin) always repels either a charged amber rod or a charged glass rod and attracts the other type rod. This makes it the same as one of the existing charges.

RE 22-4: A very simple explanation is that in a solid, all parts are stiff. But since one can melt ice into water and then boil water into a gas (water vapor) the atomic explanation seems quite plausible.

RE 22-5: I would discharge one of the spheres by touching it. Then I would allow the two spheres to touch each other. They should share the charge q equally so each sphere has charge $q/2$. If I *repeat* the process, then each sphere will have charge $(q/2)/2 = q/4$.

RE 22-6: (a) If the paper bits are uncharged, then there is no mutual attraction or repulsion. (b) "Induction" always causes the neutral object to be *attracted* toward the charged object, independent of the sign of the charge on the charged object. So, no, you can't tell the sign of the charge on the charged object in this way.

RE 22-7: (1) *A, B* is attractive (unlike charges), (2) *A, A* is repulsive (like charges), (3) *B, B* is repulsive (like charges), (4) *B, C* attract (by induction), (5) *C, C* nonexistent forces (both neutral), and (6) *C, A* attract (by induction).

RE 22-8: (a) Scotch tape acts like an insulator since charge doesn't draw away as you handle the tape at its ends. (b) A balloon behaves like an insulator, because when you charge it, it can stick by induction to a wall rather than touch and pull away.

RE 22-9: (a) No, since charges on it are not mobile. (b) If we start with a positively charged glass plate as the bottom plate in Fig. 22-10 and perform all the same steps, the aluminum pie plate will be negatively charged.

RE 22-10: All of these assertions are inconsistent with the experimental results in the text.

RE 22-11: (a) The central proton is attracted toward the electron, so this force is to the left. (b) The central proton is repelled by the other proton, so this force is also to the left. (c) Thus the net force on the central proton is to the left. (d) There are no locations along the line connecting the charges where the force on the former central proton can be zero. Since the magnitudes of the charges on the proton and electron are the same, the only location where the force magnitudes on the other proton are zero is halfway between the first two, but we know the forces don't cancel there.

Problems

1. -1.32×10^{13} C **3.** 6.3×10^{11} **5.** 122 mA **7.** (a) positron; (b) electron **9.** 1.38 m **11.** (a) 4.9×10^{-7} kg; (b) 7.1×10^{-11} C **13.** (a) 0.17 N; (b) -0.046 N **15.** either $-1.00\ \mu$C and $+3.00\ \mu$C or $+1.00\ \mu$C and $-3.00\ \mu$C **17.** (a) charge $-4q/9$ must be located on the line joining the two positive charges, a distance $L/3$ from charge $+q$. **19.** $q = Q/2$ **21.** (a) 3.2×10^{-19} C; (b) two **23.** (a) 0; (b) 1.9×10^{-9} N **25.** (a) 6.05 cm; (b) 6.05 cm from central bead **27.** $+13e$ **29.** (a) positive; (b) +9 **31.** 9.0 kN **33.** $1.72a$, directly rightward **35.** $-11.1\ \mu$C **37.** $q = 0.71Q$ **39.** (b) $1e$, 0.654 rad; $2e$, 0.889 rad; $3e$, 0.988 rad; $4e$, 1.047 rad; $5e$, 1.088 rad **41.** (a) Let $J = qQ/4\pi\varepsilon_0 d^2$. For $\alpha < 0$, $F = -J[\alpha^{-2} + (1 + |\alpha|)^{-2}]$; for $0 < \alpha < 1$, $F = J[\alpha^{-2} - (1 - \alpha)^{-2}]$; for $1 < \alpha$, $F = J[\alpha^{-2} + (\alpha - 1)^{-2}]$ **43.** (a) 5.7×10^{13} C, no; (b) 6.0×10^5 kg **45.** (b) $\pm 2.4 \times 10^{-8}$ C **47.** (a) $\frac{L}{2}\left(1 + \frac{1}{4\pi\varepsilon_0}\frac{qQ}{Wh^2}\right)$; (b) $\sqrt{3qQ/4\pi\varepsilon_0 W}$

Chapter 23

RE 23-1: $F^{elec} \propto 1/r^2$. Thus at 4 cm, F^{elec} would be $(1/2)^2 = 1/4$ of its value at 2 cm, or 9 mm. At 6 cm, F^{elec} would be $(1/3)^2 = 1/9$ of its value at 2 cm, or 4 mm.

RE 23-2: Since the force on the test object to the sources, $\vec{F}_{s \to t}$, varies from point to point in space, the test object must be small enough spatially to test the "local" value rather than the average value over too large a volume of space.

RE 23-3: The type of test charge makes no difference! For a negative test charge we would still use Eq. 23-9 to determine the electric field vector. But, the new $(\vec{F}^{elec})' = -\vec{F}^{elec}$ and the new negative charge $q_t' = -q_t$. So $\vec{E}_s'$ will equal E_s' (no charge).

RE 23-4: (a) Rightward, (b) leftward, (c) leftward, (d) rightward (p and e have the same charge magnitude and p is farther).

RE 23-5: (a) To the left, (b) to the left in a parabolic path, (c) its speed decreases at first, then increases. It will move in a straight line first rightward, then leftward.

RE 23-6: All four experience the same magnitude torque.

RE 23-7: Near a positive charge, $\vec{E}$ points always *away* from the charge; near a negative charge, $\vec{E}$ points always *toward* the charge.

RE 23-8: Just as for the two equidistant point charges in Fig. 23-10, we can "pair up" equal patches of charge equidistant from the point at which we are calculating $\vec{E}$ for all such patches of charge on the sheet, canceling the contributions to $\vec{E}$ parallel to the sheet.

Problems

1. 56 pC **3.** 3.07×10^{21} N/C, radially outward **5.** 50 cm from q_A and 100 cm from q_B **7.** 0 **9.** 1.02×10^5 N/C, upward **11.** (a) 47 N/C; (b) 27 N/C **13.** $4kQ/3d^2$ or $Q/3\pi\varepsilon_0 d^2$ **15.** 1.38×10^{-10} N/C, 180° from $+x$ **17.** 6.88×10^{-28} C · m **23.** $q/\pi^2\varepsilon_0 r^2$, vertically downward **25.** (a) $-q/L$; (b) $q/4\pi\varepsilon_0 a(L + a)$ **29.** (a) -1.72×10^{-15} C/m; (b) -3.82×10^{-14} C/m^2; (c) -9.56×10^{-15} C/m^2; (d) -1.43×10^{-12} C/m^3 **31.** $E = 2k|Q|(\sin\theta/2)/\theta R^2$ **33.** 217° **35.** 3.51×10^{15} m/s^2 **37.** 6.6×10^{-15} N **39.** (a) 1.5×10^3 N/C; (b) 2.4×10^{-16} N, up; (c) 1.6×10^{-26} N; (d) 1.5×10^{10} **41.** (a) 1.92×10^{12} m/s^2; (b) 1.96×10^5 m/s **43.** (a) 2.7×10^6 m/s; (b) 1000 N/C **45.** 27 μm **47.** (a) yes; (b) upper plate, 2.73 cm **49.** (a) 27 km/s; (b) 50 μm **51.** 5.2 cm **53.** (a) 0; (b) 8.5×10^{-22} N · m; (c) 0 **55.** $(1/2\pi)\sqrt{pE/I}$ **57.** 1.92×10^{-21} J **59.** (a) 6.4×10^{-18} N; (b) 20 N/C **63.** (a) to the right in the figure; (b) $(2kqQ\cos 60°)/a^2$

Chapter 24

RE 24-1: (a) $\phi = \vec{v} \cdot \Delta\vec{A} = (3\text{ m/s})(2 \times 10^{-4}\text{ m}^2)\cos 60° = (3 \times 10^{-4}\text{ m}^3/\text{s})$. Whatever fluid that is represented by this vector velocity field is flowing through this surface area dA. (b) $\phi = \vec{E} \cdot \Delta\vec{A} = (3\text{ N/C})(2 \times 10^{-4}\text{ m}^2)\cos 60° = 3 \times 10^{-4}\text{ N} \cdot \text{m}^2/\text{C}$. Nothing is flowing through the small area. Instead, the flux represents the product of the E-field component normal to the area.

RE 24-2: To find the answers we simply sum the flux through all six faces. We get $\phi^{net}_{cube\ 1} = 0$ N · m^2/C, $\phi^{net}_{cube\ 2} = +5$ N · m^2/C, and $\phi^{net}_{cube\ 3} = -3$ N · m^2/C. (a) Cube 2, (b) cube 3, and (c) cube 1.

RE 24-3: The central charge always acts along the central line. For each noncentral charge (for example, the one to the left) that acts at a point on this central line, there is a conjugate charge (in this example, the one to the right of center) that is exactly the same distance from the point as the original point. The E-field vectors have the same magnitude. The E-components perpendicular to the plane act in the same direction and add vectorially. The parallel components act in opposite directions and cancel.

RE 24-4: Since Gauss' law states that $\phi^{net} = q^{enc}/\varepsilon_0$ as long as the same charge is enclosed by the new Gaussian surfaces, ϕ^{net} is unchanged.

RE 24-5: Negative charges would be induced on the inside surface of the cavity so that $q^{enc} = q^{induced} + q^{center} = 0$. Thus, the net flux at the cavity's Gaussian surface would be zero.

