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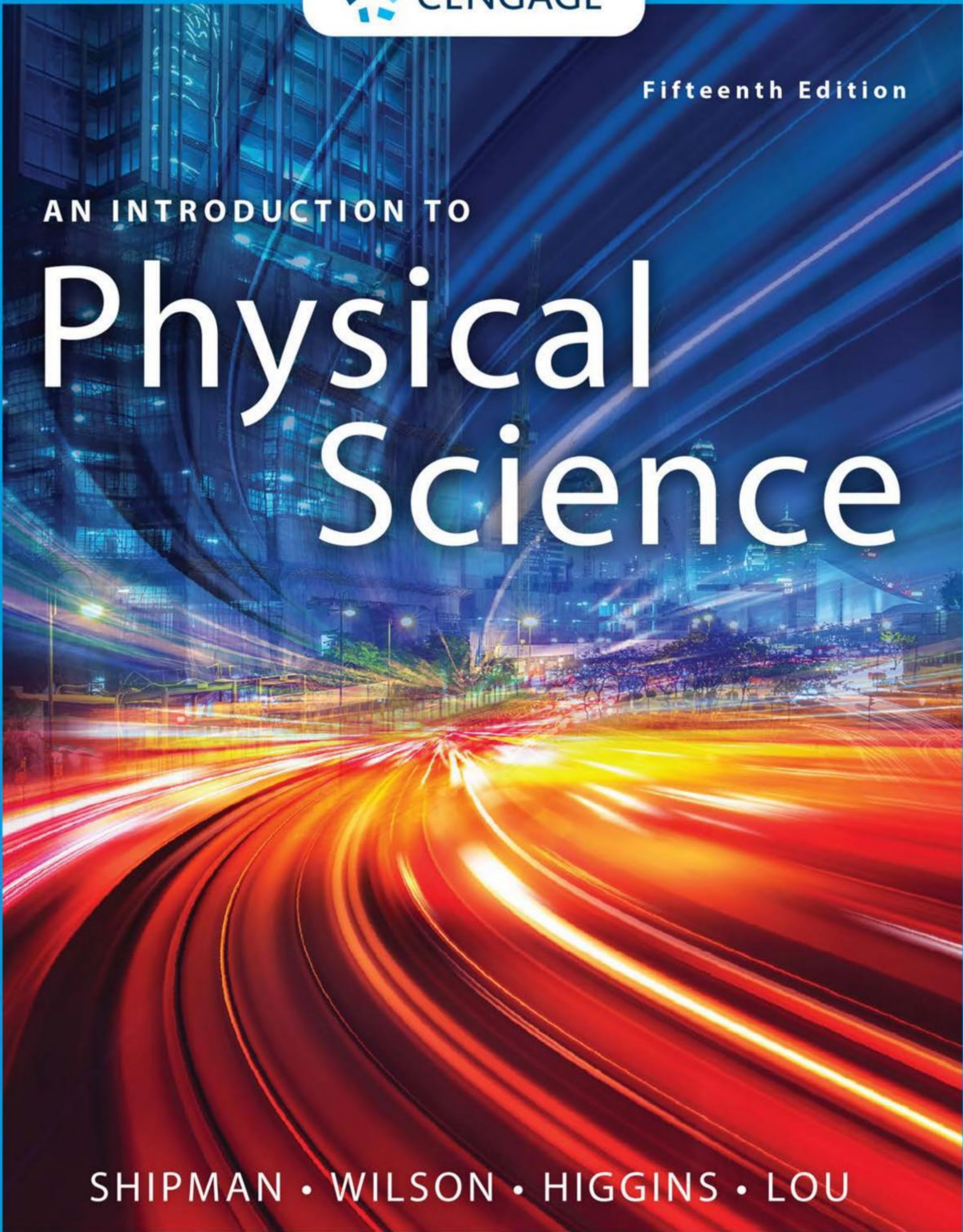

Fifteenth Edition

AN INTRODUCTION TO

Physical Science

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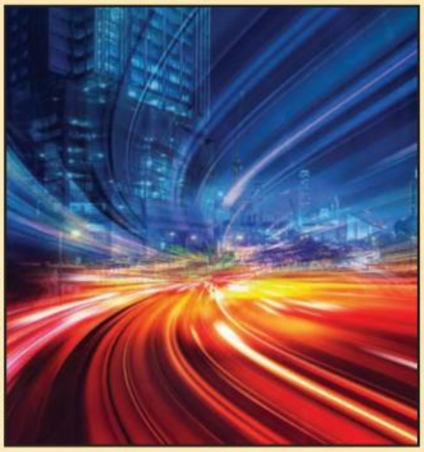

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AN INTRODUCTION TO

Physical Science

Fifteenth Edition

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Fifteenth Edition
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Brief Contents

Chapter 1 Measurement 1

Chapter 2 Motion 28

Chapter 3 Force and Motion 52

Chapter 4 Work and Energy 81

Chapter 5 Temperature and Heat 107

Chapter 6 Waves and Sound 141

Chapter 7 Optics and Wave Effects 166

Chapter 8 Electricity and Magnetism 200

Chapter 9 Atomic Physics 237

Chapter 10 Nuclear Physics 267

Chapter 11 The Chemical Elements 308

Chapter 12 Chemical Bonding 337

Chapter 13 Chemical Reactions 368

Chapter 14 Organic Chemistry 401

Chapter 15 Place and Time 431

Chapter 16 The Solar System 458

Chapter 17 Moons and Small Solar System Bodies 490

Chapter 18 The Universe 520

Chapter 19 The Atmosphere 557

Chapter 20 Atmospheric Effects 591

Chapter 21 Structural Geology and Plate Tectonics 629

Chapter 22 Minerals, Rocks, and Volcanoes 659

Chapter 23 Surface Processes 691

Chapter 24 Geologic Time 717

Contents

Preface x

About the Authors xvi

Chapter 1 Measurement 1

1.1 The Physical Sciences 2
1.2 Scientific Investigation 3
1.3 The Senses 4
HIGHLIGHT 1.1 The "Face" on Mars 5
1.4 Standard Units and Systems of Units 6
CONCEPTUAL Q&A 1.1 Time and Time Again 10
1.5 More on the Metric System 12
1.6 Derived Units and Conversion Factors 14
PHYSICAL SCIENCE TODAY 1.1 What's Your Body Density? Try BMI 17
HIGHLIGHT 1.2 Is Unit Conversion Important? It Sure Is 20
1.7 Significant Figures 21

Key Terms **23**, Matching **23**, Multiple Choice **23**, Fill in the Blank **24**, Short Answer **24**, Visual Connection **25**, Applying Your Knowledge **25**, Important Equation **25**, Exercises **26**

Chapter 2 Motion 28

2.1 Defining Motion 29
2.2 Speed and Velocity 30
2.3 Acceleration 34
CONCEPTUAL Q&A 2.1 Putting the Pedal to the Metal 37
HIGHLIGHT 2.1 Galileo and the Leaning Tower of Pisa 38
PHYSICAL SCIENCE TODAY 2.1 Rotating Tablet Screens 41
CONCEPTUAL Q&A 2.2 And the Winner Is … 41
2.4 Acceleration in Uniform Circular Motion 42
2.5 Projectile Motion 44

Key Terms **47**, Matching **47**, Multiple Choice **47**, Fill in the Blank **48**, Short Answer **48**, Visual Connection **49**, Applying Your Knowledge **49**, Important Equations **50**, Exercises **50**

Chapter 3 Force and Motion 52

3.1 Force and Net Force 53
3.2 Newton's First Law of Motion 54
CONCEPTUAL Q&A 3.1 You Go Your Way, I'll Go Mine 56
3.3 Newton's Second Law of Motion 57
CONCEPTUAL Q&A 3.2 Fundamental Is Fundamental 60
3.4 Newton's Third Law of Motion 62
HIGHLIGHT 3.1 The Automobile Air Bag 64
3.5 Newton's Law of Gravitation 65
CONCEPTUAL Q&A 3.3 A Lot of Mass 66
3.6 Archimedes' Principle and Buoyancy 68
CONCEPTUAL Q&A 3.4 Float the Boat 69
3.7 Momentum 69

Key Terms **75**, Matching **75**, Multiple Choice **76**, Fill in the Blank **76**, Short Answer **77**, Visual Connection **78**, Applying Your Knowledge **78**, Important Equations **79**, Exercises **79**

Chapter 4 Work and Energy 81

4.1 Work 82
4.2 Kinetic Energy and Potential Energy 84
CONCEPTUAL Q&A 4.1 Double Zero 89
4.3 Conservation of Energy 89
CONCEPTUAL Q&A 4.2 The Race Is On 91
4.4 Power 92
CONCEPTUAL Q&A 4.3 Payment for Power 95
4.5 Forms of Energy and Consumption 95
4.6 Alternative and Renewable Energy Sources 97
PHYSICAL SCIENCE TODAY 4.1 Light Bulbs That Last 50,000 Hours? 101

Key Terms **102**, Matching **102**, Multiple Choice **102**, Fill in the Blank **103**, Short Answer **103**, Visual Connection **105**, Applying Your Knowledge **105**, Important Equations **105**, Exercises **105**

Chapter 5 Temperature and Heat 107

5.1 Temperature 108
CONCEPTUAL Q&A 5.1 The Easy Approximation 111
5.2 Heat 111
HIGHLIGHT 5.1 Human Body Temperature 112
HIGHLIGHT 5.2 Freezing from the Top Down 114
5.3 Specific Heat and Latent Heat 115
CONCEPTUAL Q&A 5.2 Under Pressure 121
5.4 Heat Transfer 121
CONCEPTUAL Q&A 5.3 Hug the Rug 122
5.5 Phases of Matter 124
5.6 The Kinetic Theory of Gases 126
PHYSICAL SCIENCE TODAY 5.1 Boyle's Law: Breathing and the Heimlich Maneuver 128
HIGHLIGHT 5.3 Hot Gases: Aerosol Cans and Popcorn 131
5.7 Thermodynamics 131
CONCEPTUAL Q&A 5.4 Common Descriptions 134

Key Terms **136**, Matching **136**, Multiple Choice **136**, Fill in the Blank **137**, Short Answer **137**, Visual Connection **139**, Applying Your Knowledge **139**, Important Equations **140**, Exercises **140**

Chapter 6 Waves and Sound 141

6.1 Waves and Energy Propagation 141
6.2 Wave Properties 143
6.3 Light Waves 146

6.4 Sound Waves 148
CONCEPTUAL Q&A 6.1 A Tree Fell 152
HIGHLIGHT 6.1 Noise Exposure Limits 152
PHYSICAL SCIENCE TODAY 6.1 Deaf and Can Still Hear? Bone Conduction 153
6.5 The Doppler Effect 156
CONCEPTUAL Q&A 6.2 Faster Than Sound 157
6.6 Standing Waves and Resonance 158
CONCEPTUAL Q&A 6.3 It Can Be Shattering 160

Key Terms **161**, Matching **162**, Multiple Choice **162**, Fill in the Blank **163**, Short Answer **163**, Visual Connection **164**, Applying Your Knowledge **164**, Important Equations **164**, Exercises **165**

Chapter 7 Optics and Wave Effects 166

7.1 Reflection 167
CONCEPTUAL Q&A 7.1 No Can See 168
CONCEPTUAL Q&A 7.2 Nighttime Mirror 170
7.2 Refraction and Dispersion 170
CONCEPTUAL Q&A 7.3 Twinkle, Twinkle 172
HIGHLIGHT 7.1 The Rainbow: Dispersion and Internal Reflection 178
7.3 Spherical Mirrors 179
CONCEPTUAL Q&A 7.4 Up and Down 183
7.4 Lenses 183
CONCEPTUAL Q&A 7.5 Right-Side-Up from Upside-Down 187
PHYSICAL SCIENCE TODAY 7.1 Visual Acuity and 20/20 Vision 188
7.5 Polarization 189
HIGHLIGHT 7.2 Liquid Crystal Displays (LCDs) 191
7.6 Diffraction and Interference 192

Key Terms **196**, Matching **196**, Multiple Choice **196**, Fill in the Blank **197**, Short Answer **197**, Visual Connection **198**, Applying Your Knowledge **199**, Important Equations **199**, Exercises **199**

Chapter 8 Electricity and Magnetism 200

8.1 Electric Charge, Electric Force, and Electric Field 201
CONCEPTUAL Q&A 8.1 Defying Gravity 204
PHYSICAL SCIENCE TODAY 8.1 Sensitive to the Touch: Touch Screens 206
8.2 Current, Voltage, and Electrical Power 206
HIGHLIGHT 8.1 United States and Europe: Different Voltages 211
8.3 Simple Electric Circuits and Electrical Safety 212
CONCEPTUAL Q&A 8.2 Series or Parallel 215
HIGHLIGHT 8.2 Electrical Effects on Humans 218
8.4 Magnetism 219
HIGHLIGHT 8.3 Magnetic North Pole 225
8.5 Electromagnetism 225
CONCEPTUAL Q&A 8.3 No Transformation 229

Key Terms **232**, Matching **232**, Multiple Choice **233**, Fill in the Blank **233**, Short Answer **234**, Visual Connection **235**, Applying Your Knowledge **235**, Important Equations **235**, Exercises **236**

Chapter 9 Atomic Physics 237

9.1 Early Concepts of the Atom 238
9.2 The Dual Nature of Light 239
CONCEPTUAL Q&A 9.1 Step Right Up 241
HIGHLIGHT 9.1 Albert Einstein 243
9.3 Bohr Theory of the Hydrogen Atom 244
9.4 Microwave Ovens, X-Rays, and Lasers 251
CONCEPTUAL Q&A 9.2 Can't Get Through 252
HIGHLIGHT 9.2 X-Ray CAT Scan and MRI 253
9.5 Heisenberg's Uncertainty Principle 256
9.6 Matter Waves 257
CONCEPTUAL Q&A 9.3 A Bit Too Small 258
9.7 The Electron Cloud Model of the Atom 259
HIGHLIGHT 9.3 Electron Microscopes 260

Key Terms **262**, Matching **263**, Multiple Choice **263**, Fill in the Blank **264**, Short Answer **264**, Visual Connection **265**, Applying Your Knowledge **265**, Important Equations **266**, Exercises **266**

Chapter 10 Nuclear Physics 267

10.1 Symbols of the Elements 267
10.2 The Atomic Nucleus 269
10.3 Radioactivity and Half-Life 273
HIGHLIGHT 10.1 The Discovery of Radioactivity 274
CONCEPTUAL Q&A 10.1 A Misprint? 276
10.4 Nuclear Reactions 283
CONCEPTUAL Q&A 10.2 Around the House 284
PHYSICAL SCIENCE TODAY 10.1 Zapped with Gamma Rays: Irradiated Food 285
10.5 Nuclear Fission 286
CONCEPTUAL Q&A 10.3 Out of Control 291
10.6 Nuclear Fusion 292
10.7 Effects of Radiation 296
PHYSICAL SCIENCE TODAY 10.2 Smoking and Tobacco Radiation: Bad for Your Health 298
HIGHLIGHT 10.2 Nuclear Power and Waste Disposal 298
10.8 Elementary Particles 300
CONCEPTUAL Q&A 10.4 *Star Trek* Adventure 302

Key Terms **302**, Matching **302**, Multiple Choice **303**, Fill in the Blank **304**, Short Answer **304**, Visual Connection **305**, Applying Your Knowledge **305**, Important Equations **305**, Exercises **306**

Chapter 11 The Chemical Elements 308

11.1 Classification of Matter 309
CONCEPTUAL Q&A 11.1 A Compound Question 310
11.2 Discovery of the Elements 312

HIGHLIGHT 11.1 What Are the Naturally Occurring Elements? **314**
HIGHLIGHT 11.2 Berzelius and How New Elements Are Named **315**
11.3 Occurrence of the Elements **315**
11.4 The Periodic Table **319**
CONCEPTUAL Q&A 11.2 An Elemental Rarity **321**
11.5 Naming Compounds **325**
CONCEPTUAL Q&A 11.3 A Table of Compounds? **326**
11.6 Groups of Elements **328**

Key Terms **332**, Matching **332**, Multiple Choice **332**, Fill in the Blank **333**, Short Answer **333**, Visual Connection **334**, Applying Your Knowledge **335**, Exercises **335**

Chapter 12 Chemical Bonding **337**

12.1 Law of Conservation of Mass **338**
HIGHLIGHT 12.1 Lavoisier, "The Father of Chemistry" **339**
12.2 Law of Definite Proportions **340**
12.3 Dalton's Atomic Theory **342**
12.4 Ionic Bonding **343**
PHYSICAL SCIENCE TODAY 12.1 Lithium-Ion Rechargeable Batteries **350**
12.5 Covalent Bonding **352**
CONCEPTUAL Q&A 12.1 A Matter of Purity **358**
12.6 Hydrogen Bonding **361**
CONCEPTUAL Q&A 12.2 Hydrogen Bond Highways **362**

Key Terms **363**, Matching **363**, Multiple Choice **364**, Fill in the Blank **364**, Short Answer **365**, Visual Connection **366**, Applying Your Knowledge **366**, Important Equations **366**, Exercises **366**

Chapter 13 Chemical Reactions **368**

13.1 Balancing Chemical Equations **369**
13.2 Energy and Rate of Reaction **373**
PHYSICAL SCIENCE TODAY 13.1 Auto Air Bag Chemistry and Millions of Recalls **376**
CONCEPTUAL Q&A 13.1 Burning Iron! **378**
13.3 Acids and Bases **380**
CONCEPTUAL Q&A 13.2 Crying Time **383**
HIGHLIGHT 13.1 Acids and Bases in Your Stomach **384**
CONCEPTUAL Q&A 13.3 Odors, Be Gone! **386**
13.4 Single-Replacement Reactions **389**
13.5 Avogadro's Number **392**

Key Terms **395**, Matching **395**, Multiple Choice **396**, Fill in the Blank **397**, Short Answer **397**, Visual Connection **398**, Applying Your Knowledge **399**, Important Equation **399**, Exercises **399**

Chapter 14 Organic Chemistry **401**

14.1 Bonding in Organic Compounds **402**
14.2 Aromatic Hydrocarbons **403**
14.3 Aliphatic Hydrocarbons **405**
14.4 Derivatives of Hydrocarbons **413**
HIGHLIGHT 14.1 Breathalyzers **416**
14.5 Synthetic Polymers **418**
CONCEPTUAL Q&A 14.1 What Is Hair Spray? **419**
14.6 Biochemistry **421**
CONCEPTUAL Q&A 14.2 My Twisted Double Helix **422**
CONCEPTUAL Q&A 14.3 Should We Eat Too Many Carbohydrates? **423**
PHYSICAL SCIENCE TODAY 14.1 DNA Gene Therapy **425**

Key Terms **426**, Matching **426**, Multiple Choice **426**, Fill in the Blank **427**, Short Answer **427**, Visual Connection **428**, Applying Your Knowledge **429**, Exercises **429**

Chapter 15 Place and Time **431**

15.1 Cartesian Coordinates **432**
CONCEPTUAL Q&A 15.1 3-D Coordinates **433**
15.2 Latitude and Longitude **433**
15.3 Time **436**
CONCEPTUAL Q&A 15.2 Polar Time **439**
HIGHLIGHT 15.1 Time Traveler **440**
15.4 Determining Latitude and Longitude **442**
15.5 The Seasons and the Calendar **445**
HIGHLIGHT 15.2 Global Positioning System (GPS) **446**
CONCEPTUAL Q&A 15.3 Equal Days and Nights **447**
CONCEPTUAL Q&A 15.4 Hot and Cold Weather **449**
HIGHLIGHT 15.3 A Brief History of the Western Calendar **451**
15.6 Precession of the Earth's Axis **452**

Key Terms **453**, Matching **454**, Multiple Choice **454**, Fill in the Blank **455**, Short Answer **455**, Visual Connection **456**, Applying Your Knowledge **457**, Exercises **457**

Chapter 16 The Solar System **458**

16.1 The Solar System and Planetary Motion **459**
16.2 Major Planet Classifications and Orbits **462**
16.3 The Planet Earth **465**
CONCEPTUAL Q&A 16.1 Another Foucault Pendulum **467**
16.4 The Terrestrial Planets **468**
16.5 The Jovian Planets **472**
CONCEPTUAL Q&A 16.2 Space Exploration and Gravity Assist **473**
HIGHLIGHT 16.1 Juno Reveals Jupiter **475**
16.6 The Dwarf Planets **478**
16.7 The Origin of the Solar System **483**
16.8 Other Planetary Systems **484**
HIGHLIGHT 16.2 The Search for Exoplanets **485**

Key Terms **486**, Matching **486**, Multiple Choice **486**, Fill in the Blank **487**, Short Answer **487**, Visual Connection **488**, Applying Your Knowledge **489**, Important Equation **489**, Exercises **489**

Chapter 22 Minerals, Rocks, and Volcanoes 659

22.1 Minerals **660**
CONCEPTUAL Q&A 22.1 Cutting Diamonds **664**
22.2 Rocks **666**
CONCEPTUAL Q&A 22.2 Energy for the Rock Cycle **668**
22.3 Igneous Rocks **668**
22.4 Igneous Activity and Volcanoes **671**
HIGHLIGHT 22.1 Kīlauea: The Most Active Volcano in the World **674**
22.5 Sedimentary Rocks **678**
22.6 Metamorphic Rocks **683**
Key Terms **686**, Matching **686**, Multiple Choice **687**, Fill in the Blank **688**, Short Answer **688**, Visual Connection **689**, Applying Your Knowledge **689**

Chapter 23 Surface Processes 691

23.1 Weathering **692**
CONCEPTUAL Q&A 23.1 Moon Weathering **694**
23.2 Erosion **696**
23.3 Groundwater **702**
HIGHLIGHT 23.1 The Earth's Largest Crystals **703**
CONCEPTUAL Q&A 23.2 Powering the Hydrologic Cycle **704**
23.4 Shoreline and Seafloor Topography **707**
HIGHLIGHT 23.2 The Highest Tides in the World **708**
Key Terms **713**, Matching **713**, Multiple Choice **714**, Fill in the Blank **714**, Short Answer **715**, Visual Connection **715**, Applying Your Knowledge **716**

Chapter 24 Geologic Time 717

24.1 Fossils **718**
HIGHLIGHT 24.1 How Fossils Were Formed **720**
CONCEPTUAL Q&A 24.1 Fossilized Jellyfish **721**
24.2 Relative Geologic Time **721**
24.3 Radiometric Dating **726**
CONCEPTUAL Q&A 24.2 Dinosaur Dating **731**
24.4 The Age of the Earth **732**
24.5 The Geologic Time Scale **733**
HIGHLIGHT 24.2 The K-Pg Event: The Disappearance of the Dinosaurs **737**
Key Terms **738**, Matching **739**, Multiple Choice **739**, Fill in the Blank **740**, Short Answer **740**, Visual Connection **741**, Applying Your Knowledge **742**, Exercises **742**

Appendixes A-1
Answers to Confidence Exercises A-23
Answers to Selected Questions A-26
Glossary G-1
Index I-0

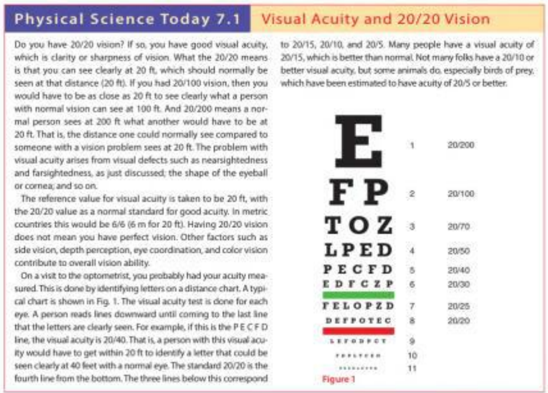
platform. The Digital Workbook lessons will expose students to in-depth, comprehensive activities with rich targeted feedback that will help them build a conceptual and practical mastery of key ideas in physical science. It provides a new source of contextual support for students and teachers, and provides an auxiliary study guide for when assessment time comes around.

To address the need for critical reasoning and problem-solving skills in an ever-changing technological world, we emphasize fundamental concepts in the five divisions of physical sciences: physics, chemistry, astronomy, meteorology, and geology. Topics are treated both descriptively and quantitatively, in a fashion ideal for nonscience majors, providing instructors with greater flexibility in teaching. Concepts are thoroughly introduced and are followed with quantitative examples. Features like *Highlights* and *Physical Science Today* provide extended information on applied sciences. Consistent with prior editions, the end-of-chapter section has dozens of questions for review in various forms. We hope that instructors find the textbook up-to-date, with clear, concise, and classical treatment of the physical sciences. As instructors, you have great flexibility in emphasizing certain topics for a one-semester course or using the full set of topics for a two-semester course.

Organizational Updates and Key Features in the Fifteenth Edition

Physical Science Today (PST)—These descriptions link important concepts in physical science to current technologies and applications of current interest. Some are important biological and medical applications. These include:

Chapter 1: What's Your Body Density? Try BMI
Chapter 2: Rotating Tablet Screens
Chapter 4: Light Bulbs That Last 50,000 Hours?
Chapter 5: Boyle's Law: Breathing and the Heimlich Maneuver
Chapter 6: Deaf and Can Still Hear? Bone Conduction
Chapter 7: Visual Acuity and 20/20 Vision
Chapter 8: Sensitive to the Touch: Touch Screens
Chapter 10: Zapped with Gamma Rays: Irradiated Food
Chapter 10: Smoking and Tobacco Radiation: Bad for Your Health
Chapter 12: Lithium-Ion Rechargeable Batteries
Chapter 13: Auto Air Bag Chemistry and Millions of Recalls
Chapter 14: DNA Gene Therapy
Chapter 17: Total Solar Eclipses
Chapter 18: Gravity Waves
Chapter 20: Don't Go Under That Tree! Lightning Formation and Tree Strikes
Chapter 20: Ruminating Up Some CH_4


Physical Science Today 7.1 Visual Acuity and 20/20 Vision

Do you have 20/20 vision? If so, you have good visual acuity, which is clarity or sharpness of vision. What the 20/20 means is that you can see clearly at 20 ft, which should normally be seen at that distance (20 ft). If you had 20/100 vision, then you would have to be as close as 20 ft to see clearly what a person with normal vision can see at 100 ft. And 20/200 means a normal person sees at 200 ft what another would have to be at 20 ft. That is, the distance one could normally see compared to someone with a vision problem sees at 20 ft. The problem with visual acuity arises from visual defects such as nearsightedness and farsightedness, as just discussed; the shape of the eyeball or cornea; and so on.

The reference value for visual acuity is taken to be 20 ft, with the 20/20 value as a normal standard for good acuity. In metric countries this would be 6/6 (6 m for 20 ft). Having 20/20 vision does not mean you have perfect vision. Other factors such as side vision, depth perception, eye coordination, and color vision contribute to overall vision ability.

On a visit to the optometrist, you probably had your acuity measured. This is done by identifying letters on a distance chart. A typical chart is shown in Fig. 1. The visual acuity test is done for each eye. A person reads lines downward until coming to the last line that the letters are clearly seen. For example, if this is the P E C F D line, the visual acuity is 20/40. That is, a person with this visual acuity would have to get within 20 ft to identify a letter that could be seen clearly at 40 feet with a normal eye. The standard 20/20 is the fourth line from the bottom. The three lines below this correspond to 20/15, 20/10, and 20/5. Many people have a visual acuity of 20/15, which is better than normal. Not many folks have a 20/10 or better visual acuity, but some animals do, especially birds of prey, which have been estimated to have acuity of 20/5 or better.

Figure 1

New Topic Highlights for this edition:

Chapter 13: Acids and Bases in Your Stomach
Chapter 14: Breathalyzers
Chapter 15: Time Traveler
Chapter 16: Juno Reveals Jupiter
Chapter 21: Tectonic Activity on Mars
Chapter 22: Kīlauea: The Most Active Volcano in the World


NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

- Updated photographs and information of the latest astronomical discoveries like exoplanets, Pluto's surface, gravity waves, supermassive black holes, and the age of the universe.
- *Thinking It Through (TIT)*—Following *Example* questions and before given *Solutions*, *TIT* sections help students engage critical thinking, analysis, and problem-solving strategies while working through the example.

- *Did You Know*—Each chapter begins with key questions and their accompanying sections to help quickly orient students and introduce them to the central ideas of the chapter.
- *Facts*—Each chapter begins with a list of *Facts*, a brief description of pertinent, interesting, and user-friendly items regarding concepts and topics to be covered in the chapter.
- *Key Questions*—A short set of preview questions ask about important topics that will be covered in the following section.
- *Did You Learn?*—A short set of answers to the *Key Questions* reviews what the student should know after reading a section.
- *Conceptual Question and Answer*—These test student comprehension with a *Conceptual Question*, often related to an everyday application, and give the answer, which reinforces the topic of the text.