Problems

1. (a) 0; (b) -3.92 N · m^2/C; (c) 0; (d) 0 for each field **3.** 2.0×10^5 N · m^2/C **5.** (a) 8.23 N · m^2/C; (b) 8.23 N · m^2/C; (c) 72.8 pC in each case **7.** 3.54 μC **9.** 0 through each of the three faces meeting at q, $q/24\varepsilon_0$ through each of the other faces **11.** -7.5 nC **15.** -1.04 nC **19.** (a) $E = (q/4\pi\varepsilon_0 a^3)r$; (b) $E = q/4\pi\varepsilon_0 r^2$; (c) 0; (d) 0; (e) inner, $-q$; outer, 0 **21.** $q/2\pi a^2$ **23.** $6K\varepsilon_0 r^3$ **25.** 5.0 μC/m **27.** (a) $E = q/2\pi\epsilon_0 LR$, radially inward; (b) $-q$ on both inner and outer surfaces; (c) $E = q/2\mu\epsilon_0 Lr$, radially outward **29.** (a) 2.3×10^6 N/C, radially out; (b) 4.5×10^5 N/C, radially in **31.** (b) $\rho R^2/2\varepsilon_0 r$ **33.** (a) 5.3×10^7 N/C; (b) 60 N/C **35.** 5.0 nC/m^2 **37.** 0.44 mm **39.** 2.0 μC/m^2 **41.** (a) 37 μC; (b) 4.1×10^6 N · m^2/C

Chapter 25

RE 25-1: Question 1: Because charges that are infinitely far apart exert no forces on each other. Question 2: Zero separation between particles would involve infinite attractive or repulsive forces.

RE 25-2: (a) If we assume the E-field does not change as a result of the reconfiguration of the charge then the positive charge displacement is opposite to the direction of the E-field, so the E-field does negative work. (b) It takes external work to move the charge against the field so ΔU increases, and (c) because we are interested in the *change* of electric potential between points 1 and 2.

RE 25-3: (a) The external force does positive work. (b) The proton moves to a higher potential so $V_2 > V_1$.

RE 25-4: (a) The E-field acts from left to right. (b) Positive external work is done on the electron in paths 1, 2, 3, and 5. Negative work is done on Path 4. (c) $\Delta V_3 > \Delta V_1 = \Delta V_2 = \Delta V_5 > \Delta V_4$.

RE 25-5: Given the charge distribution, we can simply add the contribution to the potential at a point P due to each of the charges, taken separately, using Eq. 25-25. If all we know is $\vec{E}(\vec{r})$ then we must calculate $V(\vec{r})$ using Eq. 25-17.

RE 25-6: V at P is the same for all three of these configurations. The potential at P due to each proton only depends on how far away that proton is from P and not on the direction.

RE 25-7: Using Eq. 25-29 for case (a) $\theta = 0$ and so $\cos\theta = +1$, for case (b) $\theta = 180°$ and $\cos\theta = -1$, and for case (c) $\theta = 90°$ so $\cos\theta = 0$. All other terms remain constant, so ranked from most to least positive, $V_a > V_c > V_b$.

RE 25-8: (a) $E_2 > E_1 = E_3$, (b) Pair 3. (c) It accelerates leftward.

RE 25-9: Since potential energy is a scalar quantity, its superposition involves only scalar addition while the superposition of electric fields requires adding vectors.

RE 25-10: (a) A is wrong since it originates on $-$ and terminates on $+$. B is wrong since it is not perpendicular to the plate near the plate. C is wrong since it has a kink. D is wrong for the same reason as A. E is wrong since it both originates and terminates on a $+$ charge. F is ok. (b) A correct drawing would have curves like A, D, and F but with arrows pointing toward the negatively-charged sphere.

RE 25-11: Because her skin is a conductor and thus an equipotential surface. Charges will redistribute so they have a higher density near the top of her head, which has more curvature than the sides of her head. The strength of the electric field is higher where the charges bunch so the equipotential surfaces are closer together than they were.

Problems

1. (a) 3.0×10^5 C; (b) 3.6×10^6 J **3.** (a) 3.0×10^{10} J; (b) 7.7 km/s; (c) 9.0×10^4 kg **5.** 8.8 mm **7.** (a) 136 MV/m; (b) 8.82 kV/m **9.** (b) because $V = 0$ point is chosen differently; (c) $q/(8\pi\varepsilon_0 R)$; (d) potential differences are independent of the choice for the $V = 0$ point **11.** (a) $Q/4\pi\varepsilon_0 r$; (b) $\dfrac{\rho}{3\varepsilon_0}\left(\dfrac{3}{2}r_2^2 - \dfrac{1}{2}r^2 - \dfrac{r_1^3}{r}\right)$, $\rho = \dfrac{Q}{\frac{4\pi}{3}(r_2^3 - r_1^3)}$; (c) $\dfrac{\rho}{2\varepsilon_0}(r_2^2 - r_1^2)$, with ρ as in (b); (d) yes **13.** (a) -4.5 kV; (b) -4.5 kV **15.** $x = d/4$ and $x = -d/2$ **17.** (a) 0.54 mm; (b) 790 V **19.** 6.4×10^8 V **21.** $2.5q/4\pi\varepsilon_0 d$ **23.** $-0.21q^2/\varepsilon_0 a$ **25.** (a) $+6.0 \times 10^4$ V; (b) -7.8×10^5 V; (c) 2.5 J; (d) increase; (e) same; (f) same **27.** $W = \dfrac{qQ}{8\pi\varepsilon_0}\left(\dfrac{1}{r_1} - \dfrac{1}{r_2}\right)$ **29.** 2.5 km/s **31.** (a) 0.225 J; (b) A, 45.0 m/s^2; B, 22.5 m/s^2; (c) A, 7.75 m/s, B, 3.87 m/s **33.** 0.32 km/s **35.** 1.6×10^{-9} m **39.** $(c/4\pi\varepsilon_0)[L - d\ln(1 + L/d)]$ **41.** 17 V/m at 135° counterclockwise from $+x$ **45.** (a) $\dfrac{Q}{4\pi\varepsilon_0 d(d + L)}$, leftward; (b) 0 **47.** 2.5×10^{-8} C **49.** (a) -180 V; (b) 2700 V, -8900 V **51.** (a) -0.12 V; (b) 1.8×10^{-8} N/C, radially inward

Chapter 26

RE 26-1: Volta probably felt a tingling sensation or perhaps a shock or jolt that would cause him to let go of the terminals.

RE 26-2: "Circuit" means a full round trip around some route. This is just what the electric charge does.

RE 26-3: (a) If the overall circuit had $q^{net} = 0$ before the switch was closed, it will remain charge neutral after the switch is closed since the circuit is a closed system and charge is neither created nor destroyed, but merely flows around the circuit. (b) Individual wires in the circuit can and do acquire a (small) net positive or negative charge, but this charge must come from other parts of the circuit.

RE 26-4: Electrical current *is* the net transport of charge past a given point in a circuit in a given time. If equal amounts of positive charge moving, say, right, and negative charge moving right go past the same point, there is no net transport of charge past that point, so $i = 0$ A.

RE 26-5: Let's assume that the unknown current i flows from right to left. Then the net current flowing into (+) or out of (−) the *middle* node is $(+2 + 3 + 4 - 1 + 2 - 2 + i)$ A. But currents must all add to zero at this node. Thus $i = -8$ A, meaning our assumption was wrong and that $i = 8$ A flowing from left to right.

RE 26-6: A voltmeter is attached *across* a circuit element because it is designed to measure the potential difference *between* the ends of the circuit. An ammeter is inserted in a branch of a circuit because it is designed to measure the current *through* that part of the circuit. In a series circuit where there are no branches or alternate paths for current to flow, it doesn't matter whether the ammeter is placed before or after a series circuit element.

RE 26-7: Device 1 is ohmic since $(\Delta V/i) = 2.25\ \Omega$ = constant and $i = 0$ A when $\Delta V = 0$ V. Device 2 is nonohmic since $(\Delta V/i) \neq$ constant. Device 3 is nonohmic. Although a plot of ΔV vs. i is a straight line, i is nonzero at $\Delta V = 0$, so i is not proportional to ΔV.

RE 26-8: If the cross-sectional area of the Nichrome wire is cut in half, its resistance will double, so the slope of the i vs. ΔV graph which is $1/R$ will be cut in half.

RE 26-9: (a) $R \propto 1/r^2$ for most wires, suggesting the current flows through the whole cross-sectional area of the wire, not just on its surface as indicated in Eq. 26-8. (b) If the current flowed only in a thin layer near the surface then I'd expect $R \propto 1/r$ since the circumference is $2\pi r$ for a wire with a circular cross section.

RE 26-10: Since $R = \rho L/A$, $(a) = (c) > (b)$.

RE 26-11: $(a) = (b) > (d) > (c)$.

RE 26-12: Only the cross-sectional area A matters in comparing current densities, so $(a) = (d) > (b) = (c)$.

RE 26-13: Since the current density is $(I/A) = (\Delta V/(RA))$ and $RA = \rho L$, we see here that the current density is just inversely proportional to the length of each wire. So $(b) = (d) > (a) = (c)$.

Problems

1. (a) 1200 C; (b) 7.5×10^{21} **3.** 5.6 ms **5.** 100 V **7.** $2.0 \times 10^{-8}\ \Omega \cdot$ m **9.** 2.4 Ω **11.** 54 Ω **13.** 3.0 **15.** (a) 0.43%, 0.0017%, 0.0034% **17.** 560 W **19.** (a) 1.0 kW; (b) 25 ¢ **21.** 0.135 W **23.** (a) 10.9 A; (b) 10.6 Ω; (c) 4.5 MJ **25.** 660 W **27.** (a) 3.1×10^{11}; (b) 25 μA; (c) 1300 W, 25 MW **29.** (a) 17 mV/m; (b) 243 J **31.** (a) 6.4 A/m^2, north; (b) no, cross-sectional area **33.** 0.38 mm **35.** (a) 2×10^{12}; (b) 5000; (c) 10 MV **37.** 13 min **39.** $8.2 \times 10^{-4}\ \Omega \cdot$ m **41.** (a) 0.67A; (b) toward the negative terminal **43.** (a) 1.73 cm/s; (b) 3.24 pA/m^2

Chapter 27

RE 27-1: $R = \rho L/A; A = \pi r^2 = \frac{1}{4}\pi d^2$

$\rho_{Cu} = 1.7 \times 10^{-8}\,\Omega \cdot \text{m}; d = 2.4 \times 10^{-4}\text{ m}; L = 0.30\text{ m}$

$\therefore R = (1.7 \times 10^{-8}\,\Omega \cdot \text{m})(0.30\text{ m})/(\frac{1}{4}\pi(2.4 \times 10^{-4}\text{ m})^2)$

$= 0.113\,\Omega.$

RE 27-2: (a) If all the current were "used up" in the first bulb, the second and third bulbs would be dark. (b) If most of the current were "used up" in the first bulb, the second bulb would glow more dimly than the first and the third bulb would glow more dimly than the second. (c) If only a small amount were "used up" in the first bulb, the third would be dimmer than the second, and the second would be a bit dimmer than the first.

RE 27-3: $i_a = i_b = i_c$ and $V_b > V_c > V_a$.

RE 27-4: (a) $i_1 = i_2 = i_3$. (b) $\Delta V_1 > \Delta V_2 > \Delta V_3$.

RE 27-5: Since the ammeter is wired *in series* with the resistors, its resistance *adds* to theirs. (a) With no ammeter, the current will be largest. (b) with $R_A \ll R_1 + R_2$ the current will be reduced, but only a little. (c) With $R_A = R_1 + R_2$ the current would be cut in half. Thus a good ammeter should have as *small* a resistance as possible.

RE 27-6: (a) $R_1 = R_2$ in series so $i_1 = i_2$ and $\Delta V_1 = \Delta V_2 = \frac{1}{2}\Delta V_B$ and so $i = i_1 = i_2 = \Delta V_B/(R_1 + R_2)$. (b) $R_1 = R_2$ in parallel so $i_1 = i_2$ and $\Delta V_1 = \Delta V_2 = \Delta V_B$ so now $i = i_1 + i_2 = 2\Delta V_B/R_1 = 2\Delta V_B/R_2$.

RE 27-7: Note that R_V is in parallel with R_1. Thus if $R_V << R_1$, the effective resistance between d and e in Fig. 27-7 would be dramatically decreased from R_1 to less than R_V. This would "pull down" ΔV_{de} to a smaller value that it had before I installed the voltmeter. However, if $R_V >> R_1$, then the effective resistance between d and e remains just about R_1 and the value of ΔV_{de} is about what it was without the meter present. Thus $R_V >> R$ gives more accurate measurements of potential differences.

RE 27-8: Since the bulbs are identical and wired in parallel, $i_1 = i_2 = i_3$. If only one bulb were connected to the battery its brightness would be the same as before, since the potential difference across it is still ΔV_B.

Problems

1. (a) 30 Ω; (b) clockwise; (c) A **3.** (a) 45 Ω; (b) 0.33 A each; (c) 0.33 A **5.** $V_1 = 3.5$ V; $V_2 = 4.3$ V; $V_3 = 7.2$ V **7.** 8.0 Ω **9.** (a) 0; (b) 1.25 A, downward **11.** (a) 120 Ω; (b) $i_1 = 51$ mA, $i_2 = i_3 = 19$ mA, $i_4 = 13$ mA **13.** 20 Ω **15.** (a) bulb 2; (b) bulb 1 **17.** 0.45 A **19.** $i_1 = -50$ mA, $i_2 = 60$ mA, $V_{ab} = 9.0$ V **21.** (a) Cu: 1.11 A, A1: 0.893 A; (b) 126 m **23.** 5.56 A **25.** $3d$ **29.** nine **31.** providing energy, 360 W **33.** (a) 3.0 A, downward; (b) 1.6 A, downward; (c) 6.4 W, supplying; (d) 55.2 W, supplying **35.** (a) 12 eV (1.9×10^{-18} J); (b) 6.5 W **39.** (a) 7.50 A, leftward; (b) 10.0 A, leftward; (c) 87.5 W, supplied **41.** (a) 0.33 A, rightward; (b) 720 J **43.** (a) $320; (b) 4.8 cents **45.** 14 h 24 min **47.** (a) 0.50 A; (b) $P_1 = 1.0$ W, $P_2 = 2.0$ W; (c) $P_1 = 6.0$ W supplied, $P_2 = 3.0$ W absorbed **49.** (a) $V_T = -ir + \mathscr{E}$; (b) 13.6 V; (c) 0.060 Ω **51.** (a) 14 V; (b) 100 W; (c) 600 W; (d) 10 V, 100 W **53.** (a) 50 V; (b) 48 V; (c) B is connected to the negative terminal **55.** (a) $r_1 - r_2$; (b) battery with r_1 **59.** (a) $R = r/2$; (b) $P^{\max} = \varepsilon^2/2r$ **61.** (a) 0.346 W; (b) 0.050 W; (c) 0.709 W; (d) 1.26 W; (e) −0.158 W **63.** (a) battery 1, 0.67 A down; battery 2, 0.33 A up; battery 3, 0.33 A up; (b) 3.3 V

Chapter 28

RE 28-1: The capacitance of a capacitor remains the same, whatever the amount of excess charge on its plates and whatever potential difference is applied across it. Doubling $|q|$ doubles ΔV_c while tripling ΔV_c triples $|q|$.

RE 28-2: Each of these three types of capacitors becomes electrically isolated when removed from a battery so the excess charge on each of the "plates" does not change.

RE 28-3: In these cases ΔV is constant and C and hence $|q|$ must change when spacings change, so $|q|$ (a) decreases, (b) increases, and (c) decreases.

RE 28-4: Each capacitor initially has the same $|q|$ and the same $|\Delta V|$. (a) Wiring them in parallel, positive plate to positive and negative to negative, leaves $|q|$ and $|\Delta V|$ on each unchanged. Wiring them in parallel, positive to negative, makes $|\Delta V| = 0$ and so $|q| = 0$ on each. (b) Wiring them in series leaves these quantities unchanged.

RE 28-5: (a) Since $i_0 = |\Delta V_B|/R$, $(i_0)_1 > (i_0)_2 > (i_0)_4 > (i_0)_3$. (b) Since $t_{(1/2)}$ is proportional to $\tau = RC$, $(t_{(1/2)})_4 > (t_{(1/2)})_1 = (t_{(1/2)})_2 > (t_{(1/2)})_3$.

Probl.ems

1. 7.5 pC **3.** 3.0 mC **5.** (a) 140 pF; (b) 17 nC **7.** $5.04\pi\varepsilon_0 R$ **11.** 9090 **13.** 3.16 μF **17.** 43 pF **19.** (a) 50 V; (b) 5.0×10^{-5} C; (c) 1.5×10^{-4} C

21. $q_1 = \dfrac{C_1C_2 + C_1C_3}{C_1C_2 + C_1C_3 + C_2C_3} C_1\Delta V_0,$

$q_2 = q_3 = \dfrac{C_2C_3}{C_1C_2 + C_1C_3 + C_2C_3} C_1\Delta V_0$

23. 72 F **25.** 0.27 J **27.** (a) 2.0 J **29.** (a) $2\Delta V$; (b) $U_i = \varepsilon_0 A\Delta V^2/2d$, $U_f = 2U_i$; (c) $\varepsilon_0 A\Delta V^2/2d$ **35.** Pyrex **37.** 81 pF/m **39.** 0.63 m² **43.** (a) 10 kV/m; (b) 5.0 nC; (c) 4.1 nC

45. (a) $C = 4\pi\varepsilon_0\kappa\left(\dfrac{ab}{b-a}\right)$; (b) $q = 4\pi\varepsilon_0\kappa\Delta V\left(\dfrac{ab}{b-a}\right)$;

(c) $q' = q(1 - 1/\kappa)$ **47.** 4.6 **49.** (a) 2.41 μs; (b) 161 pF **51.** (a) 2.17 s; (b) 39.6 mV **53.** (a) 1.0×10^{-3} C; (b) 1.0×10^{-3} A; (c) $\Delta V_C = 1.0 \times 10^3\, e^{-t}$ V, $\Delta V_R = 1.0 \times 10^3\, e^{-t}$ V; (d) $P = e^{-2t}$ W

Chapter 29

RE 29-1: (a) z axis, (b) $-x$ axis, (c) no direction since $\vec{F} = 0$ N.

RE 29-2: (a) The electron, because it's less massive and "bends" more easily in the presence of a perpendicular force, (b) the electron travels clockwise.

RE 29-3: $\vec{F}^{\,\text{net}} = \vec{F}^{\,\text{elec}} + \vec{F}^{\,\text{mag}}$. The force exerted on the charge by the E-field is the same in all 4 cases and points out of the page. In cases 1 and 3, $\vec{B}$ and $\vec{v}$ are parallel so there is no magnetic force on the charged particle. In cases 2 and 4, $\vec{B}$ and $\vec{v}$ are perpendicular with magnetic forces out of and into the page respectively. (a) In terms of force magnitude $|\vec{F}_2^{\text{net}}| > |\vec{F}_1^{\text{net}}| = |\vec{F}_3^{\text{net}}|$. $|\vec{F}_4^{\text{net}}|$ can take on any value from zero to larger than $|\vec{F}_4^{\text{net}}|$ and so can not be ranked. (b) A zero net force is only possible for case 4.