Math Coverage and Support

Each discipline in science is treated both descriptively and quantitatively. To make the Fifteenth Edition user-friendly for students who are not mathematically inclined, we continue to introduce concepts to be treated mathematically as follows. First, the concept is defined, as briefly as possible, using words. The definition is then presented, where applicable, as an equation in word form. And, finally, the concept is expressed in symbolic notation.

1. The acceleration produced by an unbalanced force acting on an object (or mass) is directly proportional to the magnitude of the force ($a \propto F$) and in the direction of the force (the $\propto$ symbol is a proportionality sign). In other words, the greater the unbalanced force, the greater the acceleration.
2. The acceleration of an object being acted on by an unbalanced force is inversely proportional to the mass of the object ($a \propto 1/m$). That is, for a given unbalanced force, the greater the mass of an object, the smaller the acceleration.

Combining these effects of force and mass on acceleration gives

$$\text{acceleration} = \frac{\text{unbalanced force}}{\text{mass}}$$

When appropriate units are used, the effects of force and mass on acceleration can be written in equation form as $a = F/m$. Or, as commonly written in terms of force in magnitude form, we have **Newton's second law of motion**:

$$\text{force} = \text{mass} \times \text{acceleration}$$
$$F = ma \qquad 3.1$$

This is an example of the language-first introduction to a mathematical concept for Newton's Second Law. It first describes the empirical features of the law in a narrative form, then writes out the relationship as a 'word equation' and then finally using symbols as a numbered equation.

The level of mathematics in the textbook continues to be no greater than that of general high school math. Appendixes A, B, C, D, E, F, and G provide a review of the math skills needed to deal with the mathematical exercises in this textbook. It may be helpful for students to begin their study by working through these seven appendixes. This will help identify and remediate common challenges students face in mathematics and thereby build their confidence and ability to solve quantitative exercises in the textbook. Additional *Practice Exercises* for mathematical concepts and skills are available in WebAssign.

Assistance is also offered to students by means of in-text worked *Examples* and follow-up *Confidence Exercises* (with answers). However, the emphasis on these exercises, whether descriptive or quantitative, is left to the discretion of the instructor. For instance, the end-of-chapter material may be selected according to the instructor's preferences. For those who want to maintain a more descriptive approach, they can choose to omit the Exercises and use the other end-of-chapter sections for assignments.

Complete Ancillary Support

An Introduction to Physical Science, Fifteenth Edition, is supported by a complete set of ancillaries. Each piece has been designed to enhance student understanding and to facilitate creative instruction.

Instructor Resources

Instructor Solutions Manual (ISM): Includes worked-out solutions to all exercises in the text. The ISM is available through the Instructor Companion Site and WebAssign.

Instructor's Guide to Accompany Laboratory Guide: Contains useful information and sample data for many of the experiments in this manual, and has worked-out calculations and even typical answers for the exercises and questions. This material has been prepared to help both experienced and inexperienced laboratory instructors, and will be especially useful to laboratory assistants assigned to do the grading for these experiments when they are used in a formal laboratory setting, but anyone needing to prepare lecture or demonstration material for physical science classes at any level can benefit from this information. The Instructor's Guide to Accompany Laboratory Guide is available through the Instructor Companion Site and WebAssign.

PowerPoint Lecture Tools: PowerPoint slides are available for every chapter of the text. Each presentation contains important concepts, images, and questions from each chapter and section to help guide lectures and activities. In addition to lecture slides, other available presentations contain only the images from each chapter, for use on assignments, tests, and projects and clicker content is also available. All PowerPoint lecture tools are available through the Instructor Companion Site and WebAssign.

Cengage Testing, Powered by Cognero®: Cognero is a flexible online system that allows you to author, edit, and manage test bank content online. You can create multiple versions of your test in an instant and deliver tests from your LMS or exportable PDF or Word docs you print for in-class assessment.

Test Banks: Microsoft Word-compatible versions of the text's test banks are included and can be imported into your Learning Management System (LMS). Word-compatible test banks are available through the Instructor Companion Site.

Student Ancillaries

Laboratory Guide: The Laboratory Guide contains 55 experiments in the five major divisions of physical science: physics, chemistry, astronomy, geology, and meteorology. Each experiment includes an introduction, learning objectives, a list of apparatus, procedures for taking data, and questions. The Laboratory Guide is available as a print-on-demand item.

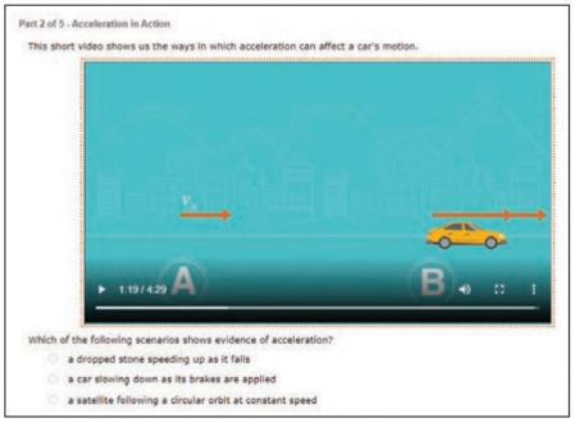
Active Learning Online with WebAssign

WebAssign for Shipman, Wilson, Higgins, Lou's *An Introduction to Physical Science*, Fifteenth Edition: Exclusively from Cengage Learning, WebAssign combines the exceptional mathematics, physics, and astronomy content that you know and love with the most powerful online homework solution. Designed with engaging activities, immediate feedback, an interactive eBook, and a digital workbook, this platform helps students develop a deeper conceptual understanding of their subject matter. Online assignments can be constructed by selecting from hundreds of text-specific problems or supplemented with problems from any Cengage Learning textbook. WebAssign also includes the Cengage MindTap Reader: an engaging and customizable eBook that lets you tailor the textbook to fit your course and connect with your students. It includes highlighting and other tools for students and is also available to download in the Cengage Mobile App.

WebAssign for *An Introduction to Physical Science*, Fifteenth Edition

New Opportunities for Active Learning

Digital Workbook The new Digital Workbook is a series of online lessons that interweave narrative, assessment elements, and a variety of interactive media to form a singular learning activity.

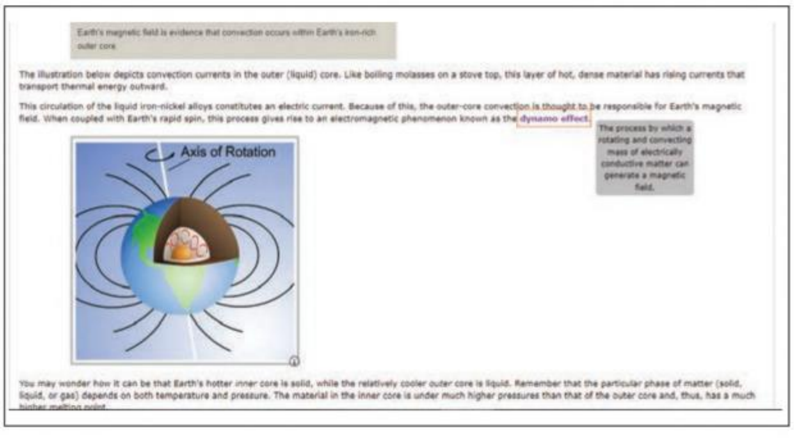


Written in a conversational and engaging tone, these lessons constitute a primer of relevant topics essential to developing a functional awareness of the topic at hand. The goal then is to address each topic as a dialogue with the reader explaining the idea to them in the most straightforward and direct way possible. It is not a formalized approach as those nuances can be sought out by the learner as needed.

Educational research on introductory science courses tells us that no one "gets" science on their first instruction. Rather than trying to cover the topic exhaustively, the workbook acts as the very first exposure to each idea in order to set up a solid basis of understanding that can be built upon via subsequent reading, discussions, and exercises.

The pacing of the workbook is such that there are frequent checkpoints and opportunities for brief reflection throughout the lesson using a variety of different question types following narrative, short animations, or html interactive simulations. Definitions are available by moving the cursor over the highlighted key terms providing context-specific reminders to those students who need them without disrupting the narrative flow for those that do not. Each question contains rich targeted feedback that explains not only what went wrong but also in what context their answer would have been correct. The feedback also serves to reinforce the lesson by offering a rejoinder following a correct response. Because the rejoinder text persists after the lesson has been completed, the student is able to return to the lesson in order to review the extended narrative that they "created" by going through the workbook activities.

Virtual Astronomy Labs A strong understanding of astronomy, cosmology, and the foundations of the universe are essential components of *An Introduction to Physical Science*. WebAssign now offers students a chance to dive deeper into Astronomy through Virtual Astronomy Labs that are integrated into the IPS WebAssign course. This is a set of interactive, active learning experiences that combine analysis of real astronomical data with robust simulations to provide a true online laboratory experience for your course. Each lab is presented in a modular format containing individual auto-graded segments, giving you the control to assign it as a standalone activity or as part of a larger learning experience.



Concise tutorials summarize the relevant content in sections that can be opened and closed for quick access during follow-up activity or assessment. Targeted feedback guides students in revising any incorrect answers. Many items provide scaffolding to build skills and confidence in the use of simple algebra, geometry, and proportional reasoning to solve astronomy problems.

About the Authors

With the Fifteenth Edition of *An Introduction to Physical Science*, first published nationally in 1971, the textbook has had a long run of 50 years. This accomplishment reflects the contributions over the years of several authors who are now deceased. We pay tribute to them: *James T. Shipman*, originator of the text and contributing to Editions 1–9 (as the book is known as the "Shipman" book, his name is retained on the authors' list); *Jerry L. Adams*, Editions 1–5; and *Aaron W. Todd*, Editions 7–11. Their contributions remain an integral part of *An Introduction to Physical Science*.

That being said, we have for the current edition:

Jerry D. Wilson received his physics degrees from: B.S., Ohio University; M.S., Union College (Schenectady, NY); and Ph.D., Ohio University. He is one of the original authors of the first edition of *An Introduction to Physical Science* and has several physical science and physics textbooks to his credit. In addition, Wilson has for over 35 years written a weekly question-and-answer column, the *Curiosity Corner* (originally the *Science Corner*), published in several area newspapers. He is currently Emeritus Professor of Physics at Lander University, Greenwood, SC. Email: jwilson@greenwood.net

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1.1 The Physical Sciences

Key Questions*

- What are the two major divisions of natural science?
- What are the five major divisions of physical science?

Think about the following:

- ***Hung up.*** A basketball player leaping up to make a shot seems to "hang" in the air before he slam-dunks a basketball.
- ***Spot you one.*** Driving in the summer, you may see what looks like water or a "wet spot" on the road ahead, but you never get to it.
- ***All stuck up.*** The professor rubs a balloon on his sweater and touches it to the ceiling, and the balloon stays there.
- ***Mighty small.*** There are pictures of individual atoms.
- ***It doesn't add up.*** Exactly 100 cc of ethanol alcohol is mixed with exactly 100 cc of water, and the resulting mixture is less than 200 cc.
- ***Get in line.*** There won't be a total solar eclipse visible from the United States until 2024, but there will be more visible elsewhere before then.
- ***Dark Moon.*** The dark side of the Moon isn't dark all the time.
- ***A bolt from the blue.*** You don't have to be in a thunderstorm for lightning to strike.
- ***No blow.*** One continent has no hurricanes, and a particular latitude has none either.
- ***All shook up.*** An earthquake with a magnitude of 8.0 on the Richter scale is not twice as energetic as one with a magnitude of 4.0 (but about a million times more).
- ***Keep an eye on the sky.*** There is evidence that a meteorite caused dinosaurs to become extinct.

Would you like to know how or why such things occur, or how they are known? All these statements are explained in this book. Most people are curious about such topics, and explanations of these and many other phenomena are obtained through scientific observations. The above statements pertain to physical science, but there are several other branches of science as well.

Science *(from the Latin scientia, meaning "knowledge") may be defined as an organized body of knowledge about the natural universe and the processes by which that knowledge is acquired and tested.* In general, there are *social sciences*, which deal with human society and individual relationships, and *natural sciences*, which investigate the natural universe. In turn, the *natural sciences* are divided into the *biological sciences* (sometimes called *life sciences*), which are concerned with the study of living matter, and the *physical sciences*, which involve the study of nonliving matter.

This book introduces the various disciplines of physical science, the theories and laws fundamental of each, some of the history of their development, and the effect each has on our lives. Physical science is classified into five major divisions (● Fig. 1.1):

Physics, the most fundamental of the divisions, is concerned with the basic principles and concepts of matter and energy.

Chemistry deals with the composition, structure, and reactions of matter.

Astronomy is the study of the universe, which is the totality of all matter, energy, space, and time.

Meteorology is the study of the atmosphere, from the surface of the Earth to where it ends in outer space.

*Key Questions are listed at the beginning of each section. The answers to these questions are found in the section and in the related Did You Learn? at the end of the section.

PHYSICS FACTS

- Tradition holds that in the twelfth century, King Henry I of England decreed that 1 yard should be the distance from his royal nose to the thumb of his outstretched arm. (Had King Henry's arm been 3.37 inches longer, the yard and the meter would have been equal in length.)
- Is the old saying "A pint's a pound the world around" true? It depends on what you are talking about. The saying is a good approximation for water and similar liquids. Water weighs 8.3 pounds per gallon, so one-eighth of that, or 1 pint, weighs 1.04 lb.
- The United States officially adopted the metric system in 1893.

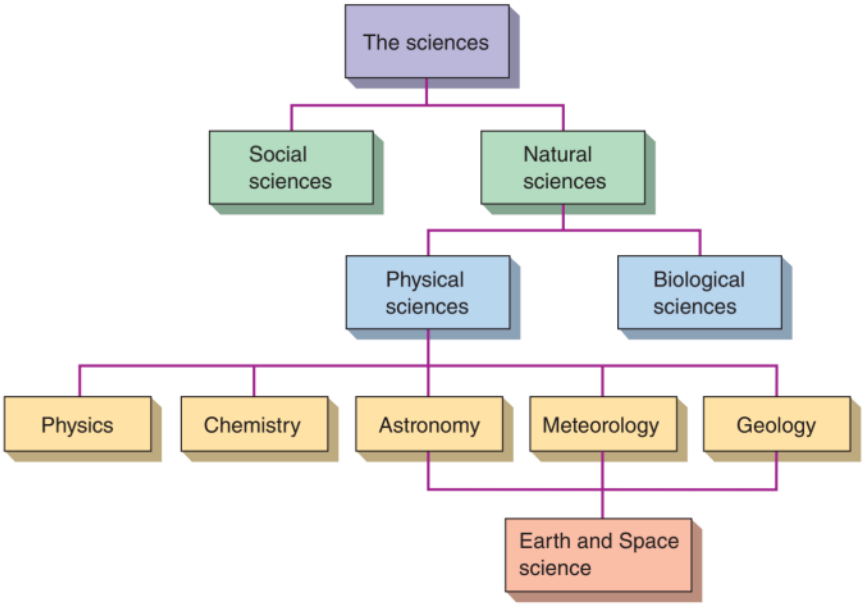


Figure 1.1 The Major Physical Sciences A diagram showing the five major physical sciences and how they fit into the various divisions of the sciences. (See text for discussion.)

Geology is the science of the planet Earth: its composition, structure, processes, and history. (The last three physical sciences are sometimes combined as *Earth and Space Science*.)

Physics is considered the most fundamental of these divisions because each of the other disciplines applies the principles and concepts of matter and energy to its own particular focus. Therefore, our study of physical science starts with physics (Chapters 1–10); then moves on to chemistry (Chapters 11–14), astronomy (Chapters 15–18), meteorology (Chapters 19 and 20); and ends with geology (Chapters 21–24).

This exploration will enrich your knowledge of the physical sciences and give you perspective on how science has grown throughout the course of human history; how science influences the world we live in today; and how it is employed through *technology* (the application of scientific knowledge for practical purposes).

Did You Learn?*

- Biological (life) and physical sciences make up the natural sciences.
- The major divisions of physical science are physics, chemistry, astronomy, meteorology, and geology.

1.2 Scientific Investigation

Key Questions

- What does the scientific method say about the description of nature?
- Do scientific laws and legal laws have anything in common?

Theory guides. Experiment decides. Johannes Kepler (1571–1630)

Today's scientists do not jump to conclusions as some of our ancestors did, which often led to superstitious results. Today, measurements are the basis of scientific investigation. Phenomena are observed, and questions arise about how or why these phenomena occur. These questions are investigated by the **scientific method**.

*Did You Learn? notes are listed at the end of each section and relate to the Key Questions at the beginning of each section.

The scientific method can be broken down into the following elements:

1. *Observations* and *measurements* (quantitative data).
2. *Hypothesis*. A possible explanation for the observations; in other words, a tentative answer or an educated guess.
3. *Experiments*. The testing of a hypothesis under controlled conditions to see whether the test results confirm the hypothetical assumptions, can be duplicated, and are consistent. If not, more observations and measurements may be needed.
4. *Theory*. If a hypothesis passes enough experimental tests and generates new predictions that also prove correct, then it takes on the status of a theory, a well-tested explanation of observed natural phenomena. (Even theories may be debated by scientists until experimental evidence decides the debate. If a theory does not withstand continued experimentation, then it must be modified, rejected, or replaced by a new theory.)
5. *Law*. If a theory withstands the test of many well-designed, valid experiments and there is great regularity in the results, then that theory may be accepted by scientists as a *law*. A law is a concise statement in words or mathematical equations that describes a fundamental relationship of nature. Scientific laws are somewhat analogous to legal *laws*, which may be repealed or modified if inconsistencies are later discovered. Unlike legal laws, scientific laws are meant to describe, not regulate.

The bottom line on the scientific method is that *no hypothesis, theory, or law of nature is valid unless its predictions are in agreement with experimental (quantitative measurement) results.* See ● Fig. 1.2 for a flowchart representing the scientific method.

The **Highlight 1.1: The "Face" on Mars**, which follows, illustrates the need for the scientific method.

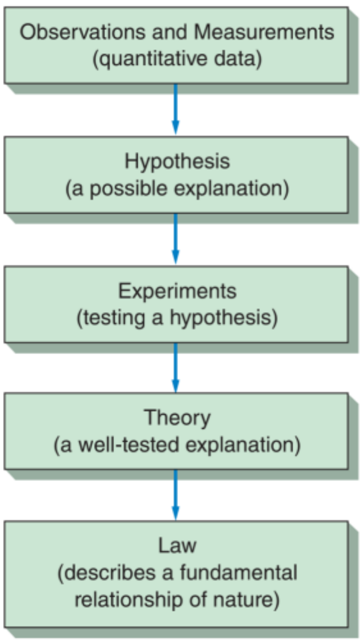


Figure 1.2 The Scientific Method A flowchart showing the elements of the scientific method. If experiments show that a hypothesis is not consistent with the facts, more observations and measurements may be needed.

Did You Learn?

- No hypothesis, theory, or law of nature is valid unless its predictions are in agreement with experimental results.
- Scientific laws describe nature, and legal laws regulate society.

1.3 The Senses

Key Questions

- Which two senses give us the most information about our environment?
- How may our senses be enhanced?

Our environment stimulates our senses, either directly or indirectly. The five senses (sight, hearing, touch, taste, and smell) make it possible for us to know about our environment. Therefore, the senses are vitally important in studying and understanding the physical world.

Most information about our environment comes through sight. Hearing ranks second in supplying the brain with information about the external world. Touch, taste, and smell, although important, rank well below sight and hearing in providing environmental information.

All the senses have limitations. For example, the unaided eye cannot see the vast majority of stars and galaxies. We cannot immediately distinguish the visible stars of our galaxy from the planets of our solar system, which all appear as points of light (although with time the planets move). The limitations of the senses can be reduced by using measuring instruments such as microscopes and telescopes. Other examples of limitations are our temperature sense of touch being limited to a range of hotness

Highlight 1.1 The "Face" on Mars

In 1976, NASA's Viking 1 spacecraft was orbiting Mars. When snapping photos, the spacecraft captured the shadowy likeness of an enormous head, 2 miles from end to end and located in a region of Mars called Cydonia (Fig. 1a).

The surprise among the mission controllers at NASA was quickly tempered as planetary scientists decided that the "face" was just another Martian mesa, a geologic landform common in the Cydonia region. When NASA released the photo to the public a few days later, the caption noted a "huge rock formation . . . which resembles a human head . . . formed by shadows giving the illusion of eyes, nose, and mouth." NASA scientists thought that the photo would attract the public's attention to its Mars mission, and indeed it did!

The "face" on Mars became a sensation, appearing in newspapers (particularly tabloids), in books, and on TV talk shows. Some people thought that it was evidence of life on Mars, either at present or in the past, or perhaps that it was the result of a visit to the planet by aliens. As for NASA's contention that the "face" could be entirely explained as a combination of a natural landform and unusual lighting conditions, howls arose from some of the public about "cover-up" and "conspiracy." Other people, with a more developed scientific attitude, gave provisional acceptance to NASA's conclusion, realizing that extraordinary claims (aliens) need extraordinary proof.

Twenty-two years later, in 1998, the Mars Global Surveyor (MGS) mission reached Mars, and its camera snapped a picture of the "face" 10 times sharper than the 1976 Viking photo. Thousands waited for the image to appear on NASA's website. The photo revealed a natural landform, not an alien monument. However, the image was taken through wispy clouds, and some people were still not convinced that the object was just a plain old mesa.

Not until 2001 did the MGS camera again pass over the object. This time there were no clouds, and the high-resolution picture was clearly that of a mesa similar to those common in the Cydonia region and the American West (Fig. 1b).

Why would so many articles and books be written extolling the alien origin of the "face"? Perhaps many authors were trading on the gullibility and ignorance of part of our population to line their own pockets or to gain attention. If so, the best ways to deal with similar situations in the future would be to improve the standard of education among the general public and to emphasize the importance of a well-developed scientific method.

Source: Most of the information for this Highlight came from Tony Phillips, "Unmasking the Face on Mars," NASA, May 24, 2001.


NASA/JPL

(a)


JPL/MSSS/NASA

(b)

Figure 1 The Face on Mars
(a) In 1976, at the low resolution of the Viking 1 camera, the appearance of a sculpted face can be seen. (b) In 2001, at the high resolution of the Mars Global Surveyor camera, the object is seen to be a common mesa.

and coldness before injury and our hearing being limited to a certain frequency range (Chapter 6.4).

Not only do the senses have limitations, but they also can be deceived, thus providing false information about our environment. For example, perceived sight information may not always be a true representation of the facts because the brain can be fooled. There are many well-known optical illusions, such as those shown in ● Fig. 1.3. Some people may be quite convinced that what they see in such drawings actually exists as they perceive it. However, we can generally eliminate deception by using instruments. For example, rulers can be used to answer the questions in Fig. 1.3a and b.

Did You Learn?

- Sight and hearing give us the greatest amount of information about our environment.
- The limitations of the senses can be reduced by using instruments, such as microscopes and telescope for sight.

Figure 1.4 A Mostly Metric World Map of world showing metric and nonmetric nations (in green). The metric system is used throughout most of the world. The United States is the only major country that has not gone completely metric. Other countries include Liberia in Africa and Myanmar in Asia.

Length

The description of space might refer to a location or to the size of an object (amount of space occupied). To measure these properties, we use the fundamental quantity of **length**, *the measurement of space in any direction.*

Space has three dimensions, each of which can be measured in terms of length. The three dimensions are easily seen by considering a rectangular object such as a bathtub (● Fig. 1.5). It has length, width, and height, but each dimension is actually a length. The dimensions of space are commonly represented by a three-dimensional Cartesian coordinate system (named in honor of French mathematician René Descartes, 1596–1650, who developed the system).

The standard unit of length in the metric system is the **meter** (m), from the Greek *metron*, "to measure." It was defined originally as one ten-millionth of the distance from the geographic North Pole to the Earth's equator (● Fig. 1.6a). A portion of the meridian between Dunkirk, France, and Barcelona, Spain, was measured to determine the meter length, and that unit was first adopted in France in the 1790s. One meter is slightly longer than 1 yard, as illustrated in Fig. 1.6b.

From 1889 to 1960, the standard meter was defined as the length of a platinum–iridium bar kept at the International Bureau of Weights and Measures in Paris, France. However, the stability of the bar was questioned (for example, length variations occur with temperature changes), so new standards were adopted in 1960 and again in 1983. The current definition links the meter to the speed of light in a vacuum, as illustrated in Fig. 1.6c. Light travels at a speed of 299,792,458 meters/second (usually listed as 3.00×10^8 m/s). So, by definition, 1 meter is the distance light travels in 1/299,792,458 of a second.

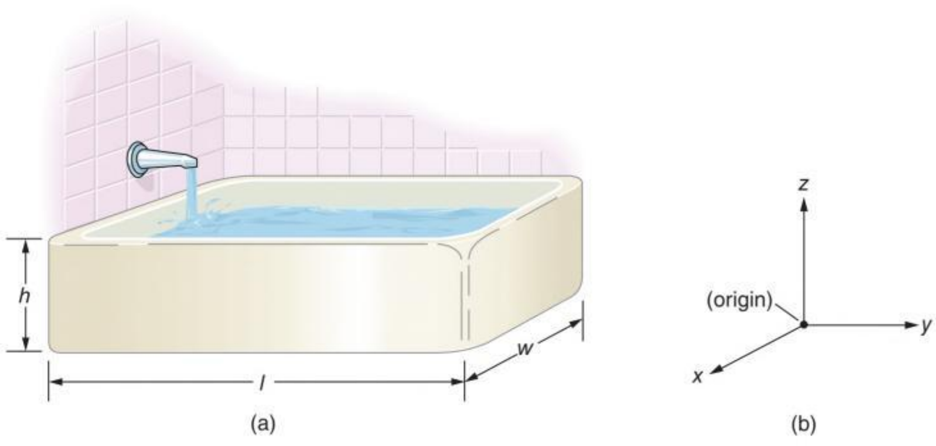


Figure 1.5 Space Has Three Dimensions (a) The bathtub has dimensions of length (*l*), width (*w*), and height (*h*), but all are actually measurements of length. (b) The dimensions of space are commonly represented by a three-dimensional Cartesian coordinate system (*x*, *y*, *z*) with the origin as the reference point.

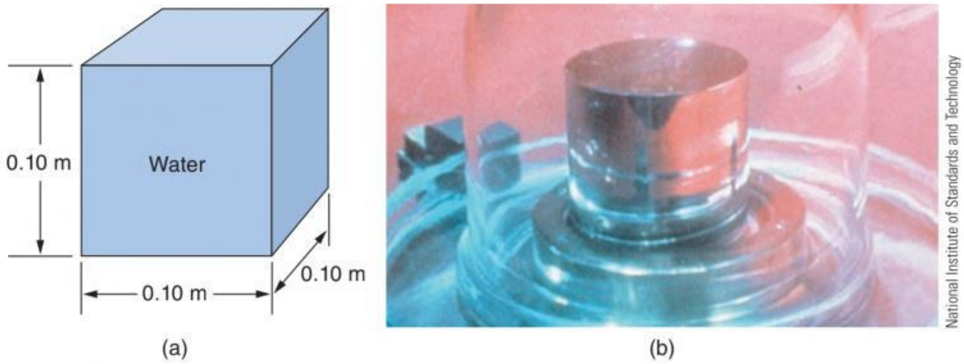


Figure 1.7 The Metric Mass Standard: The Kilogram (a) The kilogram was originally defined in terms of a specific volume of water, that of a cube 0.10 m on a side (at 4°C, the temperature at which water has its maximum density). As such, the mass standard was associated with the length standard. (b) Prototype kilogram number 20 is the U.S. standard unit of mass. The prototype is a platinum–iridium cylinder 39 mm in diameter and 39 mm high.

quantity, and its use often gives rise to confusion. Of course, a fundamental quantity should be the same and not change. However, weight is the gravitational attraction on an object by a celestial body, and this attraction is different for different celestial bodies. The gravitational attraction of a body depends on its mass.

For example, on the less massive Moon, the gravitational attraction is $\frac{1}{6}$ of that on the Earth, so an object on the Moon weighs $\frac{1}{6}$ of its weight on the Earth. This means a suited astronaut who weighs 300 pounds on the Earth will weigh $\frac{1}{6}$ that amount, or 50 pounds, on the Moon, but the astronaut's mass will be the same (● Fig. 1.8).

A fundamental quantity does not change at different locations. The astronaut has the same mass, or quantity of matter, wherever he or she is. As will be learned in Chapter 3.3, mass and weight are related, but they are not the same. For now, keep in mind that *mass, not weight, is the fundamental quantity*.

Time

Each of us has an idea of what time is, but when asked to define it, you may have to ponder a bit.

Some terms often used when referring to time are *duration, period, and interval*. A common descriptive definition is that **time** is the *continuous, forward flow of events*. Without

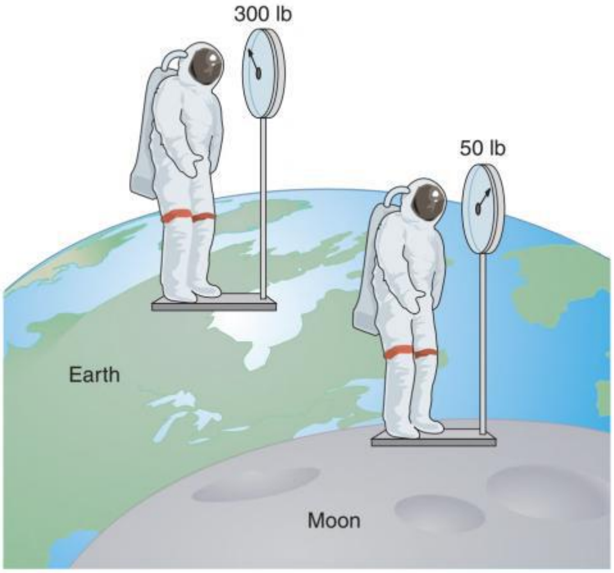


Figure 1.8 Mass Is the Fundamental Quantity The weight of an astronaut on the Moon is $\frac{1}{6}$ the astronaut's weight on the Earth, but the astronaut's mass is the same at any location.

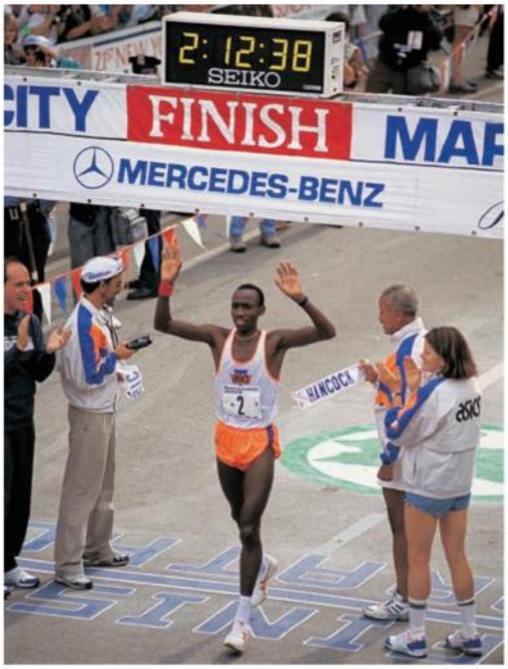


Figure 1.9 Time and Events Events mark intervals of time. Here, at the New York City Marathon, after starting out (beginning event), a runner crosses the finish line (end event) in a time of 2 hours, 12 minutes, and 38 seconds.

events or happenings of some sort, there would be no perceived time (● Fig. 1.9). The mind has no innate awareness of time, only an awareness of events taking place in time. In other words, we do not perceive time as such, only events that mark locations in time, similar to marks on a meterstick indicating length intervals.

Note that time has only one direction—forward. Time has never been observed to run backward. That would be like watching a film run backward in a projector.

Conceptual Question and Answer 1.1

Time and Time Again

Q. What is time?

A. Time is a difficult concept to define. The common definition that *time is the continuous, forward flow of events* is more of an observation than a definition.

Others have thought about time. Marcus Aurelius, the Roman emperor and philosopher, wrote:

Time is a strong river of passing events, and strong is its current.

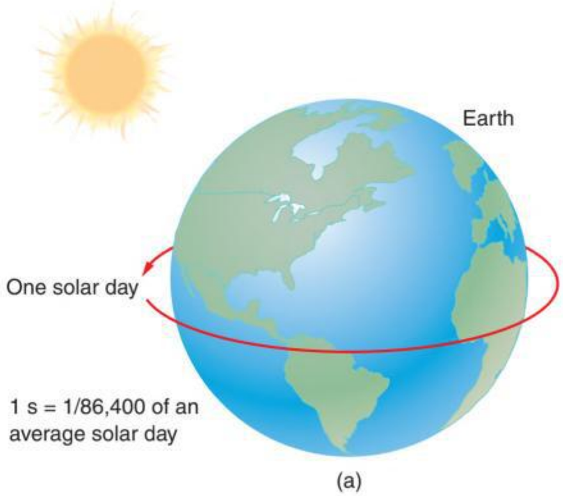
St. Augustine pondered this question, too:

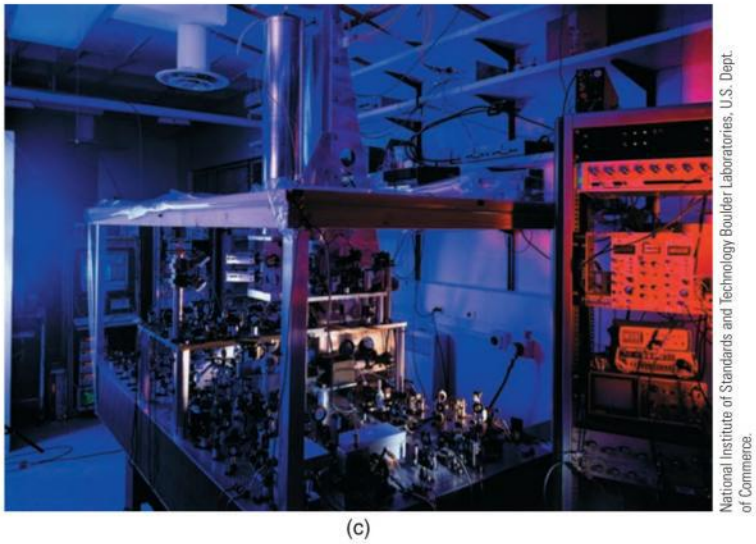
What is time? If no one asks me, I know; if I want to explain it to a questioner, I do not know.

The Mad Hatter in Lewis Carroll's *Alice in Wonderland* thought he knew time:

If you know time as well as I do, you wouldn't talk about wasting it. It's him.… Now, if you only kept on good terms with him, he'd do almost anything you liked with the clock. For instance, suppose it were nine o'clock in the morning, just time to begin lessons; you'd only have to whisper a hint to Time, and around goes the clock in a twinkling: Half past one, time for dinner.

A safe answer is: *Time is a fundamental property or concept*. This definition masks our ignorance, and physics goes on from there, using the concept to describe and explain what we observe.





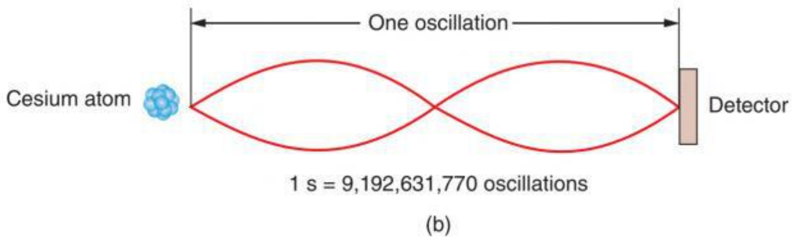


Figure 1.10 A Second of Time
(a) The second was defined originally in terms of a fraction of the average solar day. (b) One second is currently defined in terms of the frequency of radiation emitted from the cesium atom. (c) A clock? Yes, the National Institute of Standards and Technology (NIST) "fountain" cesium atomic clock. Such a clock provides the time standard for the United States.

Time and space seem to be linked. In fact, time is sometimes considered a fourth dimension, along with the other three dimensions of space. If something exists in space, it also must exist in time. But for our discussion, space and time will be regarded as separate quantities.

Fortunately, the standard unit of time is the same in both the metric and British systems: the **second**. The second was originally defined in terms of observations of the Sun, as a certain fraction of a solar day (● Fig. 1.10a).

In 1967, an atomic standard was adopted. The second was defined in terms of the radiation frequency of the cesium-133 atom (Fig. 1.10b). An "atomic clock" used a beam of cesium atoms to maintain our time standard with a variation of about 1 second in 300 years. In 1999, another cesium-133 clock was adopted. This atomic "fountain clock," as its name implies, uses a fountain of cesium atoms (Fig. 1.10c). The variation of this timepiece is within 1 second per 100 million years.

NIST has developed a "quantum logic" clock that makes use of the oscillations of a single ion of aluminum. It keeps time within 1 second every 3.7 billion years!

The standard units for length, mass, and time in the metric system give rise to an acronym, the **mks** system. The letters *mks* stand for meter, kilogram, and second.* They are also standard units for a modernized version of the metric system, called the International System of Units (abbreviated **SI**, from the French *Système International d'Unités*, see Chapter 1.5).

When more applicable, smaller units than those standard in the mks system may be used. Although the mks system is the *standard* system, the smaller *cgs system* is sometimes used, where *cgs* stands for centimeter, gram, and second. For comparison, the units for length, mass, and time for the various systems are listed in ● Table 1.1.

*The acronym for the British system of units is fps—*f*oot, *p*ound, *s*econd.

Table 1.1 Units of Length, Mass, and Time for the Metric and British Systems of Measurement

	Metric		
Fundamental Quantity	*SI or mks*	*cgs*	British
Length	meter (m)	centimeter (cm)	foot (ft)
Mass	kilogram (kg)	gram (g)	slug
Time	second (s)	second (s)	second (s)

Did You Learn?

- A standard unit is a fixed and reproducible value for accurate measurements.
- The SI standard units for length, mass, and time are the meter, kilogram, and second, respectively. A smaller *cgs* system is sometimes used: centimeter, gram, second.

1.5 More on the Metric System

Key Questions

- What are the four most common metric prefixes?
- What is the difference between a cubic centimeter and a milliliter?

The SI was established in 1960 to make comprehension and the exchange of ideas among the people of different nations as simple as possible. It now contains seven base units: the meter (m), the kilogram (kg), the second (s), the ampere (A) to measure the flow of electric charge, the kelvin (K) to measure temperature, the mole (mol) to measure the amount of a substance, and the candela (cd) to measure luminous intensity. A definition of each of these units is given in Appendix A. However, we will be concerned with only the first three of these units for several chapters.

One major advantage of the metric system is that it is a decimal (base-10) system. The British system is a duodecimal (base-12) system, as 12 inches equals a foot. The base-10 system allows easy expression and conversion to larger and smaller units. A series of *metric prefixes* is used to express the multiples of 10, but you will only need to be familiar with a few common ones:

mega- (M)	1,000,000 (million, 10^6)
kilo- (k)	1000 (thousand, 10^3)
centi- (c)	$\frac{1}{100} = 0.01$ (hundredth, 10^{-2})
milli- (m)	$\frac{1}{1000} = 0.001$ (thousandth, 10^{-3})

Examples of the relationships of these prefixes follow.

1 megabyte (Mb) is equal to a million bytes.
1 kilogram is equal to 1000 grams (g).
1 meter is equal to 100 centimeters (cm) or 1000 millimeters (mm).
1 millisecond (ms) is equal to 0.001 second (s).
(See ● Table 1.2 for more metric prefixes. A more complete list is given in Appendix A Table A.1.)

You are familiar with another base-10 system: our currency. A cent is $\frac{1}{100}$ of a dollar, or a centidollar. A dime is $\frac{1}{10}$ of a dollar, or a decidollar. Tax assessments and school bond levies are sometimes given in mills. Although not as common as a cent, a mill is $\frac{1}{1000}$ of a dollar, or a millidollar.

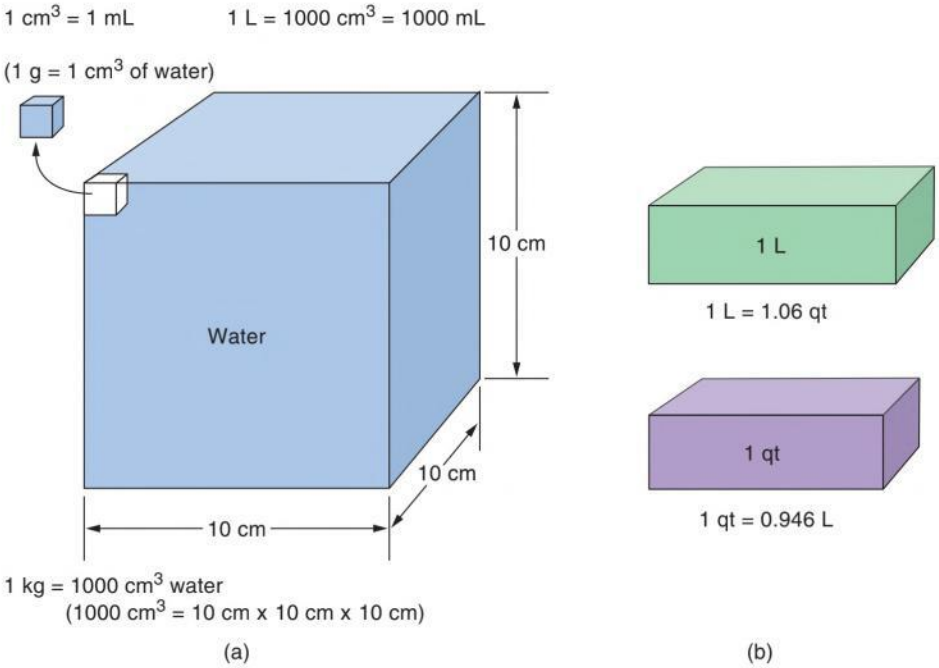


Figure 1.11 Mass and Volume (the Liter) (a) The kilogram was originally related to length. The mass of the quantity of water in a cubic container 10 cm on a side was taken to be 1 kg. As a result, 1 cm^3 of water has a mass of 1 g. The volume of the container was defined to be 1 liter (L), and 1 cm^3 = 1 mL. (b) One liter is slightly larger than 1 quart.

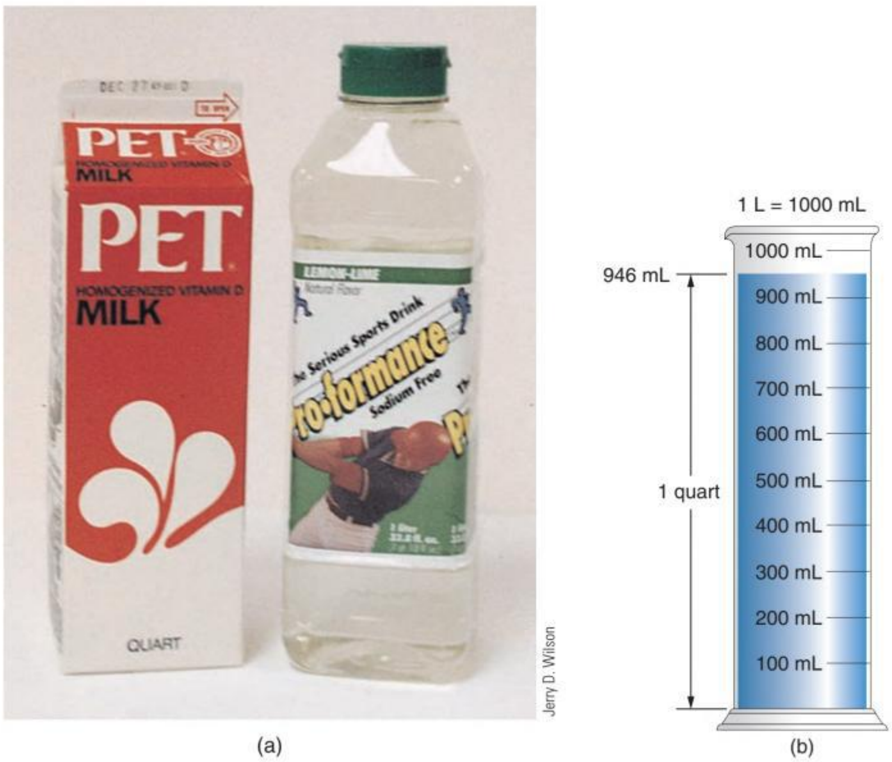


Figure 1.12 Liter and Quart (a) The liter of drink on the right contains a little more liquid than 1 quart of milk. (b) One quart is equivalent to 946 mL, or slightly smaller than 1 liter (1 L = 1.06 qt).

1.6 Derived Units and Conversion Factors

Key Questions

- What are derived units?
- How can you tell which is longer, 1 kilometer or 1 mile?

If density is expressed in units of grams per cubic centimeter, then the density of a substance can be easily compared with that of water. For example, the density of mercury is 13.6 g/cm^3 and is 13.6 times denser than water. Blood, on the other hand, has an average density of 1.06 g/cm^3 and is only slightly denser than water.

EXAMPLE 1.1 Determining Density

Density can be useful in identifying substances. For example, suppose a chemist had a sample of solid material that is determined to have a mass of 452 g and a volume of 20.0 cm^3. What is the density of the substance?

Thinking It Through

Density is mass per unit volume. Given the mass (g) and volume (cm^3), the density of the substance may be found.

Solution

Density is easily computed using Eq. 1.1:

$$\rho = \frac{m}{V} = \frac{452\ \text{g}}{20.0\ \text{cm}^3} = 22.6\ \text{g/cm}^3$$

This density is quite large, and by looking up the known densities of substances, the chemist would suspect that the material is the chemical element osmium, the densest of all elements. (Gold has a density of 19.3 g/cm^3, and silver has a density of 10.5 g/cm^3.)

Confidence Exercise 1.1

A sample of gold has the same mass as that of the osmium sample in Example 1.1. Which would have the greater volume? Show by comparing the volume of the gold with that of the osmium. (The density of gold is given in Example 1.1.)

The answers to Confidence Exercises may be found at the back of the book.

Ted M. Kinsman/Science Source

Figure 1.14 Measuring Liquid Density A hydrometer is used to measure the density of a liquid. The denser the liquid, the higher the hydrometer floats. The density can be read from the calibrated stem.

Densities of liquids such as alcohol and body fluids can be measured by means of a *hydrometer,* which is a weighted glass bulb that floats in the liquid (● Fig. 1.14). The higher the bulb floats, the greater the density of the liquid.

When a medical technologist checks a sample of urine, one test he or she performs is for density. For a healthy person, urine has a density of 1.015 to 1.030 g/cm^3; it consists mostly of water and dissolved salts. When the density is greater or less than this normal range, the urine may have an excess or deficiency of dissolved salts, usually caused by an illness.

A hydrometer is a used to test the antifreeze in a car radiator. The closer the density of the radiator liquid is to 1.00 g/cm^3, the closer the antifreeze and water solution is to being pure water, and more antifreeze may be needed. The hydrometer is usually calibrated in degrees rather than density and indicates the temperature to which the amount of antifreeze will protect the radiator.

Finally, when a combination of units becomes complicated, it is often given a name of its own. For example, as discussed in Chapter 3.3, the SI unit of force is the newton, which in terms of standard units is*

$$\text{newton (N)} = \text{kg} \cdot \text{m/s}^2$$

It is easier to talk about a newton (N) than about a $kg \cdot m/s^2$. As you might guess, the newton unit is named in honor of Sir Isaac Newton. The abbreviation of a unit named after an individual is capitalized, but the unit name itself is not: newton (N). We will encounter other such units during the course of our study.

For another health application of density, see **Physical Science Today 1.1: What's Your Body Density? Try BMI**.

*The centered dot means that the quantities for these units are multiplied.

Physical Science Today 1.1 What's Your Body Density? Try BMI.

Another density used in the health field is body density. Body density is the proportion of body fat in the human body compared to the overall mass. It is used as an indication for gauging the amount of fatty tissue in the body. Body density is important in preparing nutrition and fitness plans for good health.

As you might imagine, it is virtually impossible to determine the exact proportion of fat in a living person. Sophisticated methods are required to provide close values. However, methods have been developed to estimate body density. One of the most common is known as *body mass index* (BMI). It is not a definitive measure of body density, but rather a tool to determine whether or not your body density is at a healthy level. BMI is a number calculated from your weight and height that gives an estimate of the percentage of your total weight that comes from fat, as opposed to muscle, bone, and organ tissue. Basically, the BMI indicates individuals who may have excessive amounts of body fat for their size.

Charts, as shown in Fig. 1, may be used to easily find BMIs. Simply find your height on the vertical axis and your weight on the horizontal axis and where they intersect gives your BMI range. The result lets you see if you are at a healthy weight, according the scale on the chart.

Of course, the chart BMIs are estimates of true percentages, and a number of factors might influence whether your BMI is a true reflection of your actual body fat. For example, muscle is denser than fat, and a heavily muscled person may weigh more than an overweight person of the same height.

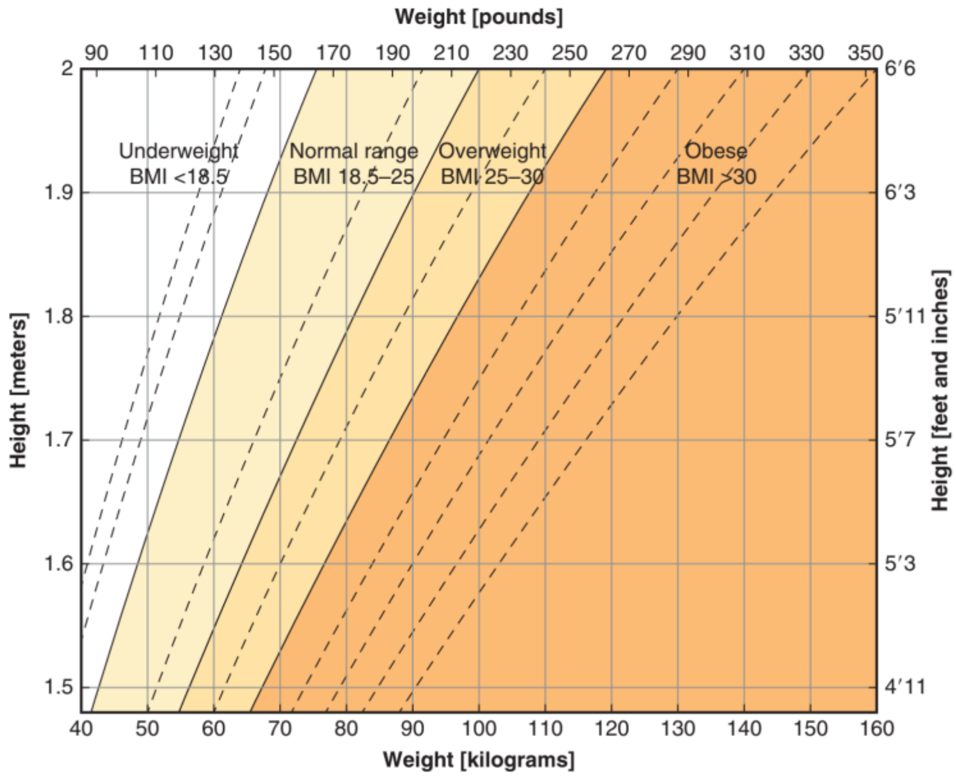


Figure 1 Body Mass Index (BMI) Find your height on the vertical axis and your weight on the horizontal axis. Where they intersect gives your BMI range. The resulting BMI indicates if you are at a healthy weight, according to the scale on the chart (near top).

Conversion Factors

Often we want to convert units within one system or from one system to another. For example, how many feet are there in 3 yards? The immediate answer would be 9 feet, because it is commonly known that there are 3 feet per yard. Sometimes, though, we may want to make comparisons of units between the metric and the British systems. In general, to convert units, a **conversion factor** is used. Such a factor relates one unit to another. Some convenient conversion factors are listed in Appendix K. For instance,

$$1 \text{ in.} = 2.54 \text{ cm}$$

Although it is commonly written in equation form, this expression is really an *equivalence statement;* that is, 1 in. has an equivalent length of 2.54 cm. (To be a true *equation*, the expression must have the same magnitudes and units or dimensions on both sides.) However, in the process of expressing a quantity in different units, a conversion relationship in ratio or factor form is used:

$$\frac{1\text{ in.}}{2.54\text{ cm}} \quad \text{or} \quad \frac{2.54\text{ cm}}{1\text{ in.}}$$

For example, suppose you are 5 ft 5 in., or 65.0 in., tall, and you want to express your height in centimeters. Then

$$65.0\ \cancel{\text{in.}} \times \frac{2.54\text{ cm}}{1\ \cancel{\text{in.}}} = 165\text{ cm}$$

Note that the in. units cancel and the cm unit is left on both sides of the equation, which is now a true equation, $65.0 \times 2.54\text{ cm} = 165\text{ cm}$ (equal on both sides). In the initial example of converting units in the same system, 3 yd to feet, a conversion factor was actually used in the form:

$$3\ \cancel{\text{yd}} \times \frac{3\text{ ft}}{1\ \cancel{\text{yd}}} = 9\text{ ft}$$

where 3 ft/1 yd, or 3 ft per yard. In this case, because the conversion is so common, the mathematics can be done mentally.

The steps may be summarized as follows:

Steps for Converting from One Unit to Another

Step 1 Use a conversion factor, a ratio that may be obtained from an equivalence statement. (Often it is necessary to look up these factors or statements in a table; see Appendix K.)

Step 2 Choose the appropriate form of conversion factor (or factors) so that the unwanted units cancel.

Step 3 Check to see that the units cancel and that you are left with the desired unit. Then perform the multiplication or division of the numerical quantities. Here is an example done in stepwise form.

EXAMPLE 1.2 Conversion Factors: One-Step Conversion

The length of a football field is 100 yards. In constructing a football field in Europe, the specifications have to be given in metric units. How long is a football field in meters?

Thinking It Through

This is a conversion from British yards to metric meters, that is, 100 yd = ? m. An appropriate conversion factor is needed and will probably have to be looked up.

Solution

Step 1 There is a convenient, direct equivalence statement between yards and meters given in Appendix K under Length:

$$1\text{ yd} = 0.914\text{ m}$$

The two possible conversion factor ratios are

$$\frac{1\text{ yd}}{0.914\text{ m}} \quad\text{or}\quad \frac{0.914\text{ m}}{\text{yd}} \text{ (conversion factors)}$$

For convenience, the number 1 is commonly left out of the denominator of the second conversion factor; that is, we write 0.914 m/yd instead of 0.914 m/1 yd.

Step 2 The second form of this conversion factor, 0.914 m/yd, would allow the yd unit to be canceled. (Here yd is the unwanted unit in the denominator of the ratio.)

Step 3 Checking this unit cancellation and performing the operation yields

$$100\ \cancel{\text{yd}} \times \frac{0.914\text{ m}}{\cancel{\text{yd}}} = 91.4\text{ m}$$

Confidence Exercise 1.2

In a football game, you often hear the expression "first and 10" (yards). How would you express this measurement in meters to a friend from Europe?

The answers to Confidence Exercises may be found at the back of the book.

As the use of the metric system in the United States expands, unit conversions and the ability to do such conversions will become increasingly important. Automobile speedometers may show speeds in both miles per hour (mi/h) and kilometers per hour (km/h). Also, road signs comparing speeds can be seen. Some are designed to help drivers with metric conversion (● Fig. 1.15).

In some instances, more than one conversion factor may be used, as shown in Example 1.3.

EXAMPLE 1.3 Conversion Factors: Multistep Conversion

A computer printer has a width of 18 in. You want to find the width in meters but you don't have a table to look up the conversion for 18 in. = ? m. What can you do?

Thinking It Through

Without a direct conversion factor, a multistep conversion may be possible. Remember that 1 in. = 2.54 cm (which is a good length equivalent statement to remember between the British and metric systems). Then using this and another well-known equivalence statement, 1 m = 100 cm, a multistep conversion can be done.

Solution

$$\text{inches} \times \text{centimeters} \times \text{meters}$$

$$18\ \cancel{\text{in.}} \times \frac{2.54\ \cancel{\text{cm}}}{\cancel{\text{in.}}} \times \frac{1\text{ m}}{100\ \cancel{\text{cm}}} = 0.46\text{ m}$$

Notice that the units cancel correctly.

Let's check this result directly with the equivalence statement 1 m = 39.4 in.

$$18\ \cancel{\text{in.}} \times \frac{1\text{ m}}{39.4\ \cancel{\text{in.}}} = 0.46\text{ m}$$

Confidence Exercise 1.3

How many seconds are there in 1 day? (Use multiple conversion factors, starting with 24 h/day.)

The answers to Confidence Exercises may be found at the back of the book.