RE 29-4: The equation $|\vec{F}^{\text{mag}}| = |i\vec{L} \times \vec{B}|$ is a maximum for a given $|\vec{B}|$ when $\vec{B}$ is perpendicular to both $\vec{F}^{\text{mag}}$ and $\vec{L}$. This is true whenever $\vec{B} = \pm|\vec{B}|\hat{\text{j}}$. Trying each direction, the right-hand rule yields $\vec{B}$ pointing along the $-y$ axis.

RE 29-5: (a) $\tau = |\vec{\mu}||\vec{B}| \sin\phi$ where $\phi = \theta$ for cases 2 and 3 and $\phi = \pi - \theta$ for cases 1 and 4. But $\sin\theta = \sin(\pi - \theta)$ so τ is the same for all 4 cases. (b) $U(\phi) = -\vec{\mu}\cdot\vec{B} = -|\vec{\mu}||\vec{B}| \cos\phi$. Now for cases 2 and 3, $\phi = \theta < \pi/2$ so $\cos\theta > 0$, and for cases 1 and 4 $\phi = \pi - \theta > \pi/2$ $\cos\phi = -\cos\theta < 0$, thus $U_1 = U_4 > U_3 = U_2$.

Problems

1. (a) 6.2×10^{-18} N; (b) 9.5×10^8 m/s^2; (c) remains equal to 550 m/s **3.** (a) 400 km/s; (b) 835 eV **5.** (a) east; (b) 6.28×10^{14} m/s^2; (c) 2.98 mm **7.** 21 μT **9.** (a) 2.05×10^7 m/s; (b) 467 μT; (c) 13.1 MHz; (d) 76.3 ns **11.** (a) 0.978 MHz; (b) 96.4 cm **15.** (a) 1.0 MeV; (b) 0.5 MeV **17.** (a) 495 mT; (b) 22.7 mA; (c) 8.17 MJ **19.** (a) 0.36 ns; (b) 0.17 nm; (c) 1.5 mm **21.** (a) 3.4×10^{-4} T, horizontal and to the left as viewed along $\vec{v}_1$; (b) yes, if its velocity is the same as the electron's velocity **23.** 0.27 mT **25.** 680 kV/m **27.** (b) 2.84×10^{-3} **29.** 38.2 cm/s **31.** 28.2N, horizontally west **33.** 467 mA, from left to right **35.** 0.10 T, at 31° from the vertical **37.** 4.3×10^{-3} N·m, negative y **41.** $2\pi aiB\sin\theta$, normal to the plane of the loop (up) **43.** 2.45 A **45.** (a) 12.7 A; (b) 0.0805 N·m **47.** (a) 0.30 J/T; (b) 0.024 N·m **49.** (a) 2.86 A·m^2; (b) 1.10 A·m^2 **51.** (a) $(8.0 \times 10^{-4}\ \text{N}\cdot\text{m})(-1.2\hat{\imath} - 0.90\hat{\jmath} + 1.0\hat{k})$; (b) -6.0×10^{-4} J

Chapter 30

RE 30-1: (a) $\vec{B}$ is to the left at point 1, (b) $\vec{B}$ is up at point 2, (c) $\vec{B}$ is to the right at point 1, (d) $\vec{B}$ is down at point 2.

RE 30-2: (a) If $\vec{B}^{\text{net}} = 0$ at point 1 then the current in the wire is coming *out* of the page. (b) Since $\vec{B}^{\text{net}} = \vec{B}^{\text{ext}} + \vec{B}^{\text{wire}}$, and since $\vec{B}^{\text{wire}}$ at point 2 points straight down and has the same magnitude as $\vec{B}^{\text{ext}}$, $\vec{B}^{\text{net}}$ is directed 45 degrees down and toward the right at point 2 and its magnitude is $\sqrt{2}\,B^{\text{ext}}$.

RE 30-3: $F_b > F_c > F_a$.

RE 30-4: $\oint \vec{B}\cdot d\vec{s} = \mu_0 i^{\text{enc}}$ where i^{enc} is the *net* current flowing *through* the loop. Therefore,

$$\left|\frac{1}{\mu_0}\oint \vec{B}\cdot d\vec{s}\right| = i \text{ for case (a)}$$
$$= 0 \text{ for case (b)}$$
$$= i \text{ for case (c)}$$
$$= 2i \text{ for case (d).}$$

(d) > (a) = (c) > (b).

RE 30-5: For $z \gg R$, $|\vec{B}|$ due to any *one* loop is proportional to $|\vec{\mu}| = iA$. Since all the i's are equal, $|\vec{B}| \propto A$ for *each* loop. Taking the directions of the currents into account and calling B_1 the magnetic field magnitude for one *small* loop, and $B_2 = 4B_1$, the magnetic field magnitude for one *large* loop, $B_a = 2B_1$; $B_b = 0$; $B_c = 0$; $B_d = 2B_1 + B_2 = 2B_1 + 4B_1 \therefore |\vec{B}_d| > |\vec{B}_a| > |\vec{B}_b| = |\vec{B}_c| = 0$.

Problems

1. (a) 3.3 μT; (b) yes **3.** (a) 16 A; (b) west to east **5.** $\mu_0 qvi/2\pi d$, antiparallel to i; (b) same magnitude, parallel to i **7.** 2 rad **9.** $\frac{\mu_0 i\theta}{4\pi}\left(\frac{1}{b} - \frac{1}{a}\right)$, out of page. **19.** $(\mu_0 i/2\pi w)\ \ln(1 + w/d)$, up **21.** 256 nT **23.** (a) it is impossible to have other than $B = 0$ midway between them; (b) 30 A **25.** 4.3 A, out of page **27.** 80 μT, up the page **29.** $0.791\mu_0 i^2/\pi a$, 162° counterclockwise from the horizontal **31.** 3.2 mN, toward the wire **33.** (a) $(-2.0\ \text{A})\mu_0$; (b) 0 **37.** $\mu_0 J_0 r^2/3a$ **43.** 0.30 mT **45.** (a) 533 μT; (b) 400 μT **49.** (a) 4.77 cm; (b) 35.5 μT **51.** 0.47 A·m^2 **53.** (a) 2.4 A·m^2; (b) 46 cm **59.** (a) 79 μT; (b) 1.1×10^{-6} N·m

Chapter 31

RE 31-1: They were trying to relate induction to the presence of a magnetic field rather than to a changing field.

RE 31-2: Since the magnetic field is uniform, the left and right segments are polarized symmetrically as shown in the diagram. There is no favored direction in which current can flow.

RE 31-3: This case is similar to the one shown in Fig. 31-7. However, now the polarization will always be stronger on the *right* side of the coil than it is on the left side, so the current will flow continuously in a *counter* clockwise direction.

RE 31-4: Yes, since observations show that the $\vec{v}$ in the magnetic force law ($\vec{F} = q\vec{v} \times \vec{B}$) turns out to be the relative velocity between the object producing the B-field and the charge.

RE 31-5: The magnet is accelerating downward as it falls at $\vec{a} = (-9.8\ \text{m/s}^2)\hat{\jmath}$. By the time its rear end is passing through the area subtended by the loop, it is traveling faster than the front pole was as it passed by, so the rate of change of the B-field is greater at $t = 0.20$ s than it was at $t = 0.10$ s and the amount of induced current is also greater.

RE 31-6: (a) $b > d = e > a = c$. (b) The magnitude $|dB/dt|$ determines that the amount of induced emf is greatest when the slope is greatest.

RE 31-7: (a) into the page to add to the decreasing field, (b) out of the page to subtract from the decreasing field.

RE 31-8: In each semicircular area $|d\Phi^{\text{mag}}/dt|$ is identical. The only issue is the "sense" of the induced emf contributed by each semicircle. Using Lenz's law, loop (a) has a nonzero, clockwise (CW) induced current. Loop (b) has a counterclockwise (CCW) current in both the upper and lower halves, so $|i_a| = |i_b|$. In loop (c), the induced emfs in the upper and lower half circles cancel one another out so $|i_c| = 0$ so $|i_a| = |i_b| > |i_c|$.

RE 31-9: As each loop enters or leaves the region where $B \neq 0$, $|\mathscr{E}| = |d\Phi^{\text{mag}}/dt| \propto (h)(v)$ where h = height of the loop and v is its speed. Since v = constant for each, $|\mathscr{E}_c| = |\mathscr{E}_d| = 2|\mathscr{E}_a| = 2|\mathscr{E}_b|$.

RE 31-10: (a) Out (given), (b) out since path 3 has $|\mathscr{E}| = 3$(mag), (c) out since path 3 has $|\mathscr{E}| = 3$(mag), (e) in, since path 4 has $|\mathscr{E}| = 0$, (d) in since path 2 has $|\mathscr{E}| = 2$(mag).

RE 31-11: When we pointed a right thumb in the direction of the current our fingers wrapped around the wire in the direction of the magnetic field. This is consistent with the direction of the magnetic field shown in Fig. 31-24.

RE 31-12: The quantity $i^{\text{dis}} = \varepsilon_0 d\Phi^{\text{elec}}/dt$ has the units of current. We can use the right hand rule to find the direction of $\vec{B}$ and we can use it to find the magnitude of $\vec{B}$ induced by a capacitor.

RE 31-13: (a) $|\Phi_d| > |\Phi_b| > |\Phi_c| > |\Phi_a|$. Since $\oint \vec{B}\cdot d\vec{A} = 0$ (Eq. 31-49),

$$\Phi^{\text{net}} = \oint_{\text{ends}} \vec{B}\cdot d\vec{A} + \oint_{\text{curve}} \vec{B}\cdot d\vec{A} \text{ so } \Phi_{\text{curve}} = -\oint_{\text{ends}} \vec{B}\cdot d\vec{A}.$$

RE 31-14: They both involve the integration of a field vector over a closed Gaussian surface. Each integral determines a net flux at the closed surface that is proportional to the net electric or magnetic charge enclosed by the surface. The major difference between the electric and magnetic situation is that the net magnetic charge enclosed is always zero (that is, north and south poles always appear together), and the net electric charge enclosed can be positive, negative, or zero.