1.7 Significant Figures

Key Questions

- What is the purpose of significant figures?
- Why are mathematical results generally rounded?

When working with quantities, hand calculators are often used to do mathematical operations. Suppose in an exercise you divided 6.8 cm by 1.67 cm and got the result shown in ● Fig. 1.16. Would you report 4.0718563? Hopefully not—your instructor might get upset.

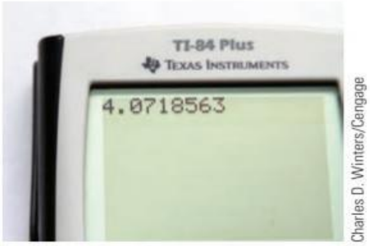


Figure 1.16 Significant Figures and Insignificant Figures Performing the division operation of 6.8/1.67 on a calculator with a floating decimal point gives many figures. However, most of these figures are insignificant, and the result should be rounded to the proper number of significant figures, which is two. (See text for further explanation.)

The reporting problem is solved by using what are called **significant figures** (or *significant digits*), a method of expressing measured numbers properly. This method involves the accuracy of measurement and mathematical operations.

Note that in the multiplication example, 6.8 cm has two figures or digits and 1.67 has three. These figures are significant because they indicate a magnitude read from some measurement instrument. In general, more digits in a measurement implies more accuracy or the greater fineness of the scale of the measurement instrument. That is, the smaller the scale (or the more divisions), the more numbers you can read, resulting in a better measurement. The 1.67-cm reading is more accurate because it has one more digit than 6.8 cm.

The number of significant figures in 6.8 cm and 1.67 cm is rather evident, but some confusion may arise when a quantity contains one or more zeros. For example, how many significant figures does the quantity 0.0254 have? The answer is three. Zeros at the beginning of a number are not significant, but merely locate the decimal point. Internal or end zeros are significant; for example, 104.6 and 3705.0 have four and five significant figures, respectively. (An end or "trailing" zero must have a decimal point associated with it. The zero in 3260 would not be considered significant.)

However, a mathematical operation cannot give you a better "reading" or more significant figures than your original quantities. Thus, as general rules,

1. When multiplying and dividing quantities, leave as many significant figures in the answer as there are in the quantity with the least number of significant figures.
2. When adding or subtracting quantities, leave the same number of decimal places in the answer as there are in the quantity with the least number of significant places.*

Applying the first rule to the example in Fig. 1.16 indicates that the result of the division should have two significant figures (abbreviated s.f.). Hence, rounding the result:

$$\underset{\substack{\uparrow \\ \text{limiting term} \\ \text{has 2 s.f.}}}{6.8\text{ cm}}/1.67\text{ cm} = \underset{\substack{\uparrow \\ \text{4.0718563 is} \\ \text{rounded to 4.1 (2 s.f.)}}}{4.1}$$

If the numbers were to be added, then, by the addition rule,

$$\begin{array}{rl} 6.8\text{ cm} & \text{(least number of decimal places)} \\ \underline{+1.67\text{ cm}} & \\ 8.47\text{ cm} & \rightarrow 8.5\text{ cm (final answer rounded to one decimal place)} \end{array}$$

Clearly, it is necessary to round numbers to obtain the proper number of significant figures. The following rules will be used to do this.

*See Appendix G for more on significant figures.

KEY TERMS

1. science (1.1)
2. scientific method (1.2)
3. standard unit (1.4)
4. system of units
5. metric system
6. British system
7. length
8. meter
9. mass
10. kilogram
11. time
12. second
13. mks
14. SI
15. mega- (1.5)
16. kilo-
17. centi-
18. milli-
19. liter
20. derived units (1.6)
21. density
22. conversion factor
23. significant figures (1.7)

MATCHING

For each of the following items, fill in the number of the appropriate Key Term from the provided list. Compare your answers with those at the back of the book.

a. _____ Million
b. _____ Defined in terms of the speed of light
c. _____ Standard unit of mass
d. _____ A valid theory of nature must be in agreement with experimental results.
e. _____ $V = 10\text{ cm} \times 10\text{ cm} \times 10\text{ cm}$
f. _____ Acronym for metric standard units
g. _____ Compactness of matter
h. _____ Modernized version of the metric system
i. _____ One-thousandth
j. _____ A system of units that is slowly being phased out
k. _____ The continuous forward flowing of events
l. _____ A fixed and reproducible value for making measurements
m. _____ Defined in terms of the radiation frequency of a cesium atom
n. _____ An organized body of knowledge about the natural universe
o. _____ The amount of matter an object contains
p. _____ A group of standard units and their combinations
q. _____ Method of properly expressing measured numbers
r. _____ One-hundredth
s. _____ The most widely used system of units
t. _____ Multiples and combinations of standard units
u. _____ Thousand
v. _____ The relationship of one unit to another
w. _____ The measurement of space in any direction

MULTIPLE CHOICE

Compare your answers with those at the back of the book.

1. Which is the most fundamental of the physical sciences? (1.1)
   (a) astronomy (b) chemistry
   (c) physics (d) meteorology
2. Which of the following is a concise statement about a fundamental relationship in nature? (1.2)
   (a) hypothesis (b) law
   (c) theory (d) experiment
3. Which human sense is first in supplying the most information about the external world? (1.3)
   (a) touch (b) taste
   (c) sight (d) hearing
4. Which is the standard unit of mass in the metric system? (1.4)
   (a) gram (b) kilogram
   (c) slug (d) pound
5. Which of the following is *not* a fundamental quantity? (1.4)
   (a) length (b) weight
   (c) mass (d) time
6. Which of the following metric prefixes is the greatest? (1.5)
   (a) mega- (b) micro-
   (c) giga- (d) nano-
7. How many base units are there in the SI? (1.5)
   (a) four (b) five
   (c) six (d) seven
8. Which metric prefix means "one-thousandth"? (1.5)
   (a) centi- (b) milli-
   (c) mega- (d) kilo-
9. Which metric prefix means "thousand"? (1.5)
   (a) centi- (b) milli-
   (c) mega- (d) kilo-
10. Which combination of units expresses density? (1.6)
    (a) mass/(time)^3 (b) mass/(kg)^3
    (c) mass/(length)^3 (d) mass/(m)^2
11. What is the expression 1 in. = 2.54 cm properly (really) called? (1.6)
    (a) equation (b) conversion factor
    (c) SI factor (d) equivalence statement
12. A student measures the length and width of a rectangle to be 36.4 cm and 0.456 cm, respectively. Wanting to find the area (in cm^2) of this rectangle, the student multiplies on a calculator and obtains a result of 16.5984. The area should be reported as ____. (1.7)
    (a) 16.5984 cm^2 (b) 16.6 cm^2
    (c) 1.66×10^2 cm^2 (d) 1.6×10^3 cm^2
13. Which of the following numbers has the greatest number of significant figures? (1.7)
    (a) 103.70 (b) 124.5
    (c) 0.09914 (d) 5.048×10^5
14. What is the answer when 8.81 is added to 5.2? (1.7)
    (a) 14 (b) 14.0
    (c) 14.01 (d) 14.1

FILL IN THE BLANK

Compare your answers with those at the back of the book.

1. The natural sciences, in which scientists study the natural universe, are divided into physical and ___ sciences. (1.1)
2. A possible explanation of observations is called a(n) ___. (1.2)
3. According to the ___, no hypothesis or theory of nature is valid unless its predictions are in agreement with experimental results. (1.2)
4. Most information about our environment reaches us through the senses of ___ and ___. (1.3)
5. All the human senses have ___. (1.3)
6. One quart is slightly ___ than 1 liter ___. (1.4)
7. One meter is slightly ___ than 1 yard. (1.4)
8. Unlike mass, weight is not a(n) ___ quantity. (1.4)
9. The standard unit of ___ is the same in all measurement systems. (1.4)
10. The metric prefix *giga-* means ___. (1.5)
11. A common nonstandard metric unit of fluid volume or capacity is the ___. (1.5)
12. If A is denser than B, then A contains more ___ per unit volume. (1.6)
13. If A and B have the same mass and A is denser than B, then A has ___volume than B.

SHORT ANSWER

What is the first step in understanding our environment?

1.1 The Physical Sciences

1. What is the definition of *science*?
2. What are the five major divisions of physical science?

1.2 Scientific Investigation

3. What are the five elements of the scientific method?
4. Which generally comes first in solving problems, hypothesis or experiment?
5. What is the difference between a law and a theory?
6. What does the controversy over the "face" on Mars illustrate?

1.3 The Senses

7. How do the five senses rank in importance in yielding information about our environment?
8. The senses cannot be completely relied on. Why?
9. Answer the questions that accompany ● Fig. 1.17.

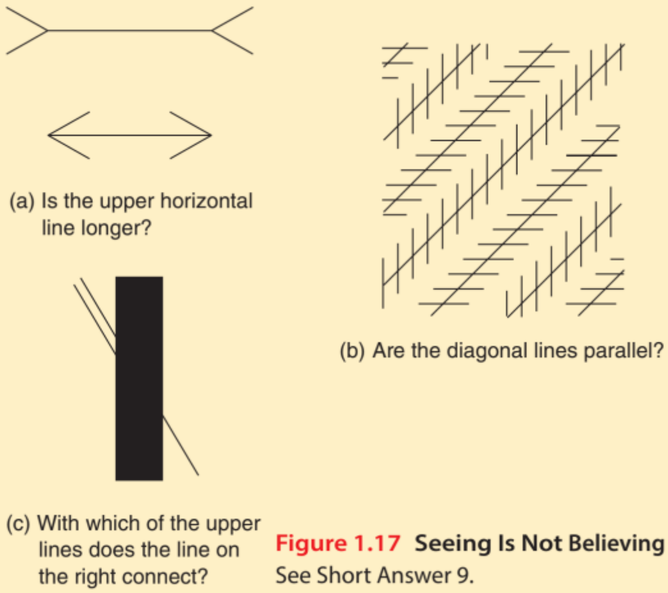


Figure 1.17 Seeing Is Not Believing
See Short Answer 9.

1.4 Standard Units and Systems of Units

10. A standard unit must have what characteristics?
11. Why are some quantities called "fundamental"?
12. What makes up a system of units?
13. For a given speed limit, would the numerical value be smaller in mi/h or in km/h?
14. Is the United States officially on the metric system? Explain.
15. What standard metric unit is referenced to an artifact, and what is that artifact?
16. Which is a fundamental quantity, weight or mass? Why?
17. Explain the acronyms mks, SI, and cgs.

1.5 More on the Metric System

18. How is the decimal base 10 of the metric system an advantage over the base 12 of the British system?
19. What are the metric prefixes for 10^3, 10^6, 10^{-3}, and 10^{-6}?
20. What is a metric ton, and how is it defined?
21. What is the standard unit of density in the SI?

1.6 Derived Units and Conversion Factors

22. How many fundamental quantities are generally used to describe the mechanics of nature?
23. What does density describe?
24. In general, when a derived unit becomes complicated (involves too many standard units), what is done?
25. Is an equivalence statement a true equation? Explain.
26. In Fig. 1.15a, the abbreviation mph is used. Is this a correct abbreviation? Why might it be confusing to some people? (*Hint:* miles, meters.)

1.7 Significant Figures

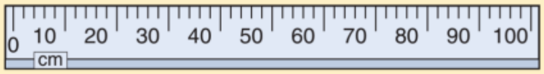
27. Why are significant figures used?
28. What are the rules for determining significant figures? Give examples.

29. If you multiplied 9874 m by 36.0 m, how many significant figures should you report in your answer?

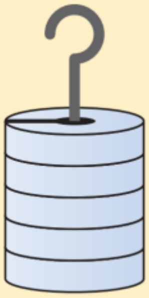
30. If you add 20.04 to 1.2, how many decimal places should the result have?

VISUAL CONNECTION

Visualize the connections and give answers in the blanks. Compare your answers with those at the back of the book.



Length



Mass

Time

Metric System units (SI)

a. __________
length

b. __________
mass

c. __________
time

d. __________
system acronym

British System units

e. __________
length

f. __________
weight (instead of mass)

g. __________
time

h. __________
system acronym

APPLYING YOUR KNOWLEDGE

1. What are the advantages of defining standard units in terms of intrinsic physical phenomena rather than artifacts? Give examples.
2. Suppose you could buy a quart of a soft drink and a liter of the soft drink at the same price. Which would you choose, and why?
3. Give two ways in which a scientific law and a legal law differ.
4. In general, common metric units are larger than their British counterparts; for example, 1 m is a little longer than 1 yd. Give two other examples, as well as one notable exception.
5. A man buys a 5 ft fishing rod in a sports store and gets on a bus to go home. The bus driver makes him get off because of a rule that forbids objects measuring over 4 ft long on the bus. The man goes back in the store, comes out with a rectangular package that measures 3 ft × 4 ft, and the bus driver lets him ride. Did the man have to buy a new 4 ft rod? Explain.
6. Currently, the tallest building in the world is the Burj Khalifa (with 163 floors) in Dubai, United Arab Emirates, which is 828 m tall. Previously, one of the tallest was the Taipei 101 skyscraper (with 101 floors) in Taiwan, which is 508 m tall. A friend wants you to describe the process by which you could find how much taller, in feet, the Burj is compared with the Taipei 101. What would you tell him?

IMPORTANT EQUATION

density: $\rho = \frac{m}{V}$ (1.1)

EXERCISES

The Exercises are given in odd-even pairs for similarity in topics and solutions. The answers to the odd-numbered exercises are given at the back of the book.

1.5 More on the Metric System

1. How many centimeters are there in a kilometer?
2. In a smart-phone, how many megabytes (MB) are there in sixteen gigabytes (GB) of memory?
3. What is the volume of a liter in cubic millimeters?
4. Show that 1 cubic meter contains 1000 L.
5. Water is sold in half-liter bottles. What is the mass, in kilograms and in grams, of the water in such a full bottle?
6. A rectangular container measuring 15 cm × 25 cm × 30 cm is filled with water. What is the mass of this volume of water in kilograms and in grams?
7. Write the following quantities in standard units.
   (a) 0.55 Ms
   (b) 2.8 km
   (c) 12 mg
   (d) 100 cm
8. Fill in the blanks with the correct numbers for the metric prefixes.
   (a) 32,000,000,000 bytes = ___ GB
   (b) 0.0543 L = ___ mL
   (c) 54.21 cm = ___ m
   (d) 6210 bucks = ___ kilobucks

1.6 Derived Units and Conversion Factors

9. Compute, in centimeters and in meters, the height of a basketball player who is 6 ft 10 in. tall.
10. If the DNA strand in a molecule could be stretched out, it would have a length on the order of 2.0 m. What would this be in feet and inches?
11. In Fig 1.15b, is the conversion on the sign exact? Justify your answer.
12. If we changed our speed limit signs to metric, what would probably replace
    (a) 70 mi/h and
    (b) 65 mi/h?
13. Is the following statement reasonable? (Justify your answer.) It took 300 L of gasoline to fill up the car's tank.
14. Is the following statement reasonable? (Justify your answer.) The area of a dorm room is 12 m^2.
15. Referring to number 6 in Applying Your Knowledge, how much shorter in feet is the Taipei 101 than the Burj Khalifa?
16. The Hoover Dam Bridge connecting Arizona and Nevada opened in October 2010 (● Fig. 1.18). It is the highest and longest arched concrete bridge in the Western Hemisphere, rising 900 ft above the Colorado River and extending 1900 ft in length. What are these dimensions in meters?
17. A popular saying is "Give him an inch, and he'll take a mile." What would be the equivalent saying using comparable metric units?
18. A metric ton is 1000 kg, and a British ton is 2000 lb. Which has the greater weight and by how many pounds?

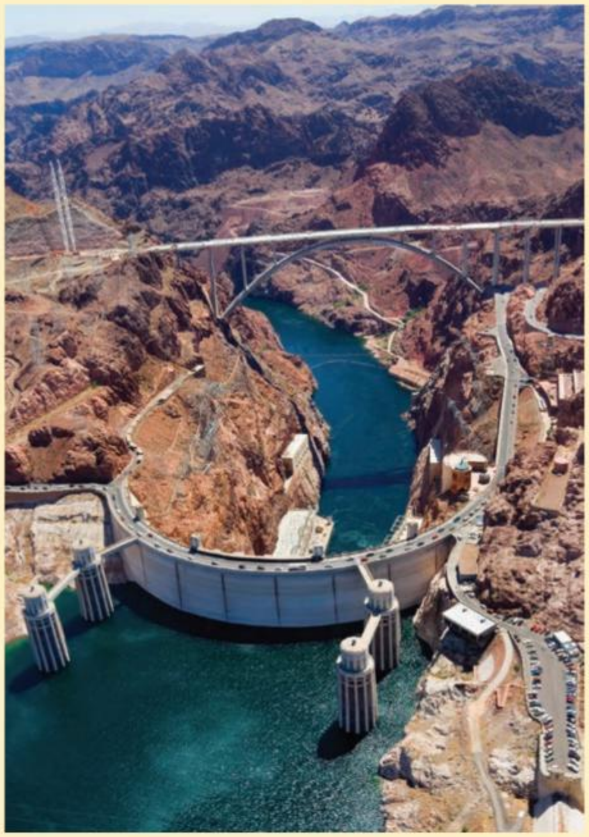


Figure 1.18 High and Wide An aerial view of the new four-lane Hoover Dam Bridge between Arizona and Nevada with the Colorado River beneath (as seen from behind the dam). See Exercise 16.

19. Compute the density in g/cm^3 of a piece of metal that has a mass of 0.500 kg and a volume of 47 cm^3.
20. What is the volume of a piece of iron ($\rho = 7.9$ g/cm^3) that has a mass of 2.0 kg?

1.7 Significant Figures

21. Round the following numbers to two significant figures.
    (a) 7.66
    (b) 0.00298
    (c) 9458
    (d) 0.000344
22. Express the following results with the correct number of decimal places:
    (a) 1.5 + 2.76 =
    (b) 3.53 − 2.5 =
    (c) 12.345 + 3.5 =
    (d) 7.9 − 2.45 =

CHAPTER

2

Motion

Give me matter and motion, and I will construct the universe.

René Descartes (1596–1650)

Strobe lighting captures a bullet tearing through a card at about 900 m/s (200 mi/h)

Robert Harding World Imagery/Robert Harding/Alamy Stock Photo

Chapter Outline

2.1 Defining Motion 29
2.2 Speed and Velocity 30
2.3 Acceleration 34
Conceptual Q&A 2.1 Putting the Pedal to the Metal 37
Highlight 2.1 Galileo and the Leaning Tower of Pisa 38
Physical Science Today 2.1 Rotating Tablet Screens 41
Conceptual Q&A 2.2 And the Winner Is … 41
2.4 Acceleration in Uniform Circular Motion 42
2.5 Projectile Motion 44
Conceptual Q&A 2.3 Hanging in There 45

Did You Know?	Section
Speed and velocity are different physical quantities.	2.2
A race car going around a circular track at a constant speed is accelerating.	2.4
A football quarterback cannot throw a "straight-line" pass.	2.5

Having been introduced to measurement and units, you are ready to begin your study of physics. **Physics**, *the most fundamental physical science, is concerned with the basic principles and concepts that describe the workings of the universe. It deals with matter, motion, force, and energy.*

There are various areas of physics:

- *Classical mechanics* is the study of the motion of objects moving at relatively low speeds.
- *Waves and sound* is the study of wave motion and its application to sound.
- *Thermodynamics* is the study of temperature, heat, and thermal processes.
- *Electromagnetism* is the study of electricity and magnetism.
- *Optics* is the study of the properties of light, mirrors, and lenses.
- *Quantum mechanics* is the study of the behavior of particles on the microscopic and submicroscopic levels.
- *Atomic and nuclear physics* is the study of the properties of atoms and nuclei.
- *Relativity* is the study of objects traveling at speeds approaching the speed of light.

We will delve into all of these areas, except relativity, and begin with classical mechanics and the study of motion.

Did You Learn?

- To designate a position or location, both a reference point and a unit measurement scale are needed.
- Motion involves a continuous change of position.

2.2 Speed and Velocity

Key Questions

- Between two points, which may be greater in magnitude, distance or displacement?
- What is the difference between speed and velocity?

The terms *speed* and *velocity* are often used interchangeably; however, in physical science, they have different distinct meanings. Speed is a *scalar* quantity, and velocity is a *vector* quantity. Let's distinguish between scalars and vectors now, because other terms will fall into these categories during the course of our study. The distinction is simple.

A **scalar** *has only magnitude (numerical value and unit of measurement).* For example, you may be traveling in a car at 90 km/h (about 55 km/h). Your speed is a scalar quantity; the magnitude has the numerical value of 90 and unit of measurement km/h.

A **vector** *has magnitude and direction.* For example, suppose you are traveling at 90 km/h *north*. This describes your velocity, which is a vector quantity because it consists of magnitude *plus* direction. By including direction, a vector quantity gives more information than a scalar quantity. No direction is associated with a scalar quantity.

Vectors may be graphically represented by arrows. The length of a vector arrow is proportional to the magnitude and may be drawn to scale. The arrowhead indicates the direction of the vector (● Fig. 2.2).

Notice in Fig. 2.2 that the red car has a negative velocity vector, $-v_c$, that is equal in magnitude (length of arrow) but opposite in direction, to the positive velocity vector, $+v_c$, for the blue car. The velocity vector for the man, v_m, is shorter than the vectors for the cars because he is moving more slowly in the positive (+) direction. (The + sign is often omitted as being understood.)

Speed

Now let's look more closely at speed and velocity, which are basic quantities used in the description of motion. The **average speed** *of an object is the total distance traveled divided*

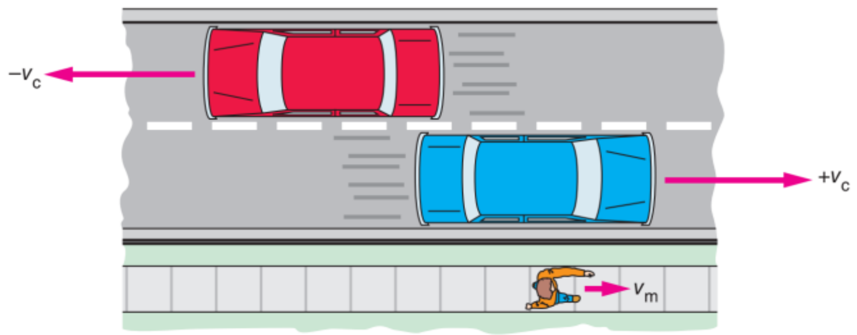


Figure 2.2 Vectors Vectors may be graphically represented by arrows. The length of a vector arrow is proportional to the magnitude of the quantity it represents, and the arrowhead indicates the direction. (See text for description.)

by the time spent in traveling the total distance. **Distance** (*d*) *is the actual length of the path that is traveled.* In equation form,

$$\text{average speed} = \frac{\text{distance traveled}}{\text{time to travel the distance}}$$

$$\bar{v} = \frac{d}{t} \qquad 2.1$$

where the bar over the symbol ($\bar{v}$, "vee-bar") indicates that it is an average value.*

Taken over a time interval, speed is an average. This concept is somewhat analogous to an average class grade. Average speed gives only a general description of motion. During a long time interval like that of a car trip, you may speed up, slow down, and even stop. The average speed, however, is a single value that represents the average rate of motion for the entire trip.

The description of motion can be made more specific by taking smaller time intervals such as a few seconds or even an instant. The speed of an object at any instant of time may be quite different from its average speed, and it gives a more accurate description of the motion at that time. In this case, we have an instantaneous speed.

The **instantaneous speed** *of an object is its speed at that instant of time* (Δt *becoming extremely small).* A common example of nearly instantaneous speed is the speed registered on an automobile speedometer. This value is the speed at which the automobile is traveling at that moment, or instantaneously (● Fig. 2.3).

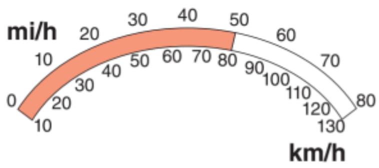


Figure 2.3 Instantaneous Speed The speed on an automobile speedometer is a practical example of instantaneous speed, or the speed of the car at a particular instant. Here it is 80 km/h, or 50 mi/h.

Velocity

Now let's look at describing motion with velocity. Velocity is similar to speed, *but* a direction is involved. **Average velocity** *is the displacement divided by the total travel time.* **Displacement** *is the straight-line distance between the initial and final positions, with direction toward the final position, and is a vector quantity* (● Fig. 2.4).

For straight-line motion in one direction, speed and velocity have something in common. Their magnitudes are the same because the lengths of the distance and the displacement are the same. The distinction between them in this case is that a displacement direction must be specified for the velocity.

As you might guess, there is also **instantaneous velocity**, *which is the velocity at any instant of time.* For example, a car's instantaneous speedometer reading and the direction in which it is traveling at that instant give the car's instantaneous velocity. Of course, the speed and direction of the car may and usually do change. This motion is then *accelerated motion*, which is discussed in the following section.

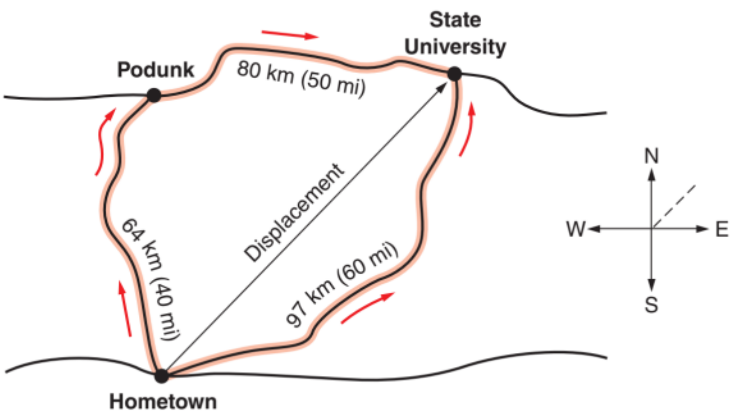


Figure 2.4 Displacement and Distance Displacement is a vector quantity and is the straight-line distance between two points (initial and final), plus direction. In traveling from Hometown to State University, the displacement would be so many kilometers NE (northeast). Distance is a scalar quantity and is the actual path length traveled. Different routes have different distances. Two routes are shown in the figure, with distances of 97 km and 144 km (64 km + 80 km = 144 km).

*Note that length *d* and time *t* are intervals. They are sometimes written Δd and Δt to indicate explicitly that they are intervals ($\Delta d/\Delta t$). The Δ (Greek delta) means "change in" or "difference in." For example, $\Delta t = t - t_o$, where t_o and *t* are the original (or initial) and final times (on a clock), respectively. If $t_o = 0$, then $\Delta t = t$. Length and time are generally written as *d* and *t* for convenience with the understanding that they are intervals.

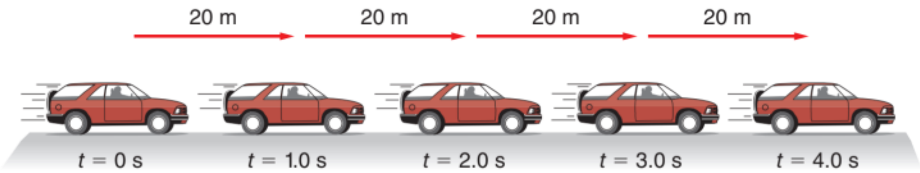


Figure 2.5 Constant Velocity The car travels equal distances in equal periods of time in straight-line motion. With constant speed and constant direction, the velocity of the car is constant, or uniform.

If the velocity is *constant*, or *uniform*, then there are no such changes. Suppose an airplane is flying at a constant speed of 320 km/h (200 mi/h) directly eastward. Then the airplane has a constant velocity and flies in a straight line. (Why?)

For this special case, you should be able to convince yourself that the constant velocity and the average velocity are the same ($\bar{v} = v$). By analogy, think about everyone in your class getting the same (constant) test score. How do the class average and the individual scores compare under these circumstances?

A car traveling with a constant velocity is shown in ● Fig. 2.5. Examples 2.1, 2.2, and 2.3 illustrate the use of speed and velocity.

EXAMPLE 2.1 Finding Speed and Velocity

Describe the motion (speed and velocity) of the car in Fig. 2.5.

Thinking It Through

Speed and velocity involve distance and time, with a direction for the velocity. Distances and times are given in the figure. Note the car's motion is uniform, that is, it travels the same distance in each second.

Solution

Step 1 The data are taken from the figure.

Given: $d = 80$ m and $t = 4.0$ s

(The car travels 80 m in 4.0 s.)

Step 2 *Wanted*: Speed and velocity. The units of the data are standard.

Step 3 The car has a constant (uniform) speed (v) and travels 20 m each second. When a speed (v) is constant, it is equal to the average speed; that is, $v = \bar{v}$. (Why?) Calculating the average speed using Eq. 2.1 yields

$$\bar{v} = \frac{d}{t} = \frac{80\text{ m}}{4.0\text{ s}} = 20\text{ m/s}$$

If the motion is in one direction (straight-line motion), then the car's velocity is also constant and is 20 m/s *in the direction of the motion*.

Confidence Exercise 2.1

How far would the car in Example 2.1 travel in 10 s?

The answers to Confidence Exercises may be found at the back of the book.

Example 2.1 was worked in stepwise fashion, as suggested in the approach to problem solving in Appendix B. This stepwise approach will be used in the first example in early chapters as a reminder. Thereafter, examples generally will be worked directly, unless a stepwise solution is considered helpful.

EXAMPLE 2.2 Finding the Time It Takes for Sunlight to Reach the Earth

The speed of light in space (vacuum) is $c = 3.00 \times 10^8$ m/s. (The speed of light is given the special symbol c.) How many seconds does it take light from the Sun to reach the Earth if the distance from the Sun to the Earth is 1.50×10^8 km?

Thinking It Through

The distance (d) between the Sun and the Earth is given, as well as the speed of light (c). Distance and speed are related by $v = d/t$, so the time is given by $t = d/v$. Check to see if units are consistent before doing calculation.

Solution

Given: $v = c = 3.00 \times 10^8$ m/s, $d = 1.5 = 10^8$ km. Converting the distance to meters (the standard unit) yields

$$d = 1.50 \times 10^8 \,\cancel{\text{km}} \left(\frac{10^3\ \text{m}}{\cancel{\text{km}}}\right) = 1.50 \times 10^{11}\ \text{m}$$

Wanted: t (time for light to travel from the Sun)

Rearranging Eq. 2.1 for the unknown t, we have $t = d/v$, where the bar over the v is omitted because the speed is constant, and $\bar{v} = v$. Then

$$t = \frac{d}{v} = \frac{1.50 \times 10^{11}\ \text{m}}{3.00 \times 10^8\ \text{m/s}}$$
$$= 5.00 \times 10^2\ \text{s} = 500\ \text{s}$$

From this example, it can be seen that although light travels very rapidly, it still takes 500 seconds, or 8.33 minutes, to reach the Earth after leaving the Sun (● Fig. 2.6). Again we are working with a constant speed and velocity (straight-line motion).

Confidence Exercise 2.2

A communications satellite is in a circular orbit about the Earth at an altitude of 3.56×10^4 km. How many seconds does it take a signal from the satellite to reach a television receiving station? (Radio signals travel at the speed of light, 3.00×10^8 m/s.)

The answers to Confidence Exercises may be found at the back of the book.

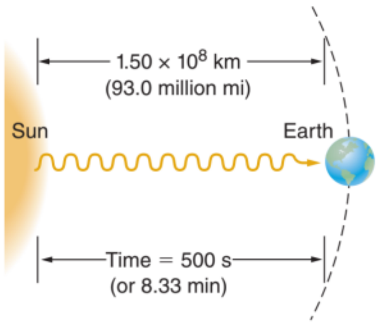


Figure 2.6 Traveling at the Speed of Light Although light travels at a speed of 3.00×10^8 m/s, it still takes more than 8 minutes for light from the Sun to reach the Earth.

EXAMPLE 2.3 Finding the Orbital Speed of the Earth

What is the average speed of the Earth in miles per hour as it makes one revolution about the Sun? (Consider the Earth's orbit to be circular.)

Thinking It Through

Our planet revolves once around the Sun in an approximately circular orbit in a time of 1 year. The distance it travels in one revolution is the circumference of this circular orbit. The circumference of a circle is given by $2\pi r$, where r is the radius of the orbit. From Fig. 2.6, r is 93.0 million miles (9.30×10^7 mi), the distance of the Earth from the Sun. The time it takes to travel this distance is 1 year or 365 days, and average speed is given by $\bar{v} = d/t$.

When any of these changes occur, an object is accelerating. Examples are

1. *a car speeding up (or slowing down) while traveling in a straight line,*
2. *a car rounding a curve at a constant speed, and*
3. *a car speeding up (or slowing down) while rounding a curve.*

Acceleration *is defined as the time rate of change of velocity.* Taking the symbol Δ (delta) to mean "change in," the equation for **average acceleration** ($\bar{a}$) can be written as

$$\text{average acceleration} = \frac{\text{change in velocity}}{\text{time for change to occur}}$$

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_o}{t} \qquad 2.2$$

The change in velocity (Δv) is the final velocity v_f minus the original velocity v_o. Also, the interval Δt is commonly written as t ($\Delta t = t - t_o = t$), with t_o taken to be zero (t is understood to be an interval). v_o is not zero if the car is initially moving.

The units of acceleration in the SI are meters per second per second, (m/s)/s, or meters per second squared, m/s^2. These units may be confusing at first. Keep in mind that an acceleration is a measure of a *change* in velocity during a given time period.

Consider a constant acceleration of 9.8 m/s^2. This value means that the velocity changes by 9.8 m/s *each* second. Thus, for straight-line motion, as the number of seconds increases, the velocity goes from 0 to 9.8 m/s during the first second, to 19.6 m/s (that is, 9.8 m/s + 9.8 m/s) during the second second, to 29.4 m/s (that is, 19.6 m/s + 9.8 m/s) during the third second, and so forth, adding 9.8 m/s each second. This sequence is illustrated in ● Fig. 2.7 for an object that falls with a constant acceleration due to gravity of 9.8 m/s^2. Because the velocity increases, the distance traveled by the falling object each second also increases, but *not* uniformly.

Our discussion will be limited to such constant accelerations. For a constant acceleration, $\bar{a} = a$ (we omit the overbar because the average acceleration is equal to the

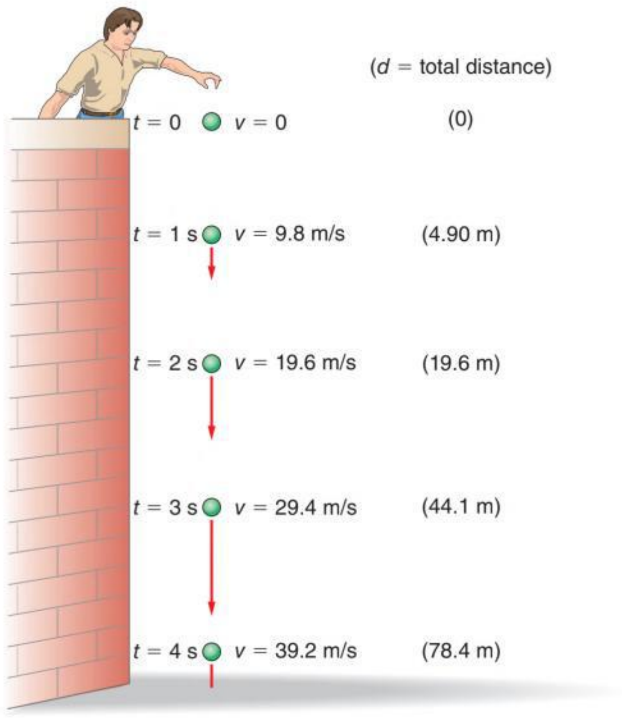


Figure 2.7 Constant Acceleration For an object with a constant downward acceleration of 9.8 m/s^2, its velocity increases 9.8 m/s each second. The increasing lengths of the velocity arrows indicate the increasing velocity of the ball. The distances do not increase uniformly. (The distances of fall are obviously not to scale.)

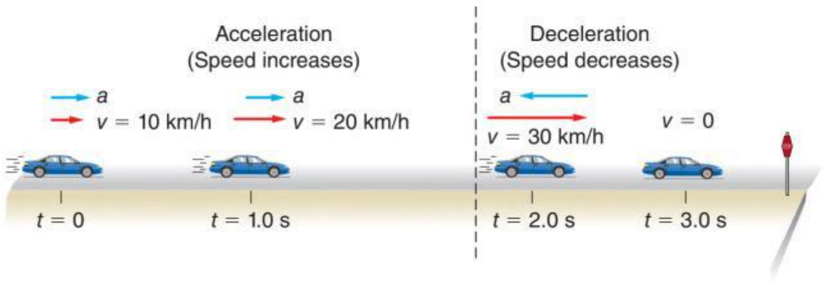


Figure 2.8 Acceleration and Deceleration When the acceleration is in the same direction as the velocity of an object in straight-line motion, the speed increases. When the acceleration is in the opposite direction of the velocity, there is a deceleration and the speed decreases.

You can easily find the rate of deceleration. With $v_o = 30$ km/h $= 8.3$ m/s (with conversion factor), $v_f = 0$, and $t = 1.0$ s, then using Eq. 2.2,

$$a = \frac{v_f - v_o}{t} = \frac{0 - 8.3 \text{ m/s}}{1.0 \text{ s}} = -8.3 \text{ m/s}^2$$

The acceleration is negative because it is in the opposite direction of the velocity.*

Conceptual Question and Answer 2.1

Putting the Pedal to the Metal

Q. Why is the gas pedal of an automobile commonly called the "accelerator"? What might the brake pedal be called? How about the steering wheel?

A. When you push down on the gas pedal or accelerator, the car speeds up (increasing magnitude of velocity), but when you let up on the accelerator, the car slows down or decelerates.

Putting on the brakes would produce an even greater deceleration, so perhaps the brake pedal should be called a "decelerator." An acceleration results from a change in the velocity's magnitude and/or direction. Technically, then, the steering wheel might also be called an "accelerator," since it changes a speeding car's direction.

In general, we will consider only constant, or uniform, accelerations. A special constant acceleration is associated with the acceleration of falling objects as in Fig. 2.7. The **acceleration due to gravity** at the Earth's surface is directed downward (toward the Earth's center) and is denoted by the letter g. Its magnitude in SI units is

$$g = 9.80 \text{ m/s}^2$$

This value corresponds to 980 cm/s^2, or about 32 ft/s^2.

The acceleration due to gravity varies slightly depending on such factors as distance from the equator (latitude) and altitude. However, the variations are very small, and for our purposes, g will be taken to be the same everywhere on or near the Earth's surface.

Italian physicist Galileo Galilei (1564–1642), commonly known just as Galileo, was one of the first scientists to assert that all objects fall with the same acceleration. Of course, this assertion assumes that frictional effects, such as air resistance, are negligible. To exclude frictional and any other effects, the term *free fall* is used. *Objects in motion solely under the influence of gravity are said to be in* **free fall**. One can illustrate the validity of this statement experimentally by dropping a small mass, such as a coin, and a larger mass, such as a ball, at the same time from the same height. They will both hit the floor, as best as can be judged, at the same time (negligible air resistance over short

*Note that a negative acceleration ($-a$) is not necessarily a deceleration. If the motion is in the negative direction ($-v$) and the velocity and the acceleration are in the *same* direction, then the object speeds up; that is, its velocity increases in the negative direction.

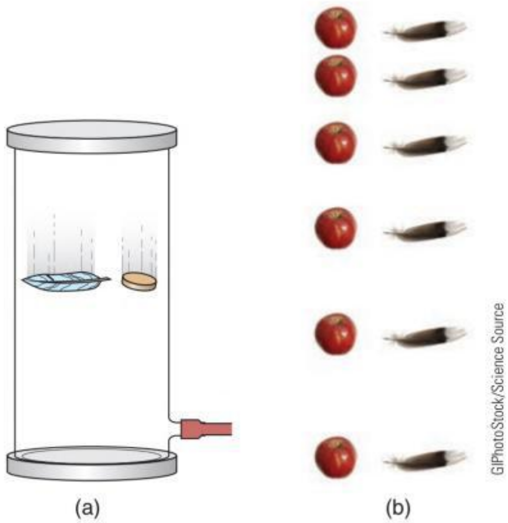


Figure 2.9 Free Fall and Air Resistance (a) When dropped simultaneously from the same height, a feather falls more slowly than a coin because of air resistance. But when both objects are dropped in an evacuated container with a good partial vacuum, where air resistance is negligible, the feather and the coin fall together with a constant acceleration. (b) An actual demonstration with multiflash photography: An apple and a feather are released simultaneously in a large vacuum chamber, and they fall together.

distances). Legend has it that Galileo himself performed such experiments. (See the **Highlight 2.1: Galileo and the Leaning Tower of Pisa.**) More modern demonstrations are shown in ● Fig. 2.9.

Highlight 2.1 Galileo and the Leaning Tower of Pisa

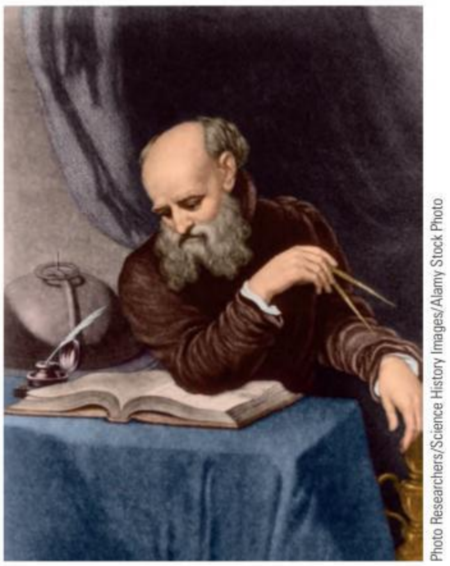


Figure 1 Galileo Galilei (1564–1642) The motion of objects was one of Galileo's many scientific inquiries.

One of Galileo's greatest contributions to science was his emphasis on experimentation, a basic part of the scientific method (Chapter 1.2). See Fig. 1. However, it is not certain whether he actually carried out a now-famous experiment. There is a popular story that Galileo dropped stones or cannonballs of different masses from the top of the Tower of Pisa to determine experimentally whether objects fall with the same acceleration (Fig. 2).

Galileo did indeed question Aristotle's view that objects fell because of their "earthiness" and that the heavier, or more earthy, an object, the faster it would fall in seeking its "natural" place toward the center of the Earth. His ideas are evident in the following excerpts from his writings.

How ridiculous is this opinion of Aristotle is clearer than light. "Who ever" would believe, for example, that … if two stones were flung at the same moment from a high tower, one stone twice the size of the other, … that when the smaller was half-way down the larger had already reached the ground?

And Aristotle says that "an iron ball of one hundred pounds falling a height of one hundred cubits reaches the ground before a one-pound ball has fallen a single cubit." I say that they arrive at the same time.

Although Galileo refers to a high tower, the Tower of Pisa is not mentioned in his writings, and there is no independent record of such an experiment. Fact or fiction? No one really knows. What we do know is that all freely falling objects near the Earth's surface fall with the same acceleration.

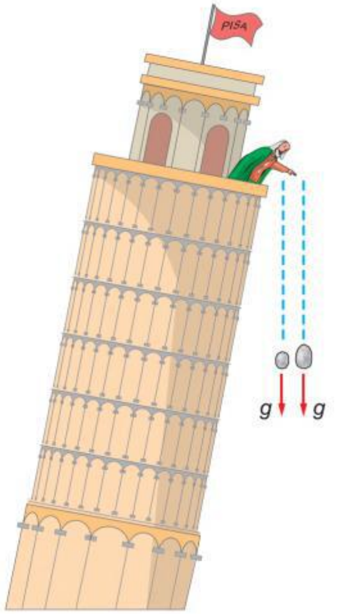


Figure 2 Free Fall All freely falling objects near the Earth's surface have the same constant acceleration. Galileo is alleged to have proved this by dropping cannonballs or stones of different masses from the Tower of Pisa. Over short distances, the air resistance can be neglected, so objects dropped at the same time will strike the ground together.

Source: L. Cooper, *Aristotle, Galileo, and the Tower of Pisa* (Ithaca, NY: Cornell University Press, 1935).

On the Moon, there is no atmosphere, so there is no air resistance. In 1971, while on the lunar surface, astronaut David Scott dropped a feather and a hammer simultaneously. They both hit the surface of the Moon at the same time because neither the feather nor the hammer was slowed by air resistance. This experiment shows that Galileo's assertion applies on the Moon as well as on the Earth. Of course, on the Moon all objects fall at a slower rate than do objects on the Earth's surface because the acceleration due to gravity on the Moon is only $\frac{1}{6}$ of the acceleration due to gravity on the Earth.

The velocity of a freely falling object on the Earth increases 9.80 m/s each second, so its magnitude increases uniformly with time, but how about the distance covered each second? The distance covered is not uniform because the object speeds up. The distance (d) a dropped object ($v_o = 0$) travels downward with time can be computed from the equation $d = \frac{1}{2}at^2$, with g substituted for a.

$$d = \frac{1}{2}gt^2 \qquad 2.4$$

EXAMPLE 2.5 Finding How Far a Dropped Object Falls

A ball is dropped from the top of a tall building. Assuming free fall, how far does the ball fall in 1.50 s?

Thinking It Through

Given the time, this is a direct application of Eq. 2.4.

Solution

With $t = 1.50$ s, the distance is given by Eq. 2.4, where it is known that $g = 9.80 \text{ m/s}^2$.

$$d = \frac{1}{2}gt^2 = \frac{1}{2}(9.80 \text{ m/s}^2)(1.50 \text{ s})^2 = 11.0 \text{ m}$$

Confidence Exercise 2.5

What is the speed of the ball 1.50 s after it is dropped?

The answers to Confidence Exercises may be found at the back of the book.

Review Fig. 2.7 for the distances and velocities of a falling object with time. Note that the increase in distance is directly proportional to the time squared ($d \propto t^2$, Eq. 2.4), and the increase in velocity is directly proportional to time ($v_f \propto t$, Eq. 2.3a).

Using these equations, it can be shown that at the end of the third second ($t = 3.00$ s), the object has fallen 44.1 m, which is about the height of a 10-story building. It is falling at a speed of 29.4 m/s, which is about 65 mi/h. Pretty fast. Look out below!

When an object is thrown straight upward, it slows down while traveling. (The velocity decreases 9.80 m/s each second.) In this case, the velocity and acceleration are in opposite directions, and there is a deceleration (● Fig. 2.10). The object slows down (its velocity decreases) until it stops *instantaneously* at its maximum height. Then it starts to fall downward as though it had been dropped from that height. The travel time downward to the original starting position is the same as the travel time upward.

The object returns to its starting point with the same speed it had initially upward. For example, if an object is thrown upward with an initial speed of 29.4 m/s, it will return to the starting point with a speed of 29.4 m/s. You should be able to conclude that it will travel 3.00 s upward, to a maximum height of 44.1 m, and return to its starting point in another 3.00 s.

The preceding numbers reflect free-fall motion, but air resistance generally retards or slows the motion. For a good example of air resistance, consider skydiving, jumping out of an airplane and falling toward the Earth (with a parachute). Before the parachute opens, the falling skydiver is said to be in "free fall," but it is not free fall by our definition. Here, there is air resistance, which skydivers use to their advantage.

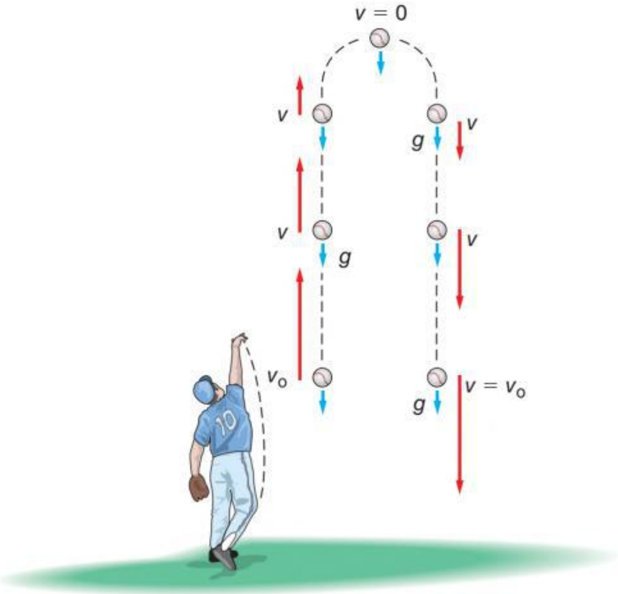


Figure 2.10 Up and Down An object projected straight upward slows down because the acceleration due to gravity is in the opposite direction of the velocity, and the object stops ($v = 0$) for an instant at its maximum height. Note the blue acceleration arrow at $v = 0$. That is, $a \neq 0$. Gravity still acts and $a = g$. The ball then accelerates downward, returning to the starting point with a velocity equal in magnitude and opposite in direction to the initial velocity, $-v_o$. (The downward path is displaced to the right in the figure for clarity.)

Air resistance is the result of a moving object colliding with air molecules. Therefore, air resistance (considered a type of friction) depends on an object's size and shape, as well as on its speed. The larger the object (or the more downward area exposed) and the faster it moves, the more collisions and the more air resistance there will be. As a skydiver accelerates downward, his or her speed increases, as does the air resistance. At some point, the upward air resistance balances the downward weight of the diver and the acceleration goes to zero. The skydiver then falls with a constant velocity, which is called the **terminal velocity**, v_t (● Fig. 2.11a).

Wanting to maximize the time of fall, skydivers assume a "spread-eagle" position to provide greater surface area and maximize the air resistance (Fig. 2.11b). The air resistance then builds up faster and terminal velocity is reached sooner, giving the skydiver more fall time. This position is putting air resistance to use. The magnitude of a skydiver's terminal velocity during a fall is reached at about 200 km/h (125 mi/h). Acceleration is used in a variety of practical applications. You probably use an accelerometer. See **Physical Science Today 2.1: Rotating Tablet Screens**.

Figure 2.11 Air Resistance and Terminal Velocity (a) As the velocity of a falling object increases, so does the upward force *f* of air resistance. At a certain velocity, called the *terminal velocity*, the force *f* is equal to the weight of the object (*mg*). The object then falls with a constant velocity. (b) Skydivers assume a "spread-eagle" position to increase air resistance and reach terminal velocity more quickly, allowing for a greater time of fall.

Did You Learn?

- Acceleration results from a change in velocity, which may result from a change in magnitude, a change in direction, or both.
- A negative acceleration ($-a$) will speed up an object with a negative velocity ($-v$).

2.4 Acceleration in Uniform Circular Motion

Key Questions

- What kind of acceleration is needed for uniform circular motion?
- For an object in uniform circular motion, are both the speed and the velocity constant?

An object in *uniform* circular motion has a constant speed. A car goes around a circular track at a uniform speed of 90 km/h (about 55 mi/h). However, the velocity of the car is *not* constant because the direction is continuously changing, giving rise to a change in velocity and an acceleration.

This acceleration cannot be in the direction of the instantaneous motion or velocity because otherwise the object would speed up and the motion would not be uniform. In what direction, then, is the acceleration? Because the object must continually change direction to maintain a circular path, the acceleration is actually perpendicular, or at a right angle, to the velocity vector.

Consider a car traveling in uniform circular motion, as illustrated in ● Fig. 2.12. At any point, the instantaneous velocity is *tangential* to the curve (at an angle of 90° to a radial line at that point). After a short time, the velocity vector has changed (in direction). The change in velocity (Δv) is given by a vector triangle, as illustrated in the figure.

This change is an average over a time interval Δt, but notice how the Δv vector generally points inward toward the center of the circle. For instantaneous measurement, this generalization is true, so for an object in uniform circular motion, the acceleration is toward the center of the circle. This acceleration is called **centripetal acceleration** (centripetal, meaning center-seeking).

Even when traveling at a constant (tangential) speed, an object in uniform circular motion must have an inward acceleration. For a car, this acceleration is supplied by friction on the tires (● Fig. 2.13). When a car hits an icy spot on a curved road, it may slide outward if the centripetal acceleration is not great enough to keep it in a circular path.

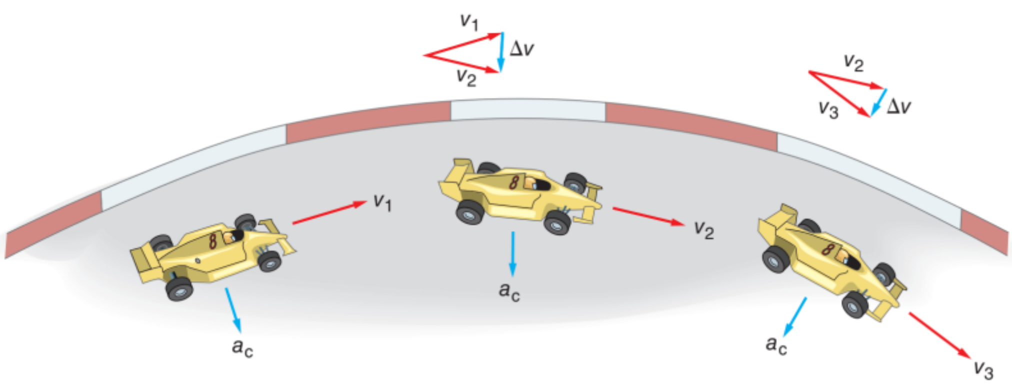


Figure 2.12 Centripetal Acceleration A car traveling with a constant speed on a circular track is accelerating because its velocity is changing (direction change). This acceleration is toward the center of the circular path and is called *centripetal* ("center-seeking") *acceleration*.

The centripetal acceleration is given by Eq. 2.5:

$$a_c = \frac{v^2}{r} = \frac{(12 \text{ m/s})^2}{50 \text{ m}}$$
$$= 2.9 \text{ m/s}^2$$

The value of 2.9 m/s^2 is about 30% of the acceleration due to gravity, $g = 9.8 \text{ m/s}^2$, and is a fairly large acceleration.

Confidence Exercise 2.6

Using the result of Example 2.3, compute the centripetal acceleration in m/s^2 of the Earth in its nearly circular orbit about the Sun ($r = 1.5 \times 10^{11}$ m).

The answers to Confidence Exercises may be found at the back of the book.

Did You Learn?

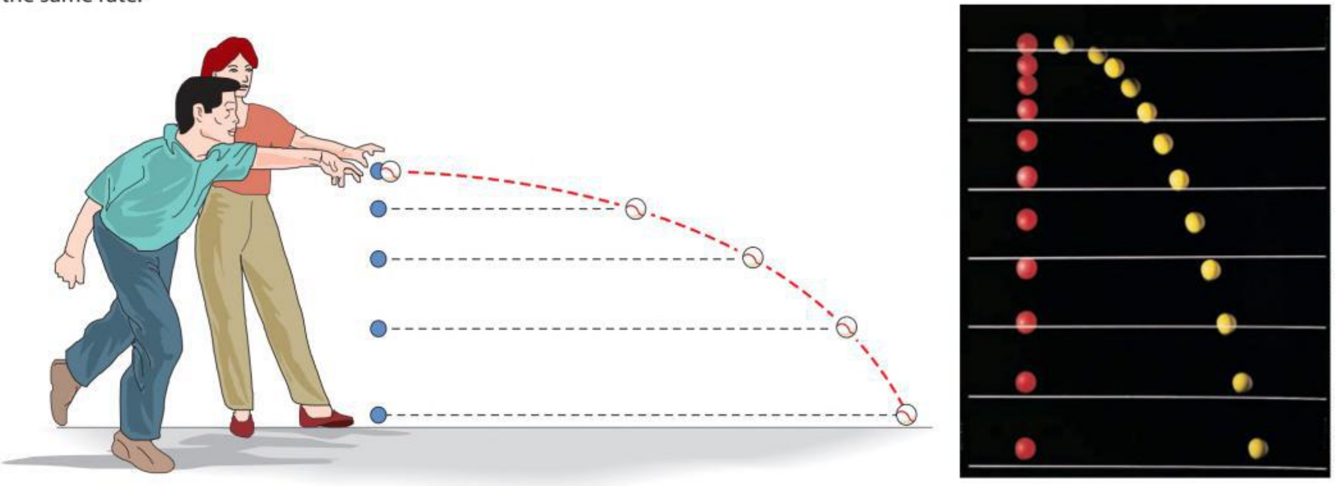
- A centripetal (center-seeking) acceleration is needed for uniform circular motion.
- In uniform circular motion, there is a change in velocity (direction), but the tangential speed is constant.

2.5 Projectile Motion

Key Questions

- Neglecting air resistance, why would a ball projected horizontally and another ball dropped at the same time from the same initial height hit the ground together?
- On what does the range of a projectile depend? (Neglect air resistance.)

Another common motion in two dimensions is that of an object thrown or projected by some means. For example, the motion of a thrown ball or a golf ball driven off a tee is called **projectile motion**. A special case of projectile motion is that of an object projected horizontally, or parallel, to a level surface. Suppose a ball is projected horizontally, while at the same time another ball is dropped from the same height (● Fig. 2.14a). You might be surprised that both balls hit the ground at the same time (neglecting air resistance). An object thrown horizontally will fall at the same rate as an object that is dropped (both fall with acceleration g). The velocity in the horizontal direction does not affect the velocity and acceleration in the vertical direction.