RE 31-15: A statement of Faraday's law is that a changing magnetic field produces an electric field. The Ampère-Maxwell law states that a changing electric field produces a magnetic field. So there is a mathematical symmetry between the two fields.

Problems

1. 1.5 mV **3.** (a) 31 mV; (b) right to left **5.** (a) $1.1 \times 10^{-3}\ \Omega$; (b) 1.4 T/s **7.** 30 mA **9.** 2.9 mV **11.** (a) $\mu_0 i R^2 \pi r^2/2x^3$; (b) $3\mu_0 i \pi R^2 r^2 v/2x^4$; (c) in the same direction as the current in the large loop **13.** (b) no **15.** 29.5 mC **17.** (a) 21.7 V; (b) counterclockwise **19.** (b) design it so that $Nab = (5/2\pi)$ m^2 **21.** 5.50 kV **23.** 80 μV, clockwise **25.** (a) 13 μWb/m; (b) 17%; (c) 0 **27.** 3.66 μW **29.** (a) 48.1 mV; (b) 2.67 mA; (c) 0.128 mW **31.** (a) 600 mV, up the page; (b) 1.5 A, clockwise; (c) 0.90 W; (d) 0.18 N; (e) same as (c) **33.** (a) 240 μV; (b) 0.600 mA; (c) 0.144 μW; (d) 2.88×10^{-8} N; (e) same as (c) **35.** (a) 71.5 μV/m; (b) 143 μV/m **39.** 2.4×10^{13} V/m·s **41.** (a) 1.18×10^{-19} T; (b) 1.06×10^{-19} T **43.** (a) 5.01×10^{-22} T; (b) 4.51×10^{-22} T **45.** 52 nT · m **51.** (a) 0.63 μT; (b) 2.3×10^{12} V/m·s **53.** (a) 710 mA; (b) 0; (c) 1.1 A **55.** (A) 2.0 A; (b) 2.3×10^{11} V/m·s; (c) 0.50 A; (d) 0.63 μT·m **57.** (a) 75.4 nT; (b) 67.9 nT **59.** (a) 27.9 nT; (b) 15.1 nT **61.** (b) sign is minus; (c) no, there is compensating positive flux through open end near magnet **63.** 47.4 μWb, inward

Chapter 32

RE 32-1: Combine Eqs. 32-1 and 32-2 to get $L = \mu_0 A n^2 l$. (a) If n doubles $L \rightarrow 4L$. (b) If l doubles $A \rightarrow 2A$.

RE 32-2: (d) decreasing rightward or (e) increasing and leftward.

RE 32-3: (a) $R_{eq} = (N_p/N_s)^2\ R$ we want R_{eq} seen by the generator to be smaller. So N_s must be greater than N_p. (b) This would be a step up transformer.

RE 32-4: A refrigerator magnet is ferromagnetic; a standard paper clip is also ferromagnetic, since it is made of steel, a ferromagnetic material; a silver wire is diamagnetic (the book says so).

RE 32-5: (a) Spin down or (2). (b) Since the proton has the opposite sign of charge, spin up or (1).

RE 32-6: A ferromagnetic material must have well more than 50% of its domains aligned with each other to act like a strong magnet. If no one alignment of the domains dominates, then it is not a permanent magnet.

RE 32-7: Hysteresis is a lack of retraceability of a magnetization curve. It occurs because the reorientation of domains are not completely reversible.

RE 32-8: (a) $\vec{F}^{\,mag}$ is directed *toward* the magnet. (b) The dipole moments are also directed *toward*. (c) The force on sphere 1 is *less*.

RE 32-9: (a) $\vec{F}^{\,mag}$ is directed *away* from the magnet. (b) The dipole moments are also directed *away*. (c) The force on sphere 1 is *less*.

RE 32-10: The Earth's B-field has a different declination and inclination at different locations at any one time. But, it also varies in time. Currently the geographic poles are moving daily. They can also reverse themselves in time periods on the scale of 1000 years.

Problems

1. 0.10 μWb **5.** let the current change at 5.0 A/s **7.** (b) so that the changing magnetic field of one does not induce current in the other; (c) $L_{eq} = \sum_{j=1}^{N} L_j$ **9.** 12 A/s **11.** (a) 0.60 mH; (b) 120 **13.** (a) 1.67 mH; (b) 6.00 mWb **15.** (b) have the turns of the two solenoids wrapped in opposite directions **17.** magnetic field exists only within the cross section of solenoid 1 **19.** (a) $\dfrac{\mu_0 N l}{2\pi} \ln\left(1 + \dfrac{b}{a}\right)$; (b) 13 μH **21.** $6.91\tau_L$ **23.** 46 Ω **25.** (a) 8.45 ns; (b) 7.37 mA **27.** 10.6 A/s **29.** (a) $i_1 = i_2 =$ 3.33 A; (b) $i_1 = 4.55$ A; $i_2 = 2.73$ A; (c) $i_1 = 0$, $i_2 = 1.82$ A (reversed); (d) $i_1 = i_2 = 0$ **31.** (a) 3.28 ms; (b) 6.45 ms; (c) infinite time; (d) for R = 6.0 Ω, the current of the 2.00 A is the equilibrium current, given by $\mathscr{E}$/R = (12 V)/(6.0 Ω); it takes an infinite time to reach. For R = 5.00 Ω, the current of 2.00 A is less than the equilibrium current and requires a finite time to reach. (e) 0; (f) 3 ms **33.** 81.1 μs **35.** (a) 2.4 V; (b) 3.2 mA, 0.16 A **37.** 10 **39.** (a) -9.3×10^{-24} J/T; (b) 1.9×10^{-23} J/T **41.** (a) 0; (b)0; (c) 0; (d) $\pm 3.2 \times 10^{-25}$ J; (e) -3.2×10^{-34} J·s, 2.8×10^{-23} J/T, $+9.7 \times 10^{-25}$ J, $\pm 3.2 \times 10^{-25}$ J **43.** (a) nine; (b) 4 $\mu_B = 3.71 \times 10^{-23}$ J/T; (c) $+9.27 \times 10^{-24}$ J; (d) -9.27×10^{-24} J **45.** 5.15×10^{-24} A·m^2 **47.** (a) 180 km; (b) 2.3×10^{-5} **49.** $\Delta\mu = e^2 r^2\ B/4m$ **51.** 20.8 mJ/T **53.** yes **55.** (b) K_i/B, opposite to the field; (c) 310 A/m **57.** 55 μT **59.** (a) 31.0 μT, 0°; (b) 55.9μT, 73.9°; (c) 62.0 μT, 90°

Chapter 33

RE 33-1: Using Eq. 33-6, $a = b > c$. (Note that coil area doesn't matter here.)

RE 33-2: At $t = 0$ s, U^{elec} = max and $U^{mag} = 0$. T = period = $1/f$. (a) $|q(t)|$ is a maximum again at $t = T/2$. (b) Δv_C is next the same at $t = T$. (c) U^{elec} is next a maximum at $t = T/2$. (d) i is next a maximum at $t = T/4$.

RE 33-3: The unit for ω is [rad/s]. Since $L = \mathscr{E}_L/(di/dt)$, we get [H] = [V/(A/s)]. Since $C = q/\Delta V$ we get [F] = [Q/V]. $\omega = 1/\sqrt{LC}$ and the units of $1/\sqrt{LC}$ are $[1/(\text{V}\cdot\text{s/A})(Q/\text{V})]^{1/2}$ but [A] = [Q/s] so $[1/\text{s}^2]^{1/2}$ or [1/s]. This matches the ω unit of [rad/s].

RE 33-4: (a) According to the loop rule, $\Delta v_C + \Delta v_L = 0$. Since $\mathscr{E}_L = \Delta v_L$, $\mathscr{E}_L = -5$ V. (b) $U^{mag} = U - U^{elec} = 160\ \mu\text{J} - 10\ \mu\text{J} = 150\ \mu\text{J}$.

RE 33-5: (a) C > B > A. (b) 1 & A, 2 & B, 3 & S, 4 & C. (c) A.

RE 33-6: (a) (1) lags, (2) leads, (3) in phase. (b) (3) ($\omega^{dr} = \omega$ when $X_L = X_C$).

RE 33-7: (a) Increase since the circuit is mainly capacitive; increase C to decrease X_C to be closer to resonance for maximum ⟨P⟩. (b) Closer.