(a) (b)

1990 Richard Megna-Fundamental Photographs

Figure 2.14 Same Vertical Motions (a) When one ball is thrown horizontally and another ball is dropped simultaneously from the same height, both will hit the ground at the same time (with air resistance neglected), because the vertical motions are the same. (Diagram not to scale.) (b) A multiflash photograph of two balls, one of which was projected horizontally at the same time the other ball was dropped. Notice from the horizontal lines that both balls fall vertically at the same rate.

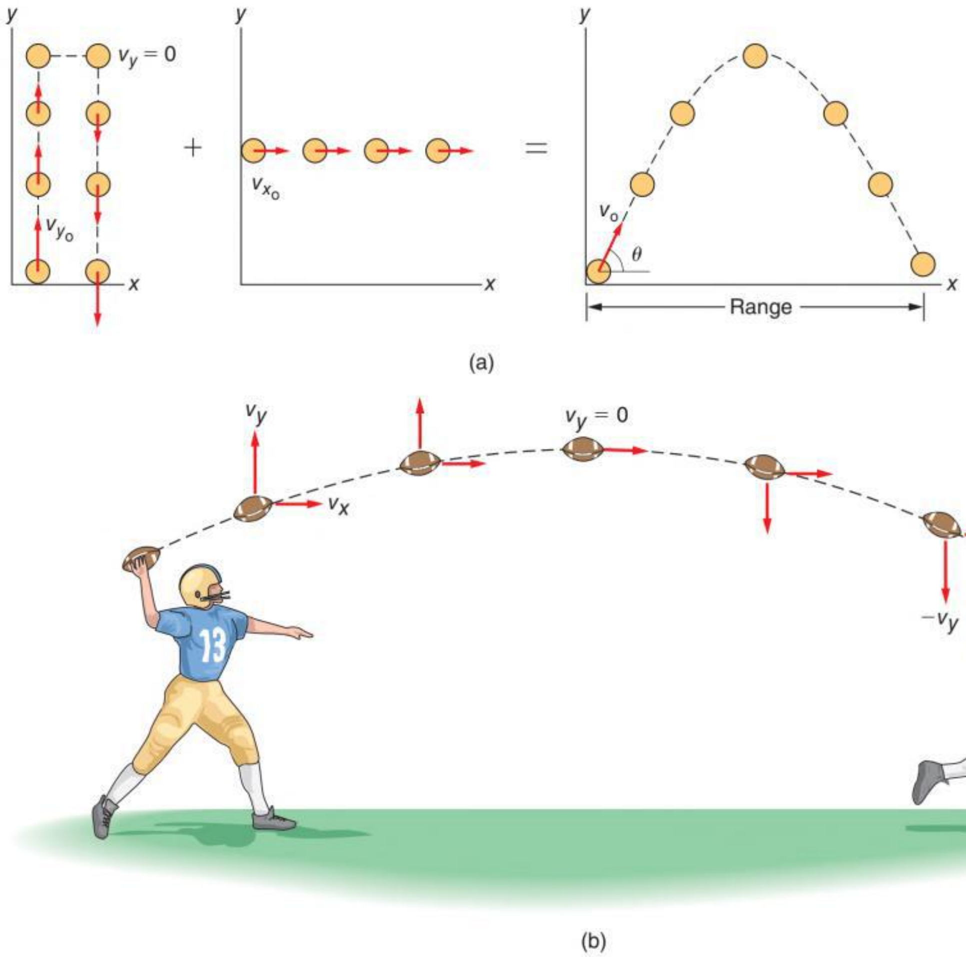


Figure 2.15 Projectile Motion (a) The curved path of a projectile is a result of the combined motions in the vertical and horizontal directions. As the ball goes up and down, it travels to the right. The combined effect is a curved path. (b) Neglecting air resistance, the projected football has the same horizontal velocity (v_x) throughout its flight, but its vertical velocity (v_y) changes in the same way as that of an object thrown upward.

The multiflash photo in Fig. 2.14b shows a dropped ball and one projected horizontally at the same time. Notice that the balls fall vertically together as the projected ball moves to the right. Neglecting air resistance, a horizontally projected object essentially travels in a horizontal direction with a constant velocity (no acceleration in that direction) while falling vertically under the influence of gravity. The resulting path is a curved arc, as shown in Fig. 2.14. Occasionally, a sports announcer may say that a hard-throwing quarterback throws a football in a straight-line pass. But this statement, of course, is not true. All objects thrown horizontally begin to fall as soon as they leave the thrower's hand.

If an object is projected at an angle θ (lowercase Greek theta) to the horizontal, then it will follow a symmetric curved path, as illustrated in ● Fig. 2.15, where air resistance is again neglected. The curved path is essentially the result of the combined motions in the vertical and horizontal directions. The projectile goes up and down vertically while at the same time traveling horizontally with a constant velocity.

Conceptual Question and Answer 2.3

Hanging in There

Q. When a basketball player drives in and jumps to shoot for a goal (or "slam dunk"), he seems to momentarily "hang in the air" (● Fig. 2.16). Why?

A. When running and jumping for the shot, the player is in near projectile motion. Notice in Fig. 2.15 that the velocity is small for the vertical motion near the maximum height, decreasing to zero and then increasing slowly downward. During this time, the combination of the slow vertical motions and the constant horizontal motion gives the illusion of the player "hanging" in midair.

Rocky Widner/National Basketball Association/Getty Images

Figure 2.16 Hanging in There Jason Richardson seems to "hang" in the air at the top of his "projectile" jump path. (See text for description.)

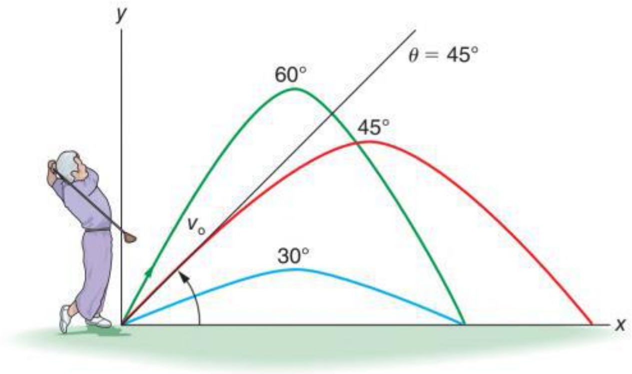


Figure 2.17 **Maximum Range** A projectile's maximum range on a horizontal plane is achieved with a projection angle of 45° (in the absence of air resistance). Projectiles with the same initial speed and projection angles the same amount above and below 45° have the same range, as shown here for 30° and 60°.

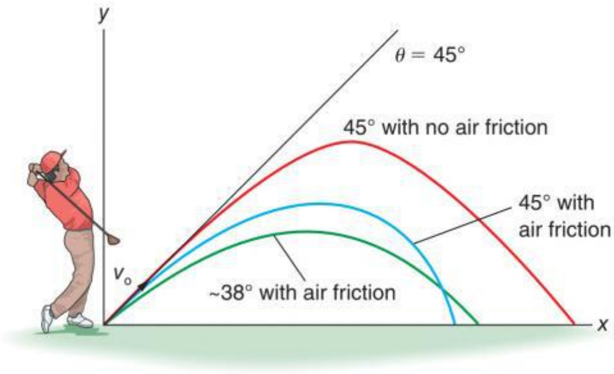


Figure 2.18 **Effects of Air Resistance on Projectiles** Long football passes, hard-hit baseballs, and driven golf balls follow trajectories similar to those shown here. Frictional air resistance reduces the range.

Figure 2.19 **Going for the Distance** Because of air resistance, the athlete hurls the javelin at an angle of less than 45° for maximum range.

John Cumming/Digital Vision/Jupiter Images

When a ball or other object is thrown or hit, the path that it takes depends on the projection angle. Neglecting air resistance, each path will resemble one of those in ● Fig. 2.17. As shown, the *range*, or horizontal distance the object travels, is maximum when the object is projected at an angle of 45° relative to level ground. Notice in the figure that for a given initial speed, projections at complementary angles (angles that add up to 90°)—for example, 30° and 60°—have the same range as long as there is no air resistance.

With little or no air resistance, projectiles have symmetric paths, but when a ball or object is thrown or hit hard, air resistance comes into effect. In such a case, the projectile path is no longer symmetric and resembles one of those shown in ● Fig. 2.18. Air resistance reduces the velocity of the projectile, particularly in the horizontal direction. As a result, the maximum range occurs at an angle less than 45°.

Athletes such as football quarterbacks and baseball players are aware of the best angle at which to throw to get the maximum distance. A good golfing drive also depends on the angle at which the ball is hit. Of course, in most of these instances there are other considerations, such as spin. The angle of throw is also a consideration in track and field events such as discus and javelin throwing. ● Figure 2.19 shows an athlete hurling a javelin at an angle of less than 45° in order to achieve the maximum distance.

Did You Learn?

- A horizontally projected ball and another ball dropped from the same height have the same downward motion because the vertical acceleration (g) is the same (neglecting air resistance).
- The range of a projectile depends on the initial velocity and angle of projection (neglecting air resistance).

KEY TERMS

1. physics (intro)
2. position (2.1)
3. motion
4. scalar (2.2)
5. vector
6. average speed
7. distance
8. instantaneous speed
9. average velocity
10. displacement
11. instantaneous velocity
12. acceleration (2.3)
13. average acceleration
14. acceleration due to gravity
15. free fall
16. terminal velocity
17. centripetal acceleration (2.4)
18. projectile motion (2.5)

MATCHING

For each of the following items, fill in the number of the appropriate Key Term from the provided list. Compare your answers with those at the back of the book.

a. _____ 9.8 m/s^2
b. _____ The location of an object
c. _____ A continuous change of position
d. _____ Time rate of change of velocity
e. _____ Zero acceleration in free fall
f. _____ Difference between final and initial velocities divided by time
g. _____ The most fundamental of the physical sciences
h. _____ Distance traveled/travel time
i. _____ Straight-line directed distance
j. _____ Actual path length
k. _____ Directed toward the center of circular motion
l. _____ Velocity at an instant of time
m. _____ Has magnitude and direction
n. _____ Motion solely under the influence of gravity
o. _____ Motion of a thrown object
p. _____ Speed at an instant of time
q. _____ Displacement/travel time
r. _____ Has magnitude only

MULTIPLE CHOICE

Compare your answers with those at the back of the book.

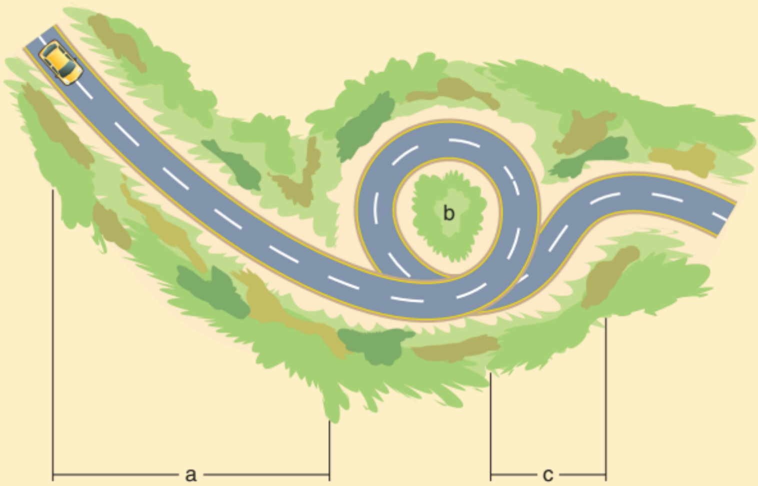
1. What is necessary to designate a position? (2.1)
   (a) a reference point (b) motion
   (c) a direction (d) time
2. Which one of the following describes an object in motion? (2.1)
   (a) A period of time has passed.
   (b) Its position is known.
   (c) It is continuously changing position.
   (d) It has reached its final position.
3. Which one of the following is always true about the magnitude of a displacement? (2.2)
   (a) It is greater than the distance traveled.
   (b) It is equal to the distance traveled.
   (c) It is less than the distance traveled.
   (d) It is less than or equal to the distance traveled.
4. Which is true of an object with constant velocity? (2.4)
   (a) It has constant speed.
   (b) It has constant direction.
   (c) It travels equal distances in equal times.
   (d) All of the preceding.
5. Acceleration may result from what? (2.5)
   (a) an increase in speed
   (b) a decrease in speed
   (c) a change in direction
   (d) all of the preceding
6. For a constant linear acceleration, what changes uniformly? (2.3)
   (a) velocity (b) acceleration
   (c) distance (d) displacement

2.5 Projectile Motion

17. For projectile motion, name two quantities that are constant. (Neglect air resistance.)
18. Can a baseball pitcher throw a fastball in a straight, horizontal line? Why or why not?
19. How do the ranges of horizontal projections with the same initial speed compare on the Earth and on the Moon?
20. On what does the range of a projectile depend?
21. Figure 2.14(b) shows a multiflash photograph of one ball dropped from rest and, at the same time, another ball projected horizontally from the same height. The two hit the floor at the same time. Explain.
22. Taking into account air resistance, how do you throw a ball to get the maximum range? Why?

VISUAL CONNECTION

Visualize the connections and give the descriptive motion answers in the blanks and describe the speed, velocity, and acceleration for parts a, b, and c (that is, increasing, decreasing, or constant). Compare your answers with those at the back of the book.



a. ___
b. ___
c. ___

APPLYING YOUR KNOWLEDGE

1. Do highway speed limit signs refer to average speeds or to instantaneous speeds? Explain.
2. (a) If we are moving at a high speed as the Earth revolves about the Sun (18.5 m/s, Example 2.3), then why don't we generally feel this motion? (b) Similarly, we are traveling through space because of the Earth's rotation (1000 mi/h at the equator, Confidence Exercise 2.3). (c) We don't generally feel this motion either, but we do easily sense it otherwise. How?
3. Is an object projected vertically upward in free fall? Explain.
4. What is the direction of the acceleration vector of a person on the spinning Earth if the person is (a) at the equator? (b) at some other latitude? (c) at the poles?
5. A student sees her physical science professor approaching on the sidewalk that runs by her dorm. She gets a water balloon and waits. When the professor is 2.0 s from being directly under her window 11 m above the sidewalk, she drops the balloon. You finish the story.
6. How would (a) an updraft affect a skydiver in reaching terminal velocity? (b) a downdraft?
7. In Example 2.5, it takes a ball 1.50 s to vertically fall 11.0 m. What if the ball is thrown horizontally with a speed of 5.0 m/s at the top of a 11.0-m tall building? How long would it take for the ball to hit the ground?
8. In ● Fig. 2.20, what is the centripetal acceleration of the lasso?

8. A jogger jogs from one end to the other of a straight track in 2.50 min and then back to the starting point in 3.20 min. What is the jogger's average speed
   (a) in jogging to the far end of the track,
   (b) coming back to the starting point, and
   (c) for the total jog?
9. An airplane flying directly eastward at a constant speed travels 300 km in 2.0 h.
   (a) What is the average velocity of the plane?
   (b) What is its instantaneous velocity?
10. A race car traveling northward on a straight, level track at a constant speed travels 0.750 km in 20.0 s. The return trip over the same track is made in 25.0 s.
   (a) What is the average velocity of the car in m/s for the first leg of the run?
   (b) What is the average velocity for the total trip?

2.3 Acceleration

11. A sprinter starting from rest on a straight, level track is able to achieve a speed of 12 m/s in 6.0 s. What is the sprinter's average acceleration?
12. Modern oil tankers weigh more than a half-million tons and have lengths of up to one-fourth mile. Such massive ships require a distance of 5.0 km (about 3.0 mi) and a time of 20 min to come to a stop from a top speed of 30 km/h.
   (a) What is the magnitude of such a ship's average acceleration in m/s^2 in coming to a stop?
   (b) What is the magnitude of the ship's average velocity in m/s? Comment on the potential of a tanker running aground.
13. A motorboat starting from rest travels in a straight line on a lake.
   (a) If the boat achieves a speed of 8.0 m/s in 10 s, what is the boat's average acceleration?
   (b) If the boat continues with the same acceleration, what would be its speed after another 5.0 s?
14. A car travels on a straight, level road.
   (a) Starting from rest, the car is going 44 ft/s (30 mi/h) at the end of 5.0 s. What is the car's average acceleration in ft/s^2?
   (b) In 4.0 more seconds, the car is going 88 ft/s (60 mi/h). What is the car's average acceleration for this time period?
   (c) The car then slows to 66 ft/s (45 mi/h) in 3.0 s. What is the average acceleration for this time period?
   (d) What is the overall average acceleration for the total time? (Note these convenient British unit conversions: 60 mi/h = 88 ft/s, 45 mi/h = 66 ft/s, and 30 mi/h = 44 ft/s.)
15. The US currency bill is exactly 6.14 in. long. Your friend teases you and holds a $100 bill vertically, just above your fingers, and says you can keep it, if you can catch the bill when dropped (● Fig. 2.22). How much time do you have from your friend dropping the bill and your fingers trying to catch the bill? (You can never catch it. It's really hard! Try it.)
16. What is the speed of the dropped $100 bill in Exercise 15, after it has fallen its length?
17. Figure 1.18 (Chapter 1) shows the Hoover Dam Bridge over the Colorado River at a height of 274 m. If a heavy object is dropped from the bridge, how much time passes before the object makes a splash?
18. A spaceship hovering over the surface of Mars drops an object from a height of 30 m. How much longer does it take to reach the surface than if dropped from the same height on Earth? Neglect air resistance in both cases. [The acceleration due to gravity on Mars is 33% of that on Earth, $g_{mars} = (0.33)g$.]

2.4 Acceleration in Uniform Circular Motion

19. A race car goes around a circular, level track with a diameter of 1.00 km at a constant speed of 90.0 km/h. What is the car's centripetal acceleration in m/s^2?
20. A person drives a car around a circular, level cloverleaf with a radius of 70 m at a uniform speed of 10 m/s.
   (a) What is the acceleration of the car?
   (b) Compare this answer with the acceleration due to gravity as a percentage. Would you be able to sense the car's acceleration if you were riding in it?

2.5 Projectile Motion

21. If you throw a baseball horizontally with an initial speed of 30 m/s from a height of 2.0 m, how long will it take the ball to hit the ground?
22. A golfer on a level fairway hits a ball at an angle of 42° to the horizontal that travels 100 yd before striking the ground. He then hits another ball from the same spot with the same speed, but at a different angle. This ball also travels 100 yd. At what angle was the second ball hit? (Neglect air resistance.)


Mark Scheuern/Alamy Stock Photo

Figure 2.22 Catch that $100 bill! See Exercise 15.

CHAPTER

3

Force and Motion

The whole burden of philosophy seems to consist of this—from the phenomena of motions to investigate the forces of nature, and from these forces to explain the other phenomena. [Physics was once called natural philosophy.]

•

Sir Isaac Newton
(1642–1727)

Syracuse Newspapers/The Image Works

A force is needed to produce > a change in motion, as the pusher well knows.

Chapter Outline

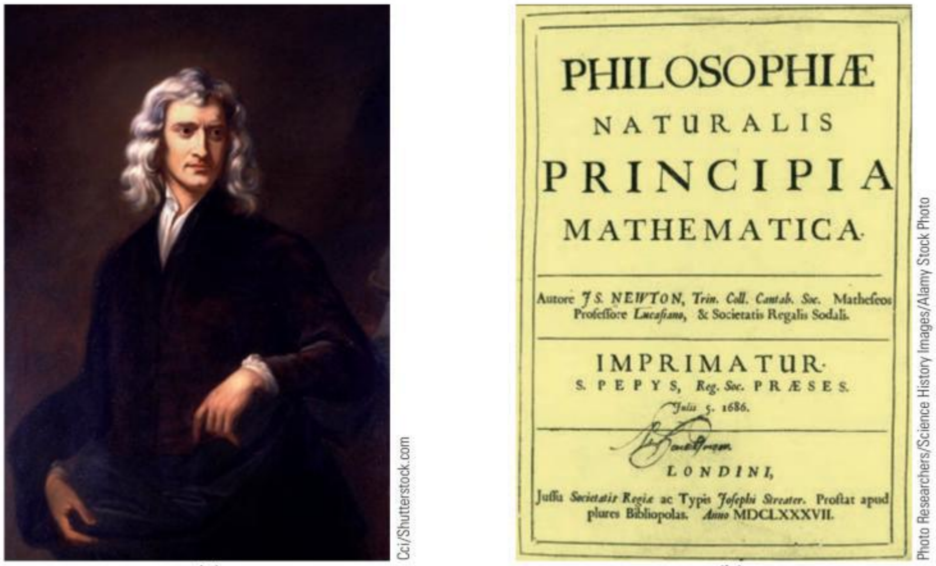
3.1 Force and Net Force 53
3.2 Newton's First Law of Motion 54
Conceptual Q&A 3.1 You Go Your Way, I'll Go Mine 56
3.3 Newton's Second Law of Motion 57
Conceptual Q&A 3.2 Fundamental Is Fundamental 60
3.4 Newton's Third Law of Motion 62
Highlight 3.1 The Automobile Air Bag 64
3.5 Newton's Law of Gravitation 65
Conceptual Q&A 3.3 A Lot of Mass 66
3.6 Archimedes' Principle and Buoyancy 68
Conceptual Q&A 3.4 Float the Boat 69
3.7 Momentum 69

Did You Know?	Section
Forces always occur in pairs.	3.4
You can't escape gravity.	3.5
Generally, humans can float in water. The amount of air in the lungs (volume) could make a difference.	3.6

In Chapter 2 the description of motion was discussed but not the cause of motion. What, then, causes motion? You might say a push causes something to start moving or to speed up or slow down, but in more scientific terms, the push is the application of a *force*. In this chapter we will go one step further and study force *and* motion. The discussion will consider Newton's three laws of motion, his law of universal gravitation, and later the laws of conservation of linear and angular momentum, making it a very legal sounding chapter with all these laws. In section 3.6 buoyant force is considered. Will an object float or sink?

During the sixteenth and seventeenth centuries, a "scientific revolution" occurred. The theories of motion, which were handed down from the Greeks for almost 2000 years, were reexamined and changed. Galileo Galilei (1564–1642) was one of the first scientists to experiment on moving objects.* It remained for Sir Isaac Newton, who was born the year Galileo died, to devise the laws of motion and explain the phenomena of moving objects on the Earth and the motions of planets and other celestial bodies.

*See Highlight 2.1.



(a) (b)

Figure 3.1 The Man and the Book (a) Sir Isaac Newton (1642–1727). (b) The title page from the *Principia*. Can you read the Roman numerals at the bottom of the page that give the year of publication?

PHYSICS FACTS

- The term *inertia* comes from the Latin *inertia*, meaning "idleness."
- Newton coined the word *gravity* from *gravitas*, the Latin word for "weight" or "heaviness."
- Astronomer Edmund Halley (name rhymes with valley) used Newton's work on gravitation and orbits to predict that a comet he had observed in 1682 would return in 1758. The comet returned as predicted and was named Comet Halley in his honor. Halley did not discover the comet. Its periodic appearance had been recorded since 263 BCE when it was first seen by Chinese astronomers. Halley died in 1742 and did not get to see the return of his comet.

Newton was only 25 years old when he formulated most of his discoveries in mathematics and mechanics. His book *Mathematical Principles of Natural Philosophy* (commonly referred to as the *Principia*) was published in Latin in 1687 when he was 45. It is considered by many to be the most important publication in the history of physics and certainly established Newton as one of the greatest scientists of all time. (See ● Fig. 3.1.)

3.1 Force and Net Force

Key Questions

- Does a force always produce motion?
- What is the condition for motion when more than one force acts?

First let's look at the meaning of force. It is easy to give examples of forces, but how would you define a force? A force is defined in terms of what it does, and as you know from experience, a force can produce changes in motion. A force can set a stationary object into motion. It can also speed up or slow down a moving object, or it can change the direction of the motion. In other words, a force can produce a *change in velocity* (speed and/or direction) or an *acceleration*. Therefore, an observed change in motion, including motion starting from rest, is evidence of a force, which leads to the following definition: *A* **force** *is a vector quantity capable of producing motion or a change in motion, that is, a change in velocity or an acceleration* (Chapter 2.3).

The word *capable* here is significant. A force may act on an object, but its capability to produce a change in motion may be balanced or canceled by one or more other forces. The net effect is then zero. Thus, a force does not *necessarily* produce a change in motion. It follows, though, that if a force acts *alone*, then the object on which it acts will exhibit a change in velocity, or an acceleration.

To take into account the application of more than one force on an object, we speak of an **unbalanced** or **net force**. To understand the difference between balanced and unbalanced forces, consider the tug of war shown in ● Fig. 3.2a. Forces are applied,

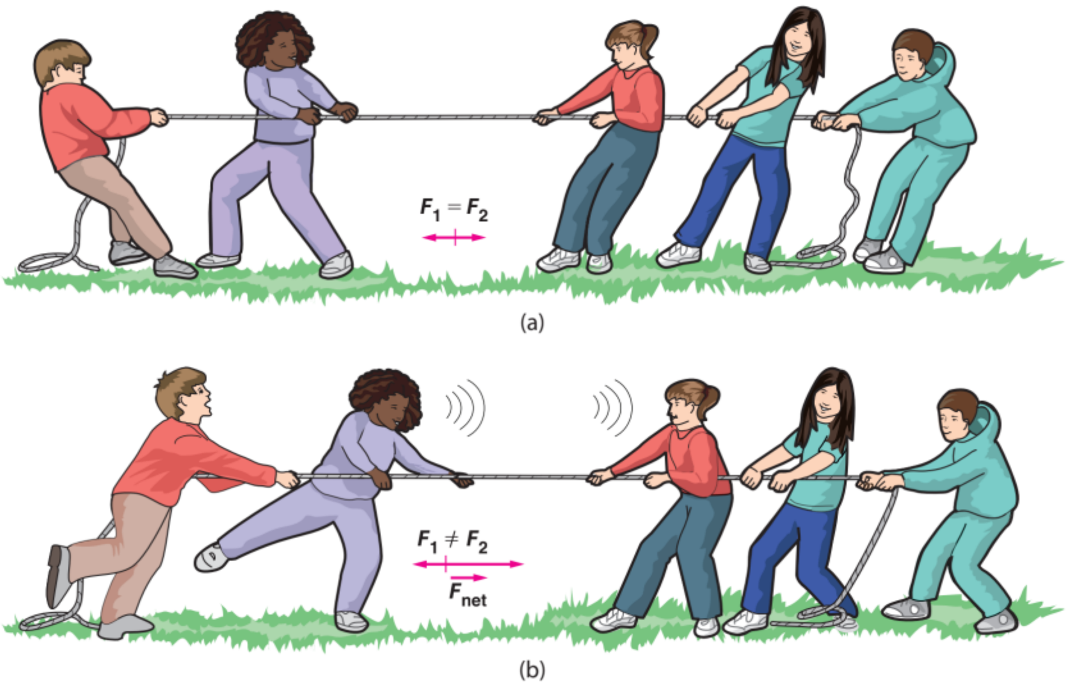


Figure 3.2 Balanced and Unbalanced Forces (a) When two applied forces are equal in magnitude and acting in opposite directions, they are said to be *balanced*, and there is no net force and no motion if the system is initially at rest. (b) When F_2 is greater than F_1, there is an *unbalanced*, or net, force to the right, and motion occurs.

but there is no motion. The forces in this case are balanced; they are equal in magnitude and opposite in direction. In effect, the forces cancel each other, and the net force is zero because the forces are "balanced." In Fig. 3.2b, motion occurs when the forces are *unbalanced*, when they are not equal and there is a *net* force F_{net} to the right.

Because forces have directions as well as magnitudes, they are *vector* quantities. Several forces may act on an object, but for there to be a change in velocity or for an acceleration to occur, there must be an unbalanced, or net, force. With this understanding, let's next take a look at both force and motion.

Did You Learn?

- A single or net applied force can produce an acceleration.
- When more than one force acts, a net or unbalanced force is needed to produce a change in velocity or an acceleration.

3.2 Newton's First Law of Motion

Key Questions

- If you were moving with a constant velocity in deep space, how far would you travel?
- How can the inertias of objects be compared?