Problems

1. 25.6 ms **3.** (a) 97.9 H; (b) 0.196 mJ **7.** (a) 34.2 J/m^3; (b) 49.4 mJ **9.** 1.5×10^8 V/m **11.** (a) 1.0 J/m^3; (b) 4.8×10^{-15} J/m^3 **13.** 9.14 nF **15.** (a) 1.17 μJ; (b) 5.58 mA **17.** with n a positive integer: (a) $t = n(5.00\ \mu\text{s})$; (b) $t = (2n - 1)(2.50\ \mu\text{s})$; (c) $t = (2n - 1)(1.25\ \mu\text{s})$ **19.** (a) 1.25 kg; (b) 372 N/m; (c) 1.75×10^{-4} m; (d) 3.02 mm/s **21.** 7.0×10^{-4} s **23.** (a) 3.0 nC; (b) 1.7 mA; (c) 4.5 nJ **25.** (a) 275 Hz; (b) 364 mA **27.** (a) 6.0:1; (b) 36 pF, 0.22 mH **29.** (a) 1.98 μJ; (b) 5.56 μC; (c) 12.6 mA; (d) −46.9°; (e) +46.9° **31.** (a) 0.180 mC; (b) T/8; (c) 66.7 W **33.** (a) 356 μs; (b) 2.50 mH; (c) 3.20 mJ **35.** Let T_2 (= 0.596 s) be the period of the inductor plus the 900 μF capacitor and let T_1 (= 0.199 s) be the period of the inductor plus the 100 μF capacitor. Close S_2, wait $T_2/4$; quickly close S_1, then open S_2; wait $T_1/4$ and then open S_1. **37.** 8.66 mΩ **39.** (L/R) ln 2 **43.** (a) 0.0955 A; (b) 0.0119 A **45.** (a) 0.65 kHz; (b) 24 Ω **47.** (a) 6.73 ms; (b) 11.2 ms; (c) inductor; (d) 138 mH **49.** (a) $X_C = 0$, $X_L = 86.7\ \Omega$, $Z = 218\ \Omega$, $I = 165$ mA, $\phi = 23.4°$ **51.** (a) $X_C = 37.9\ \Omega$, $X_L = 86.7\ \Omega$, $Z = 206\ \Omega$, $I = 175$ mA, $\phi = 13.7°$ **53.** 1000 V **55.** 89 Ω **57.** (a) 224 rad/s; (b) 6.00 A; (c)

228 rad/s, 219 rad/s; (d) 0.040 **61.** 1.84 A **63.** 141 V **65.** 0, 9.00 W, 2.73 W, 1.82 W **67.** (a) 12.1 Ω; (b) 1.19 kW **69.** (a) 0.743; (b) leads; (c) capacitive; (d) no; (e) yes, no, yes; (f) 33.4 W **71.** (a) 117 μF; (b) 0; (c) 90.0 W, 0; (d) 0°, 90°; (e) 1, 0 **73.** (a) 2.59 A; (b) 38.8 V, 159 V, 224 V, 64.2 V, 75.0 V; (c) 100 W for R, 0 for L and C.

Chapter 34

RE 34-1: (a) Since the induced emf around the dotted loop must oppose the increase in $\vec{B}$. $\vec{E}$ on the right of the rectangle points down in the negative y direction. $\vec{E} + d\vec{E}$ on the left has a greater magnitude and points in the same direction. (b) Since $\vec{E} \times \vec{B}$ must be in the positive x direction, $\vec{B}$ on the right points into the paper in the negative z direction. $\vec{B} + d\vec{B}$ on the left points in the same direction as $\vec{B}$ but has a greater magnitude.

RE 34-2: In the positive x direction.

RE 34-3: For total absorption, $P_r = I/c$ independent of area, but $F_r = P_r A$ so it decreases as the area decreases.

Problems

1. 5.0×10^{-21} H **3.** $B_x = 0$, $B_y = -6.7 \times 10^{-9} \cos[\pi \times 10^{15}(t - x/c)]$, $B_z = 0$ in SI units **5.** 0.10 MJ **7.** 8.88×10^4 m^2 **9.** (a) 16.7 nT; (b) 33.1 mW/m^2 **11.** (a) 6.7 nT; (b) 5.3 mW/m^2; (c) 6.7 W **13.** (a) 87 mV/m; (b) 0.30 nT; (c) 13 kW **15.** 3.44×10^6 T/s **17.** (a) z axis; (b) 7.5×10^{14} Hz; (c) 1.9 kW/m^2 **19.** 89 cm **21.** (a) 3.5 μW/m^2; (b) 0.078 μW; (c) 1.5×10^{-17} W/m^2; (d) 110 nV/m; (e) 0.25 fT **23.** 1.0×10^7 Pa **25.** 5.9×10^{-8} Pa **27.** (a) 100 MHz; (b) 1.0 μT along the z axis; (c) 2.1 m^{-1}, 6.3×10^8 rad/s; (d) 120 W/m^2; (e) 8.0×10^{-7} N, 4.0×10^{-7} Pa **31.** 1.9 mm/s **33.** (b) 580 nm **35.** (a) 4.68×10^{11} W; (b) any chance disturbance could move the sphere from being directly above the source, and then the two force vectors would no longer be along the same axis **37.** (a) 1.9 V/m; (b) 1.7×10^{-11} Pa **39.** 3.1% **41.** 4.4 W/m^2 **43.** 2/3 **45.** (a) 2 sheets; (b) 5 sheets **47.** 0.21 **49.** 35° **51.** 0.031 **53** 19.6° or 70.4° (= 90° − 19.6°) **55.** (a) 0.50 ms; (b) 8.4 min; (c) 2.4 h; (d) 5500 B.C. **57.** (a) 515 nm, 610 nm; (b) 555 nm, 5.41×10^{14} Hz, 1.85×10^{-15} s **59.** it would steadily increase; (b) the summed discrepancies between the apparent time of eclipse and those observed from x; the radius of Earth's orbit

Chapter 35

RE 35-1: *a*

RE 35-2: 0.2*d*, 1.8*d*, 2.2*d*.

RE 35-3: When you look into a flat mirror, you see the portion of light scattering off your face that bounces off the mirror and travels straight back into your eyes. But you assume that the light entering your eyes has traveled in a straight line to reach you, so you see an image of your face behind the mirror. The image of your face is right side up. The light from your hair hits the mirror at a slight angle and then bounces into your eyes from above which is why you see your hair on top. Left and right are a different story. If you are standing face to face with another person and your right ear points toward the east, her left ear will point toward the east. If, instead, you face a flat mirror, the light from your right ear will bounce off the mirror and enter your eyes from the east. Even though your east ear is the east ear of the image, your right ear has become the left ear of the image.

RE 35-4: Ray 1: A ray that is initially parallel to the central axis reflects as if it came originally from the focal point *behind* the mirror. Ray 2: A ray that comes from the object and is traveling toward the focal point behind the mirror emerges parallel to the central axis. Ray 3: A ray that comes from the object and is traveling toward the center of curvature C of the mirror returns along itself. Ray 4: A ray that comes from the object and reflects from the mirror at its intersection c from the central axis is reflected symmetrically from the central axis.

RE 35-5: (a) Real; (b) inverted; (c) same.

RE 35-6: (a) e; (b) virtual, same.

Problems

1. 1.48 **3.** 1.26 **5.** 1.07 m **11.** 1.22 **13.** (a) 49°; (b) 29° **15.** (a) cover the center of each face with an opaque disk of radius 4.5 mm; (b) about 0.63 **17.** (a) $\sqrt{1 + \sin^2 \theta}$; (b) $\sqrt{2}$; (c) light emerges at the right; (d) no light emerges at the right **19.** 49.0° **21.** 40 cm **23.** (a) 3 **27.** new illumination is 10/9 of the old **29.** 10.5 cm **33.** (a) 2.00; (b) none **37.** $i = -12$ cm **39.** 45 mm, 90 mm **43.** 22 cm **47.** same orientation, virtual, 30 cm to the left of the second lens; $m = 1$ **53.** (a) 13.0 cm; (b) 5.23 cm; (c) −3.25; (d) 3.13; (e) − 10.2 **55.** (a) 2.35 cm; (b) decrease **57.** (a) 5.3 cm; (b) 3.0 mm

Chapter 36

RE 36-1: *b* (least *n*), *c*, *a*.

RE 36-2: (a) 3λ, 3; (b) 2.5λ, 2.5.

Problems

1. (a) 5.09×10^{14} Hz; (b) 388 nm; (c) 1.97×10^8 m/s **3.** 1.56 **5.** 22°, refraction reduces θ **7.** (a) 3.60 μm; (b) intermediate, closer to fully constructive interference **9.** (a) 0.833; (b) intermediate, closer to fully constructive interference **11.** (a) 0.216 rad; (b) 12.4° **13.** 2.25 mm **15.** 648 nm **17.** 16 **19.** 0.072 mm **21.** 6.64 μm **23.** 2.65 **25.** $y = 27 \sin(\omega t + 8.5°)$ **27.** (a) 1.17 m, 3.00 m, 7.50 m; (b) no **29.** $I = \frac{1}{9}I_m[1 + 8\cos^2(\pi d \sin\theta/\lambda)]$, I_m = intensity of central maximum **31.** Fully constructively **33.** 0.117μm, 0.352 μm **35.** 70.0 nm **37.** 120 nm **39.** (a) 552 nm; (b) 442 nm **43.** 140 **45.** 1.89μm **47.** 2.4 μm **49.** $\sqrt{(m + \frac{1}{2})\lambda R}$, for $m = 0, 1, 2, \ldots$ **51.** 1.00 m **53.** $x = (D/2a)(m + \frac{1}{2})\lambda$, for $m = 0, 1, 2, \ldots$ **55.** 588 nm **57.** 1.00030

Chapter 37

RE 37-1: (a) expand, (b) expand

RE 37-2: (a) second side maximum, (b) 2.5

RE 37-3: (a) red, (b) violet

RE 37-4: Diminish

RE 37-5: (a) left, (b) less.

Problems

1. 60.4 μm **3.** (a) $\lambda_a = 2\lambda_b$; (b) coincidences occur when $m_b = 2m_a$ **5.** (a) 70 cm; (b) 1.0 mm **7.** 1.77 mm **11.** (d) 53°, 10°, 5.1° **13.** (b) 0 rad, 4.493 rad, etc.; (c) −0.50, 0.93, etc. **15.** (a) 1.3×10^{-4} rad; (b) 10 km **17.** 50 m **19.** (a) 1.1×10^4 km; (b) 11 km **21.** 27 cm **23.** (a) 0.347°; (b) 0.97° **25.** (a) 8.7×10^{-7} rad; (b) 8.4×10^7 km; (c) 0.025 mm **27.** five **29.** (a) 4; (b) every fourth bright fringe is missing **31.** (a) nine; (b) 0.255 **33.** (a) 3.33 μm; (b) 0.0°, ±10.2°, ±20.7°, ±32.0°, ±45.0°, ±62.2° **35.** three **37.** (a) 6.0 μm; (b) 1.5 μm; (c) $m = 0, 1, 2, 3, 5, 6, 7, 9$, **39.** 1100 **47.** 3650 **53.** 0.26 nm **55.** 39.8 pm **59.** (a) $a_0/\sqrt{2}$, $a_0/\sqrt{5}$, $a_0/\sqrt{10}$, $a_0/\sqrt{13}$, $a_0/\sqrt{17}$ **61.** 30.6°, 15.3° (clockwise); 3.08°, 37.8° (counterclockwise)

Chapter 38

RE 38-1: We observe that the second train is moving with respect to our train. The "slight vibration" we feel is evidence that our own train is moving along the tracks, but this does not tell us either the speed or the direction of that motion. Without this information on our own motion, we cannot determine whether or not the second train is at rest with respect to the tracks.

RE 38-2: (a) Our measured value of the speed of light is equal to its value measured by the rider. (b) With respect to our frame, it takes some time for the light to move from one end of the boxcar to the other. During that time the boxcar moves in a direction opposite to that of the light. As a result, we measure the distance between emission and absorption of the light to be smaller than the length of the boxcar. (c) Part (b) shows that the distance between emission and absorption is shorter in our frame than in the frame of the rider on the boxcar. The speed of light is the same for both of us. Therefore, the time between emission and detection is shorter as measured in our frame is shorter than the time measured in the boxcar frame. (You should revisit this analysis after reading Section 38-12 Lorentz Contraction. Will this reanalysis lead to the same conclusion or a different one?)

RE 38-3: These questions concern individual impressions, so there are no objective answers. Here are mine: Halfway through the performance I would experience it as a whole series of events: hard parts, easy parts, mistakes! Those who printed the program probably listed the Minute Waltz as one event in the concert. Looking back ten years later, I will probably (but not necessarily) remember it as a single event.

RE 38-4: (a) Recall that, in general, distance = velocity*time. We know the velocity (c) and the distance (30 meters) of the returning light pulse. Therefore the time taken for this return is (30 m)/(3×10^8 m/s) = 10^{-7} second = 0.1 microsecond. Therefore the pulse arrived at detector B 0.225 − 0.1 = 0.125 microsecond after it passed us at detector A. (b) The proton pulse left detector A at $t = 0$ and, according to part (a) arrived at detector B at $t = 0.125$ microseconds. Therefore its speed from A to B is (30 m)/(0.125×10^{-6} s) = 2.4×10^8 m/sec, or 2.4/3 = 0.8 of the speed of light.

RE 38-5: Decay reduces the remaining number of pions by a factor of two for every 25 meters of distance they travel (at that particular speed, whatever it is). So there will be one-quarter remaining after 50 meters of travel and one-eighth at a distance of 75 meters from the target.

RE 38-6: All the clocks will run at the rate of every other clock. If this were not so, you could use the difference between rates of different clocks to detect which inertial reference frame you are in, contrary to the principle of relativity.

RE 38-7: Rearrange Eq. 38-3 to read $\Delta\tau/\Delta t = \sqrt{1 - v^2/c^2}$. Square both sides of this equation, solve for v^2/c^2, and substitute the values given in the statement of the exercise, $v^2/c^2 = 1 - \Delta\tau/\Delta t = 1 - 1/1.01 = 0.0099$. Take the square root of both sides to obtain approximately $v/c = 0.1$. This is a rough-and-ready criterion for the speed above which relativistic effects become significant in reasonably accurate experiments.

RE 38-8: The time a light pulse takes to travel one way from Earth's surface to the moon's surface is 3.76×10^8 m/3.00×10^8 m = 1.25 second. The two firecrackers, one on each surface explode one second apart in the earth-moon frame. Nothing, not even light can travel from the first explosion to the second explosion. Therefore one explosion cannot have caused the other one.

RE 38-9: Music has been emitted from the tape player. There are vibrations in the air. This is a fact that must be true in both frames of reference. (For example, it might be arranged to have the noise set off a firecracker, whose explosion must be acknowledged by all.) Air currents and distance permitting, Sam on the ground will be able to hear the music sometime (with what distortions we do not bother to analyze here). When Sam and Susan meet over coffee, they will both verify that some tape has been wound from one spool to the other in the tape recorder.

RE 38-10: Rearrange Eq. 38-17 to read $E/mc^2 = (1 - v^2/c^2)^{-1/2}$. Take the reciprocal of both sides, then square both sides and substitute values for the ratio of energy to rest energy given in the statement of the exercise. The result is $(mc^2/E)^2 = 1/4 = 1 - v^2/c^2$. Rearrange and take a square root to obtain $v = \sqrt{3/4}\,c = 0.866c$.

RE 38-11: The algebraic equations for this solution are essentially identical to those for the solution to the preceding reading exercise 38-10. Rearrange Eq. 38-28 to read $\Delta x'/\Delta x = (1 - v^2/c^2)^{-1/2}$. Take the reciprocal of both sides, then square both sides and substitute values for the ratio of measured lengths given in the statement of the exercise. The result is $(\Delta x'/\Delta x)^2 = 1/4 = 1 - v^2/c^2$. Rearrange and take a square root to obtain $v = \sqrt{3/4}\,c = 0.866c$.

RE 38-12: The light flash will move with speed c in our frame; this is a basic assumption of special relativity (Section 38-3). Verify this result by substituting the values $u' = c$ and $v^{\text{rel}} = 0.9c$ into Eq. 38-31.

$$u = \frac{c + v^{\text{rel}}}{1 + cv^{\text{rel}}/c^2} = \frac{c + 0.9c}{1 + 0.9c^2/c^2} = \frac{1.9c}{1.9} = c \text{ as we predicted.}$$

RE 38-13: Square both sides of Eq. 38-33 and multiply through by the resulting denominator: $(f/f_0)^2(1 + v^{\text{rel}}/c) = (1 - v^{\text{rel}}/c)$. Solve for v^{rel}

$$v^{\text{rel}} = \frac{1 - (f/f_0)^2}{1 + (f/f_0)^2}c = \frac{1 - 0.81}{1 + 0.81}c = 0.1c.$$

Problems

1. (a) $v/c = 3.16 \times 10^{-18}$ (b) $v/c = 9.26 \times 10^{-8}$ (c) $v/c = 2.87 \times 10^{-6}$ (d) $v/c = 10^{-4}$ **3.** EACH of the identical experiments should give the same result in the uniformly moving train as in the closed freight container. **5.** $v/c = 0.990$ or $v = 2.97 \times 10^8$ m/s **7.** You set your clock to the time 2×10^{-4} s. **9.** $\Delta\tau = 4.7 \times 10^{-8}$ s and $\Delta t = 17 \times 10^{-8}$ s. Therefore $\Delta t/\Delta\tau = 3.6$ **11.** (a) 26.3 y (b) 52.3 y (c) 3.71 y **13.** (a) $v/c = 0.995$ (b) 4.8×10^3 m (c) 480 m (d) 48 km (e) 9.8×10^4 particles will survive. **15.** (a) $v/c = 0.9999995$ (b) one year (c) It does not matter as long as the acceleration is small. **17.** (1, 2) timelike, yes; (1, 3) spacelike, no; (2,3) lightlike, yes **21.** 3.51×10^{-8} kg/y or about 35 micrograms/year **23.** 1.4467×10^{-29} kg, or 8.127 MeV **25.** (a) 1.04×10^{10} J (b) 0.116 mg **27.** (a) $v/c = [N(N + 2)]^{1/2}/(N + 1)(b)p = [N(N + 2)]^{1/2}\,mc$ **29.** (a) $m[p^2/(2K)] - [K/(2c^2)]$. For slow particle speed this reduces to the first term, which becomes m, as expected. (b) $m/m_e = 206$ **31.** (a) The lowest total energy after the collision (equal to the total energy before the collision) leaves the products at rest. (b) Kinetic energy of each incident proton is equal to the rest energy (the mass) of one proton. (c) This incident kinetic energy is equal to 1 GeV, which is reasonable since in the zero-total-momentum frame all the incident kinetic energy goes into the creation of mass, provided that the products remain at rest. **33.** $v_x = v^{\text{rel}}$ and $v_y = v_y'[1 - (v^{\text{rel}})^2/c^2]^{1/2}$ **35.** (a) $\cos\phi = [\cos\,\phi' + v^{\text{rel}}/c]/[1 +$

$(v^{\text{rel}}/c)\cos\phi']$ (b) $\cos\phi_o = v^{\text{rel}}/c$ (c) $\phi_o = 8.1°$ **37.** (a) $v = 2.6 \times 10^8$ m/s (b) $L = 50$ m. **39.** (a) Yes, at an appropriate speed, proper time between two timelike events can be made as small as desired. (b) $v = 0.999\ 999\ 15c$ **41.** velocity with respect to the rocket $= -0.82c$ **43.** Minimum and maximum values occur when daughter particles move along direction of relative motion. $u_+ = 0.990\ c$ and $u_- = 0.282\ c$ **45.** $f = 22.9$ MHz **47.** $v^{\text{rel}} = 0.96\ c$ **49.** (a) She does not age at all. (b) Both earth and Zircon age 100 y. (c) 350 y (d) 1200 y on earth **51.** 31.6 s **55.** (a) 0.511 MeV (b) $M_{\text{sys}} = m + 2m_e$ (c) Mass of the system is $2m_e$ both before and after the collision. **57.** $E_M = (M^2 + m^2)c^2/(2m)$ **61.** Partial answer: Let T be the time lapse between the instant we see the sun explode and the instant we see Venus change color. Then we have time $T/3$ to escape earth after we see Venus change color. This assumes that the alien ship moves faster than the pulse emitted by the sun.