Long before the time of Galileo and Newton, scientists had asked themselves, "What is the natural state of motion?" The early Greek scientist Aristotle had presented a theory that prevailed for almost 20 centuries after his death. According to this theory, an object required a force in order to remain in motion. The natural state of an object was one of rest, with the exception of celestial bodies, which were naturally in motion. It is easily

(a) (b)

Figure 3.4 Mass and Inertia (a) An external, applied force is necessary to set an object in motion. The man has more mass and more inertia than the child and hence has more resistance to motion. (b) Because of inertia, it is possible to remove the paper strip from beneath the stack of quarters without toppling it, by giving the paper a quick jerk. Try it.

them swinging and then tried to stop their motions, you would notice a difference in the resistance to a change in motion again. Being more massive, the man has greater inertia and a greater resistance to a change in motion.*

Another example of inertia is shown in Fig. 3.4b. The stack of coins has inertia and resists being moved when at rest. If the paper is jerked quickly, then the inertia of the coins will prevent them from toppling. You may have pulled a magazine from the bottom of a stack with a similar action.

Because of the relationship between motion and inertia, Newton's first law is sometimes called the *law of inertia*. This law can be used to describe some of the observed effects in everyday life. For example, suppose you were in the front seat of a car traveling at a high speed down a straight road and the driver suddenly put on the brakes for an emergency stop. What would happen, according to Newton's first law, if you were not wearing a seat belt? The friction on the seat of your pants would not be enough to change your motion appreciably, so you'd keep on moving while the car was coming to a stop. The next external, unbalanced force you might experience would not be pleasant. Newton's first law makes a good case for buckling up.

Conceptual Question and Answer 3.1

You Go Your Way, I'll Go Mine

Q. An air-bubble level on a surface, as illustrated in ● Fig. 3.5, is given an applied horizontal force toward the left. Which way does the bubble move?

A. Some might say the bubble stays behind and "moves" to the right, but it actually moves to the left in the direction of the force. The incorrect answer arises because we are used to observing the bubble instead of the liquid. The bubble is chiefly air, which has little mass or inertia, and readily moves. The correct answer is explained by Newton's first law. Because of inertia, the liquid resists motion and "piles up" toward the rear of the level, forcing the bubble forward. Think about giving a stationary pan full of water on a table a push. What happens to the water?

*A suggested inertia example: When you enter a supermarket with an empty shopping cart, the cart is easy to maneuver, but when you leave with a full cart (more mass and inertia), making changes in motion (speed and direction) requires much greater effort. (Courtesy of Dr. Philip Blanco, Grossmont College.)

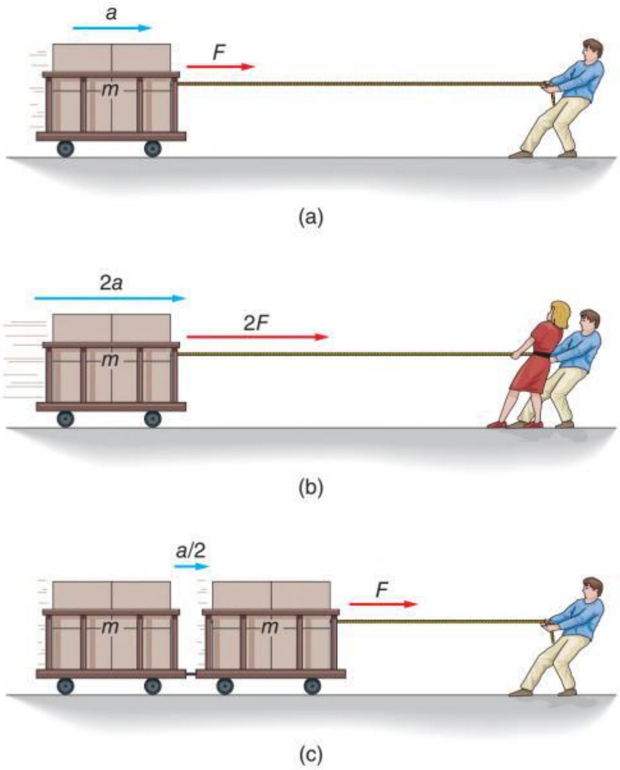


Figure 3.6 Force, Mass, and Acceleration (a) An unbalanced force *F* acting on a mass *m* produces an acceleration *a*. (b) If the mass remains the same and the force is doubled, then the acceleration is doubled. (c) If the mass is doubled and the force remains the same, then the acceleration is reduced by one-half. The friction of the cars is neglected in all cases.

These relationships are illustrated in ● Fig. 3.6. Note that if the force acting on a mass is doubled, then the acceleration doubles (direct proportion, $a \propto F$). However, if the same force is applied to twice as much mass, the acceleration is one-half as great (inverse proportion, $a \propto 1/m$).

Notice from Fig. 3.6 that the mass *m* is the *total* mass of the system or all the mass that is accelerated. A system may be two or more separate masses, as will be seen in Example 3.1. Also, *F* is the net, or unbalanced, force, which may be the vector sum of two or more forces. Unless otherwise stated, a general reference to force means an *unbalanced* force.

In the SI metric system, the unit of force is appropriately called the **newton** (abbreviated N). This is a derived unit. The standard unit equivalent may be seen from Eq. 3.1 by putting it in standard units: force = mass × acceleration = $\text{kg} \times \text{m/s}^2 = \text{kg} \cdot \text{m/s}^2 = \text{N}$.

In the British system, the unit of force is the *pound* (lb). This unit also has derived units of mass multiplied by acceleration (ft/s^2). The unit of mass is the *slug*, which is rarely used and will not be employed in this textbook. Recall that the British system is a gravitational or force system and that in this system, objects are weighed in pounds (force). As will be seen shortly, *weight* is a force and is expressed in newtons (N) in the SI and in pounds (lb) in the British system. If you are familiar with the story that Newton gained insight by observing (or being struck by) a falling apple while meditating on the concept of gravity, it is easy to remember that an average-size apple weighs about 1 newton (● Fig. 3.7).

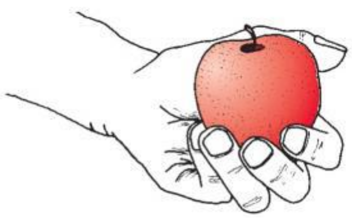


Figure 3.7 About a Newton An average-size apple weighs about 1 newton (or 0.225 lb).

Example 3.1 uses $F = ma$ to illustrate that *F* is the unbalanced or net force and *m* is the total mass.

EXAMPLE 3.1 Finding Acceleration with Two Applied Forces

Forces are applied to blocks connected by a string and resting on a frictionless surface, as illustrated in ● Fig. 3.8. If the mass of each block is 1.0 kg and the mass of the string is negligible, then what is the acceleration of the system?

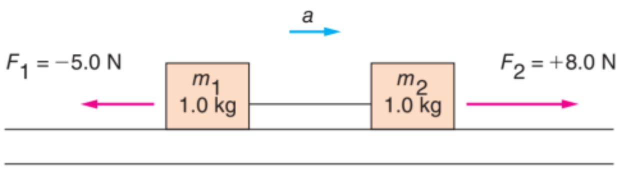


Figure 3.8 ***F*** = ***ma*** Net force and total mass. (See Example 3.1.)

Thinking It Through

Note in the figure that the forces act in opposite directions. Hence in Newton's second law, $a = F/m$, the force F would be the vector sum or net force, $F_{net} = F_2 + F_1$, where force directions are indicated by + and − signs as given in the figure. Effectively, F_1 cancels part of F_2. The total mass of the system being accelerated is $m_1 + m_2$.

F_1 = negative 5 N pulls m_1 to the left. F_2 = 8 N pulls m_2 to the right.

Solution

Step 1 *Given:* $m_1 = 1.0$ kg, $F_1 = -5.0$ N (left, negative direction)
$m_2 = 1.0$ kg, $F_2 = +8.0$ N (right, positive direction)

Step 2 *Wanted*: a (acceleration)
(The units are standard in the metric system.)

Step 3 The acceleration may be calculated using Eq. 3.1, $F = ma$, or $a = F/m$. Note, however, that F is the unbalanced (net) force, and $F_{net} = F_2 + F_1 = 8.0\text{ N} - 5.0\text{ N}$ in the direction of F_2. The total mass of the system being accelerated is $m = m_1 + m_2$. Hence, we have an acceleration in the direction of the net force (to the right).

$$a = \frac{F}{m} = \frac{F_{net}}{m_1 + m_2} = \frac{8.0\text{ N} - 5.0\text{ N}}{1.0\text{ kg} + 1.0\text{ kg}} = \frac{3.0\text{ N}}{2.0\text{ kg}} = 1.5\text{ m/s}^2$$

Question: What would be the case if the surface were not frictionless?
Answer: There would be another (frictional) force in the direction of F_1 opposing the motion.

Confidence Exercise 3.1

Given the same conditions as in Example 3.1, suppose $F_1 = -9.0$ N and $F_2 = 6.0$ N in magnitude. What would be the acceleration of the system in this case?

The answers to Confidence Exercises may be found at the back of the book.

Because Newton's second law is so general, it can be used to analyze many situations. A dynamic example is *centripetal force*. Recall from Chapter 2.4 that the centripetal acceleration for uniform circular motion is given *by* $a_c = v^2/r$ (Eq. 2.5). The magnitude of the centripetal force that supplies such an acceleration is given by Newton's second law, $F = ma_c = mv^2/r$.

Mass and Weight

This is a good place to make a clear distinction between mass and weight. As learned previously, **mass** *is the amount of matter an object contains (and a measure of inertia).* **Weight** *is related to the force of gravity (that is, related to the gravitational force acting on a mass or object).* The quantities are related, and Newton's second law clearly shows this relationship.

On the surface of the Earth, where the acceleration due to gravity is relatively constant ($g = 9.80$ m/s²), the weight w on an object with a mass m is given by

$$\text{weight} = \text{mass} \times \text{acceleration due to gravity}$$
$$w = mg \qquad 3.2$$

Note that this equation is a special case of $F = ma$ where different symbols, w and g, have been used for force and acceleration.

Conceptual Question and Answer 3.2

Fundamental Is Fundamental

Q. Is weight a fundamental quantity?

A. No, and here's why. A fundamental quantity is constant or has the same value no matter where it is measured. In general, a physical object always has the same amount of matter, so it has a constant mass. The weight of an object, on the other hand, may differ, depending on the value of the acceleration due to gravity, g.

For example, on the surface of the Moon, the acceleration due to gravity (g_M) is one-sixth the acceleration due to gravity on the surface of the Earth [$g_M = g/6 = (9.8\ \text{m/s}^2)/6 = 1.6\ \text{m/s}^2$], because of the Moon's mass and size. (See section 3.5.) Thus, an object will have the *same* mass on the Moon as on the Earth, but its weight will be *different*. Mass, not weight, is the fundamental quantity. (See Fig. 1.8.)

EXAMPLE 3.2 Computing Weight

What is the weight (in newtons) of a 1.0-kg mass on
(a) the Earth and
(b) the Moon?

Thinking It Through

This is a direct application of Eq. 3.2. But, as pointed out in the previous 3.2 Conceptual Question and Answer, the acceleration due to gravity on the Moon is different than that on the Earth.

Solution

(a) Using Eq. 3.2 and the Earth's $g = 9.8\ \text{m/s}^2$,

$$w = mg = (1.0\ \text{kg})(9.8\ \text{m/s}^2) = 9.8\ \text{N}$$

(b) On the Moon, where $g_M = g/6 = 1.6\ \text{m/s}^2$,

$$w = mg_M = (1.0\ \text{kg})(1.6\ \text{m/s}^2) = 1.6\ \text{N}$$

Although the mass is the same in both cases, the weights are different because of different g's.

Confidence Exercise 3.2

On the surface of Mars, the acceleration due to gravity is 0.39 times that on the Earth. What would a kilogram weigh in newtons on Mars?

The answers to Confidence Exercises may be found at the back of the book.

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Figure 3.9 Mass and Weight
Here an unknown mass is suspended from a scale calibrated in newtons. With a reading of 19.6 N, what is the suspended mass in kilograms? (*Hint:* $m = w/g$. For an easy approximation, take $g \approx 10\ \text{m/s}^2$.)

An unknown mass or object may be "weighed" on a scale. The scale can be calibrated in mass units (kilograms or grams) or in weight units (newtons or pounds). See ● Fig. 3.9. In Europe, weight is expressed in terms of mass. People "weigh" themselves in kilograms or "kilos."

Finally, an object in free fall has an unbalanced force of $F = w = mg$ acting on it (downward).* Why, then, do objects in free fall all descend at the same rate, as stated in the last chapter? Even Aristotle thought a heavy object would fall faster than a lighter one. Newton's laws explain.

Suppose two objects were in free fall, one having twice the mass of the other, as illustrated in ● Fig. 3.10. According to Newton's second law, the more massive object

*Recall from Chapter 2.3 that an object falling solely under the influence of gravity (no air resistance) is said to be in *free fall*.

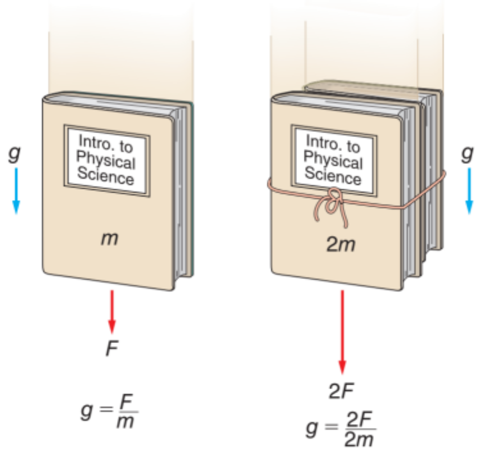

Figure 3.10 Acceleration Due to Gravity The acceleration due to gravity is independent of the mass of a freely falling object. Thus, the acceleration is the same for all such falling objects. An object with two times the mass of another has twice the gravitational force acting on it, but it also has twice the inertia and so falls at the same rate.

would have two times the weight, or gravitational force of attraction. By Newton's first law, however, the more massive object has twice the inertia, so it needs *twice the force to fall at the same rate*.

Friction

The force of friction is commonplace in our everyday lives. Without it, we would not be able to walk (our feet would slip), pick things up, and so on. **Friction** *is the ever-present resistance to relative motion that occurs whenever two materials are in contact with each other, whether they are solids, liquids, or gases.* In some instances, we want to increase friction by, for example, putting sand on an icy road or sidewalk to improve traction. In other instances, it is desired to reduce friction. Moving machine parts are lubricated to allow them to move freely, thereby reducing wear and the expenditure of energy. Automobiles would not run without friction-reducing oils and greases. With friction, energy is generally lost in the form of heat.

This section is concerned with friction between solid surfaces. (Air friction or resistance was discussed in Chapter 2.3.) All surfaces, no matter how smooth they appear or feel, are microscopically rough. It was originally thought that friction between solids arose from an interlocking of surface irregularities, or high and low spots, but research has shown that friction between contacting surfaces (particularly metals) is due to local adhesion. When surfaces are pressed together, local bonding or welding occurs in a few small patches. To overcome this local adhesion, a force great enough to pull apart the bonded regions must be applied.

Friction is characterized by a force of friction that opposes an applied force. Between solid surfaces, friction is generally classified into two types: static friction and sliding (or kinetic) friction.*

Static friction occurs when the frictional force is sufficient to prevent relative motion between surfaces. Suppose you want to slide a filing cabinet across the floor. You push on it, but it doesn't move. The force of static friction between the bottom of the cabinet and the floor is opposite and at least equal to your applied force, so there is no motion; it is a static condition.

To get the job done, you push harder, but still the cabinet does not move. This indicates that the static frictional force increased when you increased the applied force. Increasing the applied force even more, you finally get the cabinet moving, but there is still a great deal of resistance—called kinetic friction—between the cabinet bottom and the floor. *Kinetic (or sliding) friction* occurs when there is a relative sliding motion between the surfaces in contact. You may notice that it is easier to keep the cabinet sliding than it is to get it moving. This is because sliding friction is generally less than the maximum static friction.

*There is also rolling friction, such as occurs between a train wheel and a rail. This type of friction is difficult to analyze and will not be discussed here.

A more descriptive statement would be the following:

Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first object.

Expressed in equation form, Newton's third law may be written as

$$\text{action} = \text{opposite reaction}$$
$$F_1 = -F_2 \qquad 3.3$$

where

F_1 = force exerted on object 1 by object 2
$-F_2$ = force exerted on object 2 by object 1

The negative sign in Eq. 3.3 indicates that F_2 is in the opposite direction from F_1.

Jet propulsion is an example of Newton's third law. In the case of a rocket, the exhaust gas is accelerated from the rocket, and the rocket accelerates in the opposite direction (● Fig. 3.11a). A common misconception is that on launch the exhaust gas pushes against the launch pad to accelerate the rocket. If this were true, then there would be no space travel because there is nothing to push against in space. The correct explanation is one of action (gas being forced backward by the rocket) and reaction (the rocket being propelled forward by the escaping gas). The gas (or gas particles) exerts a force on the rocket, and the rocket exerts a force on the gas. The equal and opposite actions of Newton's third law should be evident in Fig. 3.11b.

Let's take a look at the third law in terms of the second law ($F = ma$). Writing Eq. 3.3 in the form

$$F_1 = -F_2$$

or

$$m_1a_1 = -m_2a_2$$

shows that if m_2 is much greater than m_1, then a_1 is much greater than a_2.

Consider dropping a book on the floor. As the book falls, it has a force acting on it (the Earth's gravity) that causes it to accelerate. What is the equal and opposite force? It is the force of the book's gravitational attraction on the Earth. Technically, the Earth accelerates upward to meet the book. However, because our planet's mass is so huge compared with the book's mass, the Earth's acceleration is so minuscule it cannot be detected.

An important distinction to keep in mind is that *Newton's third law relates two equal and opposite forces that act on two* separate *objects. Newton's second law concerns how forces acting on a* single *object cause an acceleration.* If two forces acting on a single object are equal and opposite, there will be no net force and no acceleration, but these forces are *not* the third-law force pair. (Why?)

Let's look at one more example that illustrates the application of Newton's laws. Imagine that you are a passenger in a car traveling down a straight road and entering a circular curve at a constant speed. As you know, there must be a centripetal force to provide the centripetal acceleration necessary to negotiate the curve (Chapter 2.4). This force is supplied by friction on the tires, and the magnitude of this frictional force (f) is given by $f = ma_c = mv^2/r$. Should the frictional force not be great enough—say, if you hit an icy spot (reduced friction)—the car would slide outward because the centripetal force would not be great enough to keep the car in a circular path (● Fig. 3.12).

You have, no doubt, experienced a lack of centripetal force when going around a curve in a car and have had a feeling of being "thrown" outward. Riding in the car before entering the curve, you tend to go in a straight line in accordance with Newton's first law. As the car makes the turn, you continue to maintain your straight-line motion until the car turns "into you."

It may feel that you are being thrown outward toward the door, but actually the door is coming toward you because the car is turning, and when the door gets to you, it exerts a force on you that supplies the centripetal force needed to cause you to go


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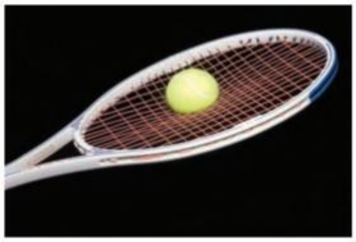
(a)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(b)

Figure 3.11 Newton's Third Law in Action (a) The rocket and exhaust gas exert equal and opposite forces on each other and so are accelerated in opposite directions. (b) The equal and opposite forces are obvious here. Notice the distortion of the racquet strings and the ball.

Did You Learn?

- A reaction is an equal, but opposite, force to an action force.
- The equal and opposite force pair of Newton's third law do not cancel each other as they act on different objects.

3.5 Newton's Law of Gravitation

Key Questions

- What keeps the Moon in orbit around the Earth?
- Are astronauts seen floating in the International Space Station really weightless?

Having gained a basic understanding of forces, let's take a look at a common fundamental force of nature—gravity. Gravity is a fundamental force because we do not know what causes it and can only observe and describe its effects. Gravity is associated with mass and causes the mutual attraction of mass particles.

The law describing the gravitational force of attraction between two particles was formulated by Newton from his studies on planetary motion. Known as **Newton's law of universal gravitation** this law may be stated as follows:

Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Suppose the masses of two particles are designated as m_1 and m_2, and the distance between them is r. Then the statement of the law is written in symbol form as

$$F \propto \frac{m_1 m_2}{r^2}$$

where $\propto$ is a proportionality sign. Notice in the figure that F_1 and F_2 are equal and opposite; they are a mutual interaction *and* a third-law force pair (● Fig. 3.13a).

When an appropriate constant (of proportionality) is inserted, the equation form of Newton's law of universal gravitation is

$$F = \frac{Gm_1 m_2}{r^2} \qquad 3.4$$

where G has a value of $G = 6.67 \times 10^{-11}\ \text{N} \cdot \text{m}^2/\text{kg}^2$ and is called the universal gravitational constant.

The gravitational force between two masses is said to have an infinite range. That is, the only way for the force to approach zero is for the masses to be separated by a distance approaching infinity $r \to \infty$. (You can't escape gravity.)

An object is made up of a lot of point particles, so the gravitational force on an object is the vector sum of all the particle forces. This computation can be quite complicated, but one simple and convenient case is a homogeneous sphere.* In this case, the net force acts as though all the mass were concentrated at the center of the sphere, and the separation distance for the mutual interaction with another object is measured from there. If it is assumed that the Earth, other planets, and the Sun are spheres with uniform mass distributions, then to a reasonable approximation the law of gravitation can be applied to such bodies (Fig. 3.13b).

In using such an approximation, your weight (the gravitational attraction of the Earth on your mass, m) is computed as though all the mass of the Earth, M_E, were concentrated at its center, and the distance between the masses is the radius of the Earth, R_E. That is, $w = mg = GmM_E/R_E^2$ (using Eq. 3.4).

**Homogeneous* means that the mass particles are distributed uniformly throughout the object.

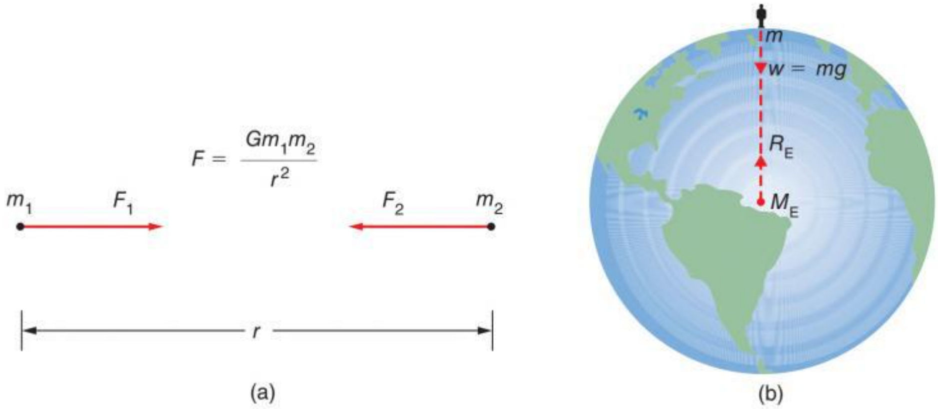


Figure 3.13 Newton's Law of Gravitation (a) Two particles attract each other gravitationally, and the magnitude of the forces is given by Newton's law of gravitation. The forces are equal and opposite: Newton's third-law force pair. (b) For a homogeneous or uniform sphere, the force acts as though all the mass of the sphere were concentrated as a particle at its center.

In Eq. 3.4, as r increases, the force of gravity becomes less. Hence, gravity and the acceleration due to gravity become less with altitude above the Earth.

Conceptual Question and Answer 3.3

A Lot of Mass

Q. If you look in Appendix K, you will find the mass of the Earth is listed as 6.0×10^{24} kg. How could the Earth be "weighed" or "massed"?

A. It would take some big scales, and of course isn't possible. Like many quantities in physics, values are gained indirectly. If you use Eq. 3.4 for your weight (mg) on the surface of the Earth, then you will note that the m's cancel and you are left with $g = GM_E/R^2_E$. With a little mathematical manipulation, the mass of the Earth is given by $M_E = gR_E^2/G$. The values of g, G, and R_E are known. (The circumference of the Earth was measured in the first century BCE, from which the radius R_E was calculated.) So, plug in the numbers and you have the mass of the Earth.

Newton used his law of gravitation and second law of motion to show that gravity supplies the centripetal acceleration and force required for the Moon to move in its nearly circular orbit about the Earth. But the force could not be calculated as he did not know or experimentally measure the value of G. This very small value was measured some 70 years after Newton's death by the English scientist Henry Cavendish, who used a very delicate balance to measure the force between two masses.

When an object is dropped, the force of gravity is made evident by the acceleration of the falling object. But if there is a gravitational force of attraction between every two objects, why don't you feel the attraction between yourself and this textbook? (No pun intended.) Indeed there *is* a force of attraction between you and this textbook, but it is so small that you don't notice it. Gravitational forces can be very small, as illustrated in Example 3.3.

EXAMPLE 3.3 Applying Newton's Law of Gravitation

Two objects with masses of 1.0 kg and 2.0 kg are 1.0 m apart (● Fig. 3.14). What is the magnitude of the gravitational force between these masses?

Thinking It Through

Given the masses and their separation distance, Eq. 3.4 can be used to find the magnitude of the gravitational force.

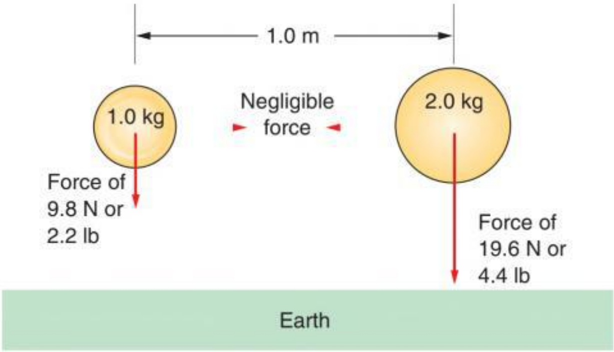


Figure 3.14 The Amount of Mass Makes a Difference A 1.0-kg mass and a 2.0-kg mass separated by a distance of 1.0 m have a negligible mutual gravitational attraction (about 10^{-10} N). However, because the Earth's mass is quite large, the masses are attracted to the Earth with forces of 9.8 N and 19.6 N, respectively. These forces are the weights of the masses.

Solution

The magnitude of the force is given by Eq. 3.4:

$$\begin{aligned} F &= \frac{Gm_1m_2}{r^2} \\ &= \frac{(6.67 \times 10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2)(1.0\,\text{kg})(2.0\,\text{kg})}{(1.0\,\text{m})^2} \\ &= 1.3 \times 10^{-10}\,\text{N} \end{aligned}$$

This number is very, very small. A grain of sand would weigh more. For an appreciable gravitational force to exist between two masses, at least one of the masses must be relatively large.

Confidence Exercise 3.3

If the distance between the two masses in Fig. 3.14 were tripled, by what factor would the mutual gravitational force change? (*Hint:* Use a ratio.)

The answers to Confidence Exercises may be found at the back of the book.

With regard to astronauts in space, we hear the (incorrect) terms *zero g* and *weightlessness*. These terms are not true descriptions. *Microgravity* and *apparent weightlessness* are more applicable terms. Gravity certainly acts on an astronaut in an orbiting spacecraft to provide the necessary centripetal force. Without gravity, the spacecraft (and astronaut) would not remain in orbit but instead would fly off tangentially in a straight line (analogous to swinging a ball on a string about your head and the string breaks). Because gravity is acting, the astronaut by definition has weight (● Fig. 3.15).

The reason an astronaut floats in the spacecraft and feels "weightless" is that the spacecraft and the astronaut are both centripetally "falling" toward the Earth. Imagine yourself in a freely falling elevator standing on a scale. The scale would read zero because it

Figure 3.15 Hold On! Astronauts in a space shuttle orbiting the Earth are said to "float" around because of "zero *g*" or "weightlessness." Actually, the gravitational attraction of objects keeps them in orbit with the spacecraft. Because gravity is acting, by definition an astronaut has weight. Here, astronaut Eileen M. Collins holds on to keep from "floating."

is falling just as fast as you are. You are not weightless, however, and g is not zero, as you would discover upon reaching the bottom of the elevator shaft.

Did You Learn?

- The gravitational attraction between the Earth and the Moon supplies the necessary centripetal force to keep the Moon in its orbit around the Earth.
- By definition, astronauts in an Earth-orbiting spacecraft are not "weightless." Gravity acts on them, so they have weight.

3.6 Archimedes' Principle and Buoyancy

Key Questions

- What is the magnitude of the buoyant force on an object in a fluid?
- What determines if an object will float or sink in water?