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Mathematical Formulas*

Quadratic Formula

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

Binomial Theorem

$$(1 + x)^n = 1 + \frac{nx}{1!} + \frac{n(n-1)x^2}{2!} + \cdots \qquad (x^2 < 1)$$

Products of Vectors

Let θ be the smaller of the two angles between $\vec{a}$ and $\vec{b}$. Then

$$\vec{a} \cdot \vec{b} = \vec{b} \cdot \vec{a} = a_x b_x + a_y b_y + a_z b_z = |\vec{a}||\vec{b}| \cos\theta$$

$$\vec{a} \times \vec{b} = -\vec{b} \times \vec{a} = \begin{vmatrix} \hat{\mathrm{i}} & \hat{\mathrm{j}} & \hat{\mathrm{k}} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$

$$= \hat{\mathrm{i}} \begin{vmatrix} a_y & a_z \\ b_y & b_z \end{vmatrix} - \hat{\mathrm{j}} \begin{vmatrix} a_x & a_z \\ b_x & b_z \end{vmatrix} + \hat{\mathrm{k}} \begin{vmatrix} a_x & a_y \\ b_x & b_y \end{vmatrix}$$

$$= (a_y b_z - b_y a_z)\hat{\mathrm{i}} + (a_z b_x - b_z a_x)\hat{\mathrm{j}} + (a_x b_y - b_x a_y)\hat{\mathrm{k}}$$

$$|\vec{a} \times \vec{b}| = |\vec{a}||\vec{b}| \sin\theta$$

Trigonometric Identities

$$\sin\alpha \pm \sin\beta = 2 \sin\tfrac{1}{2}(\alpha \pm \beta) \cos\tfrac{1}{2}(\alpha \mp \beta)$$

$$\cos\alpha + \cos\beta = 2 \cos\tfrac{1}{2}(\alpha + \beta) \cos\tfrac{1}{2}(\alpha - \beta)$$

Derivatives and Integrals

$$\frac{d}{dx} \sin x = \cos x \qquad \int \sin x \, dx = -\cos x$$

$$\frac{d}{dx} \cos x = -\sin x \qquad \int \cos x \, dx = \sin x$$

$$\frac{d}{dx} e^x = e^x \qquad \int e^x \, dx = e^x$$

$$\int \frac{dx}{\sqrt{x^2 + a^2}} = \ln(x + \sqrt{x^2 + a^2})$$

$$\int \frac{x \, dx}{(x^2 + a^2)^{3/2}} = -\frac{1}{(x^2 + a^2)^{1/2}}$$

$$\int \frac{dx}{(x^2 + a^2)^{3/2}} = \frac{x}{a^2(x^2 + a^2)^{1/2}}$$

Cramer's Rule

Two simultaneous equations in unknowns x and y,

$$a_1 x + b_1 y = c_1 \qquad \text{and} \qquad a_2 x + b_2 y = c_2,$$

have the solutions

$$x = \frac{\begin{vmatrix} c_1 & b_1 \\ c_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{c_1 b_2 - c_2 b_1}{a_1 b_2 - a_2 b_1}$$

and

$$y = \frac{\begin{vmatrix} a_1 & c_1 \\ a_2 & c_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{a_1 c_2 - a_2 c_1}{a_1 b_2 - a_2 b_1}.$$

* See Appendix E for a more complete list.

The Greek Alphabet

Alpha	A	α	Iota	I	ι	Rho	P	ρ
Beta	B	β	Kappa	K	κ	Sigma	Σ	σ
Gamma	Γ	γ	Lambda	Λ	λ	Tau	T	τ
Delta	Δ	δ	Mu	M	μ	Upsilon	Υ	υ
Epsilon	E	ϵ	Nu	N	ν	Phi	Φ	ϕ, φ
Zeta	Z	ζ	Xi	Ξ	ξ	Chi	X	χ
Eta	H	η	Omicron	O	o	Psi	Ψ	ψ
Theta	Θ	θ	Pi	Π	π	Omega	Ω	ω

Some Physical Constants*

Speed of light	c	3.00×10^{8} m/s
Gravitational constant	G	6.67×10^{-11} $\mathrm{N \cdot m^2/kg^2}$
Avogadro constant	N_A	6.02×10^{23} $\mathrm{mol^{-1}}$
Universal gas constant	R	8.31 J/mol·K
Mass-energy relation	c^2	8.99×10^{16} J/kg
		931.5 MeV/u
Electric constant (permittivity)	ϵ_0	8.85×10^{-12} $\mathrm{C^2/N \cdot m^2}$
Coulomb constant	$k = 1/4\pi\epsilon_0$	8.99×10^{9} $\mathrm{N \cdot m^2/c^2}$
Magnetic constant (permeability)	μ_0	1.26×10^{-6} $\mathrm{N/A^2}$
Planck constant	h	6.63×10^{-34} J·s
		4.14×10^{-15} eV·s
Stefan-Boltzmann	σ	5.67×10^{-8} $\mathrm{W/m^2 \cdot k^4}$
Boltzmann constant	k_B	1.38×10^{-23} J/K
		8.62×10^{-5} eV/K
Elementary charge	e	1.60×10^{-19} C
Electron mass	m_e	9.11×10^{-31} kg
Proton mass	m_p	1.67×10^{-27} kg
Neutron mass	m_n	1.68×10^{-27} kg
Deutron mass	m_d	3.34×10^{-27} kg
Bohr radius	r_B	5.29×10^{-11} m
Bohr magneton	μ_B	9.27×10^{-24} J/T
		5.79×10^{-5} eV/T
Rydberg constant	R	0.01097 $\mathrm{nm^{-1}}$

* For a more complete list, showing also the best experimental values, see Appendix B.

Some Conversion Factors*

Mass and Density

1 kg = 1000 g = 6.02×10^{26} u
1 slug = 14.6 kg
1 u = 1.66×10^{-27} kg
1 $\mathrm{kg/m^3}$ = 10^{-3} $\mathrm{g/cm^3}$

Length and Volume

1 m = 100 cm = 39.4 in. = 3.28 ft
1 mi = 1.61 km = 5280 ft
1 in. = 2.54 cm
1 nm = 10^{-9} m = 10 Å
1 pm = 10^{-12} m = 1000 fm
1 light-year = 9.46×10^{15} m
1 $\mathrm{m^3}$ = 1000 L = 35.3 $\mathrm{ft^2}$ = 264 gal

Time

1 d = 86,400 s
1 y = $365\frac{1}{4}$ d = 3.16×10^{7} s

Angular Measure

1 rad = 57.3° = 0.159 rev
π rad = 180° = $\frac{1}{2}$ rev

Speed

1 m/s = 3.28 ft/s = 2.24 mi/h
1 km/h = 0.621 mi/h = 0.278 m/s

Force and Pressure

1 N = 10^{6} dyne = 0.225 lb
1 lb = 4.45 N
1 ton = 2000 lb
1 Pa = 1 $\mathrm{N/m^2}$ = 10 $\mathrm{dyne/cm^2}$
= 1.45×10^{-4} $\mathrm{lb/in.^2}$
1 atm = 1.01×10^{5} Pa = 14.7 $\mathrm{lb/in.^2}$
= 76 cm-Hg

Energy and Power

1 J = 10^{7} erg = 0.239 cal = 0.738 ft·lb
1 kW·h = 3.6×10^{6} J
1 cal = 4.19 J
1 eV = 1.60×10^{-19} J
1 horsepower = 746 W = 550 ft·lb/s

Magnetism

1 T = 1 $\mathrm{Wb/m^2}$ = 10^{4} gauss

* See Appendix D for a more complete list.

Some Physical Properties

Air (dry, at 20°C and 1 atm)	
Density	1.21 kg/m^3
Specific heat at constant pressure	1010 $J/kg \cdot K$
Ratio of specific heats	1.40
Speed of sound	343 m/s
Electrical breakdown strength	3×10^6 V/m
Effective molar mass	0.0289 kg/mol
Water	
Density	1000 kg/m^3
Speed of sound	1460 m/s
Specific heat at constant pressure	4190 $J/kg \cdot K$
Heat of fusion (0°C)	333 kJ/kg
Heat of vaporization (100°C)	2260 kJ/kg
Index of refraction ($\lambda = 589$ nm)	1.33
Molar mass	0.0180 kg/mol
Earth	
Mass	5.98×10^{24} kg
Mean radius	6.37×10^6 m
Free-fall acceleration at Earth's surface	9.8 m/s^2
Standard atmosphere	1.01×10^5 Pa
Period of satellite at 100 km altitude	86.3 min
Radius of the geosynchronous orbit	42,200 km
Escape speed	11.2 km/s
Magnetic dipole moment	8.0×10^{22} $A \cdot m^2$
Mean electric field at surface	150 V/m, down
Distance to	
Moon	3.82×10^8 m
Sun	1.50×10^{11} m
Nearest star	4.04×10^{16} m
Galactic center	2.2×10^{20} m
Andromeda galaxy	2.1×10^{22} m
Edge of the observable universe	$\sim 10^{26}$ m

SI Prefixes*

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deka	da	10^{-24}	yocto	y

*In all cases, the first syllable is accented, as in ná-no-mé-ter.