Let's take a look at another common force associated with fluids. (Unlike solids, fluids can "flow," so liquids and gases are fluids.) Objects float in fluids because they are buoyant or are buoyed up. For example, if you immerse a cork in water and release it, the cork will be buoyed up to the surface and remain there. From your knowledge of forces, you know that such motion requires an upward net force. For an object to come to the surface, there must be an upward force acting on it that is greater than the downward force of its weight. When the object is floating, these forces must balance each other, and we say the object is in *equilibrium* (zero net force).

The upward force resulting from an object being wholly or partially immersed in a fluid is called the **buoyant force**. The nature of this force is summed up by **Archimedes' principle**:*

An object immersed wholly or partially in a fluid experiences a buoyant force equal in magnitude to the weight of the volume of fluid that is displaced.

We can see from Archimedes' principle that the buoyant force depends on the weight of the volume of fluid displaced. Whether an object will sink or float depends on the density of the object (ρ_o) relative to that of the fluid (ρ_f). There are three conditions to consider:

- An object will float in a fluid if its average density is less than the density of the fluid ($\rho_o < \rho_f$).
- An object will sink if its average density is greater than the density of the fluid ($\rho_o > \rho_f$).
- An object will be in equilibrium at any submerged depth in a fluid if the average density of the object and the density of the fluid are equal ($\rho_o = \rho_f$).

(Average density implies that the object does not have a uniform mass, that is, its mass may be distributed unevenly.) An example of the application of the first condition is shown in ● Fig.3.16.

---

*Archimedes (287–212 BCE), a Greek scholar, has a famous story about a crown. He was given the task of determining whether a gold crown made for the king was pure gold or contained a quantity of silver. Legend has it that the solution came to him when immersing himself in a full bath. On doing so, he noticed that water overflowed the tub. It is said that Archimedes was so excited that he ran home through the streets of the city (unclothed) shouting "Eureka! Eureka!" (Greek for "I have found it!").

To prove his point, quantities of pure gold and silver equal in weight to the king's crown were each put into bowls filled with water, and the silver caused more water overflow. When the crown was tested, more water overflowed than for the pure gold, which implied some silver content. Archimedes' solution to the problem involved density and volume, but it may have gotten him thinking about buoyancy.

Another important quantity in the description of motion is *momentum*. (Newton called it a "quantity of motion.") This term is commonly used; for example, it is said that a sports team has a lot of momentum or has lost its momentum. Let's see what momentum means scientifically. There are two types of momentum: linear and angular.

Linear Momentum

Stopping a speeding bullet is difficult because it has a high velocity. Stopping a slowly moving oil tanker is difficult because it has a large mass. In general, the product of mass and velocity is called **linear momentum**, the magnitude of which is

$$\text{linear momentum} = \text{mass} \times \text{velocity}$$

$$p = mv \tag{3.5}$$

where v is the instantaneous velocity.

Because velocity is a vector, momentum is also a vector with the same direction as the velocity. Both mass and velocity are involved in momentum. A small car and a large truck both traveling at 50 km/h in the same direction have the same velocity, but the truck has more momentum because it has a much larger mass. For a system of masses, the linear momentum of the system is found by adding the linear momentum vectors of all the individual masses.

The linear momentum of a system is important because if there are no external unbalanced forces, then the linear momentum of the system is *conserved;* it does not change with time. In other words, with no unbalanced forces, no acceleration occurs, so there is no change in velocity and no change in momentum. This property makes linear momentum extremely important in analyzing the motion of various systems. The **law of conservation of linear momentum** may be stated as follows:

The total linear momentum of an isolated system remains the same if there is no external, unbalanced force acting on the system.

Even though the internal conditions of a system may change, the vector sum of the momenta remains constant.

$$\text{total final momentum} = \text{total initial momentum}$$

or

$$P_f = P_i$$

where

$$P = p_1 + p_2 + p_3 + \dots \tag{3.6}$$

(sum of individual momentum vectors)

Suppose you are standing in a boat near the shore, and you and the boat are the system (● Fig. 3.18). Let the boat be stationary, so the total linear momentum of the system is zero (no motion for you or the boat, so zero linear momentum). On jumping toward the shore, you will notice immediately that the boat moves in the opposite direction. The boat moves because the force you exerted in jumping is an *internal* force. Thus, the total linear momentum of the system is conserved and must remain zero (water resistance neglected).

The man has momentum in one direction, and to cancel this vectorially so that the total momentum remains zero, the boat must have an equal and opposite momentum. Remember that momentum is a vector quantity, and momentum vectors can add to zero.

which tells us that the momenta are equal and opposite. Then, in terms of mv,

$$m_1 v_1 = -m_2 v_2$$

Solving for v_2 yields

$$v_2 = -\frac{m_1 v_1}{m_2} = -\frac{(1.0 \text{ kg})(1.8 \text{ m/s})}{2.0 \text{ kg}} = -0.90 \text{ m/s}$$

to the left in Fig. 3.19, because v_1 was taken to be positive to the right.

Confidence Exercise 3.4

Suppose you were not given the values of the masses but only that $m_1 = m$ and $m_2 = 3m$. What could you say about the velocities in this case?

The answers to Confidence Exercises may be found at the back of the book.

Earlier we looked at the jet propulsion of rockets in terms of Newton's third law. This phenomenon can also be explained in terms of linear momentum. The burning of the rocket fuel gives energy by which *internal* work is done and hence internal forces act. As a result, the exhaust gas goes out the back of the rocket with momentum in that direction, and the rocket goes in the opposite direction to conserve linear momentum. Here the many, many exhaust gas molecules have small masses and large velocities, whereas the rocket has a large mass and a relatively small velocity.

You can demonstrate this rocket effect by blowing up a balloon and letting it go. The air comes out the back and the balloon is "jet" propelled, but without a guidance system the balloon zigzags wildly.

Angular Momentum

Another important quantity Newton found to be conserved is angular momentum. Angular momentum arises when objects go in paths around a center of motion or axis of rotation. The magnitude of **angular momentum** (L) is given by

angular momentum = mass × velocity × object distance from axis of rotation

or $L = mvr$ **3.7**

Consider a comet going around the Sun in an elliptical orbit, as illustrated in Fig. 3.20.

An external, unbalanced force can change the linear momentum. Similarly, angular momentum can be changed by an external, unbalanced (net) **torque.** Such a torque gives rise to a twisting or rotational effect. Basically, a force produces linear motion, and a torque produces rotational motion. For example, in Fig. 3.21, a net torque on the steering wheel is produced by two equal and opposite forces acting on different parts of the wheel. These forces give rise to two torques, resulting in a net torque that causes the steering wheel to turn or rotate. (Would there be a net torque [and rotation] if both forces were upward?)

Note that these forces are at a distance r (called the *lever arm*) from the center of motion or axis of rotation. When r and F vectors are perpendicular, the magnitude of the **torque** (τ, Greek tau) is given by

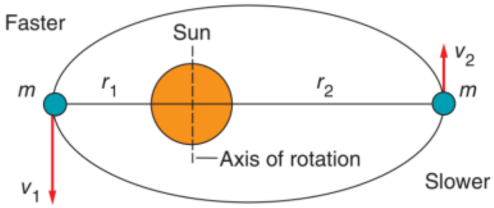


Figure 3.20 Angular Momentum The angular momentum of a comet going around the Sun in an elliptical orbit is given at the two opposite points in the orbit by mv_1r_1 and mv_2r_2. Angular momentum is conserved in this case, and $mv_1r_1 = mv_2r_2$. As the comet comes closer to the Sun, the radial distance r decreases, so the speed v must increase. Similarly, the speed decreases when r increases. Thus, a comet moves fastest when it is closest to the Sun and slowest when it is farthest from the Sun, which is also true for the Earth. (The orbit here is exaggerated to show radial differences.)

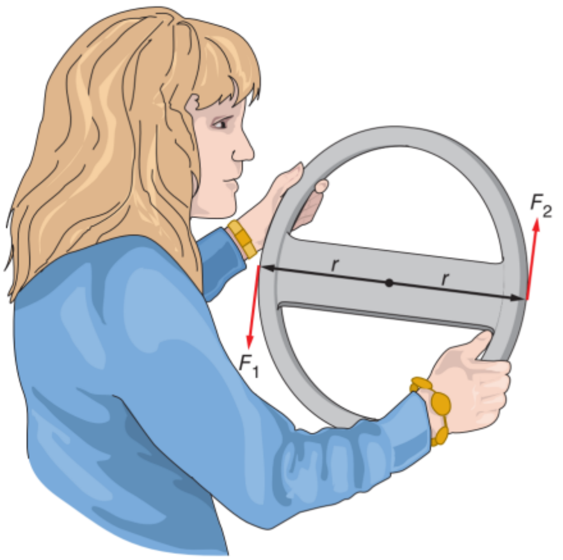


Figure 3.21 Torque A torque is a twisting action that produces rotational motion or a change in rotational motion. Torque is analogous to a force producing linear motion or a change in linear motion. The forces F_1 and F_2 supply the torque.

$$\text{torque} = \text{force} \times \text{lever arm}$$

$$\tau = Fr \qquad 3.8$$

with the units N · m.

Torque varies with r, so for a given force, the greater r is, the greater the torque. You have probably used this fact in trying to produce rotational motion to loosen something, such as a bolt or a nut (● Fig. 3.22). Increasing the lever arm r increases the torque, making it easier to loosen the nut. For the same reason, doorknobs are placed far from the hinges. Have you ever tried to push open a door near the hinges? It's very difficult; there is not enough torque because the lever arm is too short.

There is also a conservation law for angular momentum. The **law of conservation of angular momentum** states that

The angular momentum of an object remains constant if there is no external, unbalanced torque acting on it.

That is, the magnitudes of the angular momenta are equal at times 1 and 2:

$$L_1 = L_2$$

or

$$m_1v_1r_1 = m_2v_2r_2 \qquad 3.9$$

where the subscripts 1 and 2 denote the angular momentum of the object at different times.

In our example of a comet, the angular momentum mvr remains the same because the gravitational attraction is internal to the system. As the comet gets closer to the Sun, r decreases, so the speed v increases. For this reason, a comet moves more rapidly when it is closer to the Sun than when it is farther away (see Fig. 3.20). Comet orbits are highly elliptical, so they move at very different speeds in different parts of their orbits. Planets have relatively less elliptical orbits but do move with different speeds.

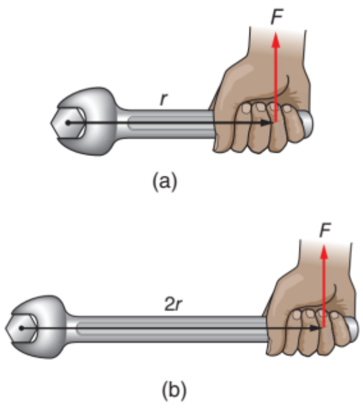


Figure 3.22 Torque and Lever Arm (a) Torque varies with the length of the lever arm r. (b) When the length of the lever arm is doubled for a given force, the torque is doubled. Thus, by using a longer wrench, more torque can be applied to a bolt or nut.

EXAMPLE 3.5 Applying the Conservation of Angular Momentum

In its orbit at the farthest point from the Sun, a certain comet is 900 million miles away and traveling at 6000 mi/h. What is its speed at its closest point to the Sun at a distance of 30 million miles?

Thinking It Through

As pointed out, the gravitational force keeping the comet in orbit is internal to the system, and there are no appreciable external forces. Hence the angular momentum is conserved, and Eq. 3.9 applies.

Solution

We are given v_2, r_2, and r_1, so v_1 can be calculated (Eq. 3.9):

$$mv_1r_1 = mv_2r_2$$

$$v_1r_1 = v_2r_2$$

or

$$v_1 = \frac{v_2r_2}{r_1}$$

$$= \frac{(6.0 \times 10^3 \text{ mi/h})(900 \times 10^6 \text{ mi})}{30 \times 10^6 \text{ mi}}$$

$$= 1.8 \times 10^5 \text{ mi/h, or } 180{,}000 \text{ mi/h}$$

Thus, the comet moves much more rapidly when it is close to the Sun than when it is far away.

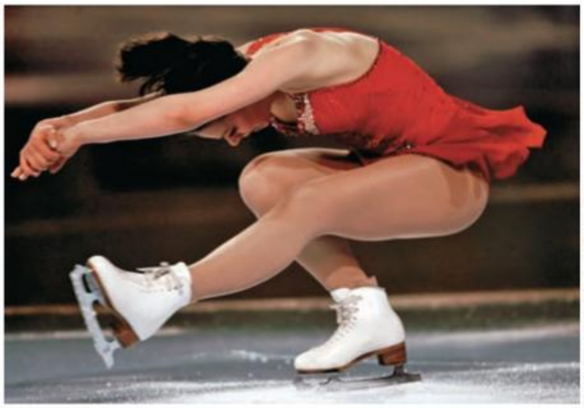
Confidence Exercise 3.5

The Earth's orbit about the Sun is not quite circular. At its closest approach, our planet is 1.47×10^8 km from the Sun, and at its farthest point, it is 1.52×10^8 km from the Sun. At which of these points does the Earth have the greater orbital speed and by what factor? (*Hint:* Use a ratio.)

The answers to Confidence Exercises may be found at the back of the book.

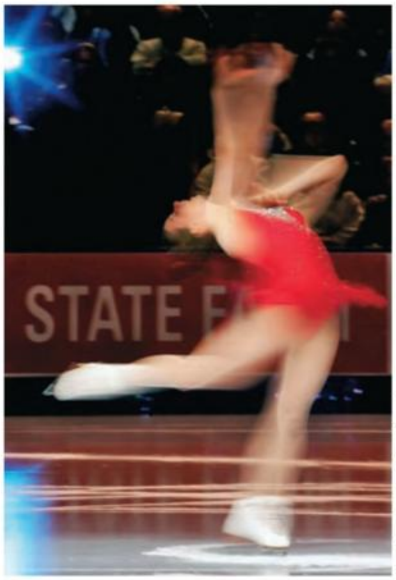
Another example of the conservation of angular momentum is demonstrated in ● Fig. 3.23. Ice skaters use the principle to spin faster. The skater extends both arms and perhaps one leg and obtains a slow rotation. Then, drawing the arms in and above the head (making r smaller), the skater achieves greater angular velocity and a more rapid spin because of the decrease in the radial distance of the mass.

Angular momentum also affects the operation of helicopters. What would happen when a helicopter with a single rotor tried to get airborne? To conserve angular momentum, the body of the helicopter would have to rotate in the direction opposite of the rotor. To prevent such rotation, large helicopters have two oppositely rotating rotors (● Fig. 3.24a). Smaller helicopters instead have small "antitorque" rotors on the tail (Fig. 3.24b). These rotors are like small airplane propellers that provide a torque to counteract the rotation of the helicopter body.



Elsa/Getty Images Sport/Getty Images

(a)



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(b)

Figure 3.23 Conservation of Angular Momentum: Ice-Skater Spin (a) An ice skater starts with a slow rotation, keeping the arms and a leg extended. (b) When the skater stands and draws the arms inward and above the head, the average radial distance of mass decreases and the angular velocity increases to conserve angular momentum, producing a rapid spin.

Did You Learn?

- Linear momentum is conserved when there is no external, unbalanced force acting on the system.
- An external, unbalanced torque causes a change in angular momentum.

(a) (b)

Figure 3.24 Conservation of Angular Momentum in Action (a) Large helicopters have two overhead rotors that rotate in opposite directions to balance the angular momentum. (b) Small helicopters with one overhead rotor have an "antitorque" tail rotor to balance the angular momentum and prevent rotation of the helicopter body.

KEY TERMS

1. force (3.1)
2. unbalanced, or net, force
3. Newton's first law of motion (3.2)
4. inertia
5. Mass
6. Newton's second law of motion (3.3)
7. newton
8. weight
9. friction
10. Newton's third law of motion (3.4)
11. Newton's law of universal gravitation (3.5)
12. *G*
13. buoyant force (3.6)
14. Archimedes' principle
15. linear momentum (3.7)
16. law of conservation of linear momentum
17. angular momentum
18. torque
19. law of conservation of angular momentum

MATCHING

For each of the following items, fill in the number of the appropriate Key Term from the provided list. Compare your answers with those at the back of the book.

a. _____ A nonzero vector sum of forces
b. _____ Resistance to relative motion
c. _____ Mass × velocity
d. _____ $F = ma$
e. _____ Gives the magnitude of the buoyant force
f. _____ A measure of inertia
g. _____ Describes the force of gravity
h. _____ Occurs in the absence of an unbalanced force
i. _____ SI unit of force
j. _____ Tendency of an object to remain at rest or in uniform, straight-line motion
k. _____ mvr
l. _____ Required for an object to float
m. _____ Conservation law requiring the absence of an unbalanced torque
n. _____ Action and reaction
o. _____ Capable of producing motion or a change in motion
p. _____ Universal constant
q. _____ Law of inertia
r. _____ mg
s. _____ Changes angular momentum

SHORT ANSWER

3.1 Force and Net Force

1. Distinguish between a fore and a net force.
2. Does a force always produce acceleration. Explain.

3.2 Newton's First Law of Motion

3. An old party trick is to pull a tablecloth out from under dishes and glasses on a table. Explain how this trick is done without pulling the dishes and glasses with the cloth.
4. Consider a child holding a helium balloon in a closed car at rest. What would the child observe the balloon to do when the car (a) accelerates from rest and (b) brakes to a stop? (The balloon does not touch the roof of the car.)
5. To tighten the loose head of a hammer, the base of the handle is sometimes struck on a hard surface. Explain the physics behind this maneuver.
6. When a paper towel is torn from a roll on a rack, a jerking motion tears the towel better than a slow pull. Why? Does this method work better when the roll is large or when it is small and near the end? Explain.

3.3 Newton's Second Law of Motion

7. It is said that Newton's first law can be derived from his second law. Explain this statement.
8. Can an object be at rest if forces are being applied to it? Explain.
9. If no forces are acting on an object, can the object be in motion? Explain.
10. What is the unbalanced force acting on a moving car with a constant velocity of 25 m/s (56 mi/h)?
11. It is harder to get something into motion than to maintain its motion. Could you explain with your knowledge of friction?
12. A 10-lb rock and a 1-lb rock are dropped simultaneously from the same height.
    (a) Some say that because the 10-lb rock has 10 times as much force acting on it as the 1-lb rock, it should reach the ground first. Do you agree?
    (b) Describe the situation if the rocks were dropped by an astronaut on the Moon.

3.4 Newton's Third Law of Motion

13. There is an equal and opposite reaction for every force. Explain how an object can be accelerated when the vector sum of these forces is zero.
14. When a rocket blasts off, is it the fiery exhaust gases "pushing against" the launch pad that cause the rocket to lift off? Explain.
15. When a person pushes on a wall, the wall pushes on the person (Newton's third law). Suppose the person puts a block of wood between his or her hand and the wall. Analyze the forces on the block of wood. "Why doesn't it fall?"
16. Two masses are attached to a spring scale as shown in ● Fig. 3.25. If both masses are 1 kg, which force, in newtons, would the scale read? (*Hint:* Think of holding a free end of the rope on one side of the scale with only the weight on the other.)

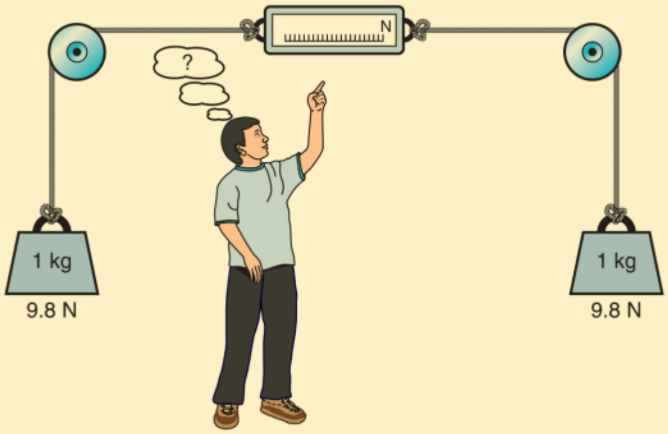

Figure 3.25 What Does the Scale Read? See Short Answer 16.

3.5 Newton's Law of Gravitation

17. An astronaut has a mass of 70 kg when measured on the Earth. What is her weight in deep space far from any celestial object? What is her mass there?
18. The gravitational force is said to have an infinite range. What does that mean?
19. If the distance between the Moon and the Earth were doubled, what would happen to the gravitational force between them?
20. The acceleration due to gravity on the surface of the Moon is one-sixth that of the acceleration due to gravity on the Earth's surface. Yet the mass of the Earth is 81 times that of the Moon. Can you explain the apparent discrepancy?
21. Is "zero g" possible? Explain.

3.6 Archimedes' Principle and Buoyancy

22. Why must a helium balloon be held with a string?
23. What is a major consideration in constructing a life jacket that will keep a person afloat?
24. As you learned in Chapter 1.5, 1 L of water has a mass of 1 kg. A thin, closed plastic bag (negligible weight) with 1 L of water in it is lowered into a lake by means of a string and submerged. When fully submerged, how much force would you have to exert on the string to prevent the bag from sinking more?
25. A large piece of iron with a volume of 0.25 m^3 is lowered into a lake by means of a rope until it is just completely submerged. It is found that the support on the rope is less than when the iron is in air. How does the support vary as the iron is lowered more?
26. In Chapter 1.6 in the discussion of the hydrometer, it is stated: "The higher the bulb floats, the greater the density of the liquid." Why is this? (See Fig. 1.14.)
27. Oak generally has a higher density than pine. If two identically sized oak and pine wood blocks were dropped into a swimming pool, which one will have more volume above the water surface?

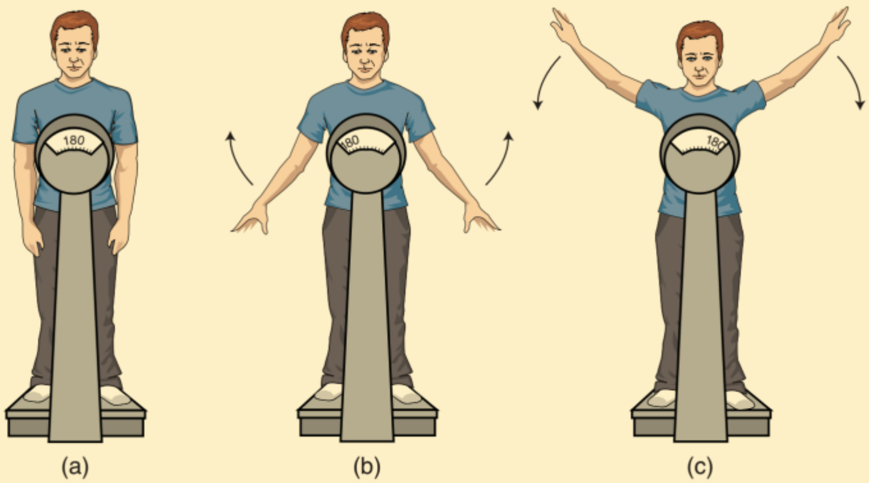

Figure 3.26 Up and Down A quick way to gain or lose weight. See Applying Your Knowledge Question 2.

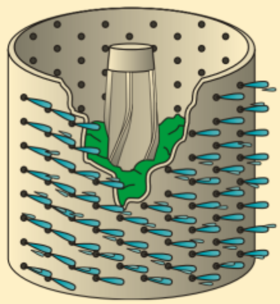

Figure 3.27 Get the Water Out See Applying Your Knowledge Question 5.

IMPORTANT EQUATIONS

Newton's Second Law: $F = ma$ (3.1)

for weight: $w = mg$ (3.2)

Newton's Third Law: $F_1 = -F_2$ (3.3)

Newton's Law of Gravitation: $F = \frac{Gm_1m_2}{r^2}$ (3.4)

(Universal gravitational constant: $G = 6.67 \times 10^{-11}\ \text{N} \cdot \text{m}^2/\text{kg}^2$)

Linear Momentum: $p = mv$ (3.5)

Conservation of Linear Momentum:

$$P_f = P_i$$

where $P = p_1 + p_2 + p_3 + \ldots$ (3.6)

Angular Momentum: $L = mvr$ (3.7)

Torque: $\tau = Fr$ (3.8)

Conservation of Angular Momentum:

$$L_1 = L_2$$

$$m_1v_1r_1 = m_2v_2r_2 \quad (3.9)$$

EXERCISES

The Exercises are given in odd-even pairs for similarity in topics and solutions. The answers to the odd-numbered exercises are given at the back of the book.

3.1 Force and Net Force

1. What is the net force of a 9.0-N force and an 8.0-N force acting on an object for each of the following conditions?
   (a) The forces act in opposite directions.
   (b) The forces act in the same direction.
2. A horizontal force of 250 N is applied to a stationary wooden box in one direction, and a 600-N horizontal force is applied in the opposite direction. What additional force is needed for the box to remain stationary?

3.3 Newton's Second Law of Motion

3. Determine the net force necessary to give an object with a mass of 4.0 kg an acceleration of 5.0 m/s^2.
4. A force of 2.1 N is exerted on a 7.0-g rifle bullet. What is the bullet's acceleration?
5. A 1000-kg automobile is pulled by a horizontal towline with a net force of 950 N. What is the acceleration of the auto? (Neglect friction.)
6. If the box in Exercise 2 has a mass of 20 kg and no additional force is applied, what is the acceleration of the box?
7. What is the weight in newtons of a 6.0-kg package of nails?
8. What is the force in newtons acting on a 4.0-kg package of nails that falls off a roof and is on its way to the ground?
9. (a) What is the weight in newtons of a 120-lb person?
   (b) What is your weight in newtons?
10. A 75-kg person is standing on a scale in an elevator. What is the reading of the scale in newtons if the elevator is (a) at rest, and (b) moving up with a constant velocity of 2.0 m/s?

3.5 Newton's Law of Gravitation

11. (a) What is the force of gravity between two 1000-kg cars separated by a distance of 25 m on an interstate highway?
    (b) How does this force compare with the weight of a car?
12. Two 3.0-kg physical science textbooks on a bookshelf are 0.15 m apart. What is the magnitude of the gravitational attraction between the books?
13. How would the force of gravity between two masses be affected if the separation distance between them were (a) doubled? (b) decreased by one-half?
14. The separation distance between two 1.0-kg masses is (a) decreased by two-thirds and (b) increased by a factor of 3. How is the mutual gravitational force affected in each case?

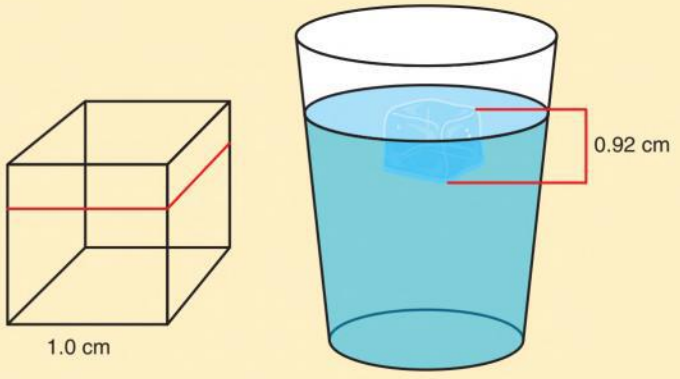

Figure 3.28 Weight of an Ice Cube. See Exercise 20.

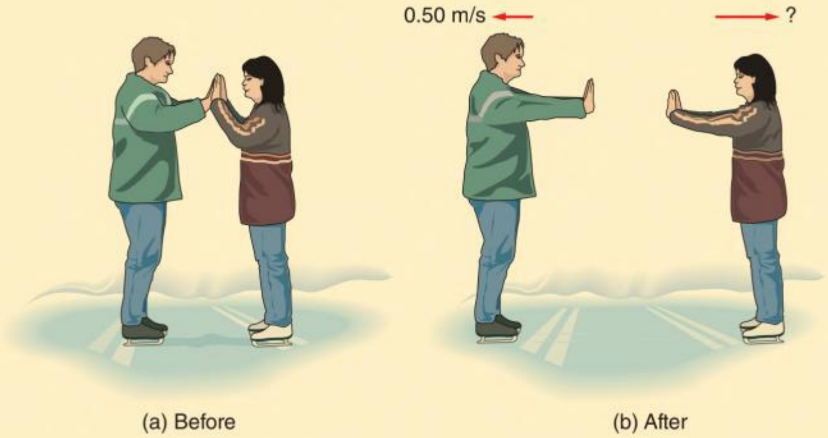

Figure 3.29 Pushing Off See Exercises 23 and 24.

15. The acceleration due to gravity on the Moon is only one-sixth of that on the Earth. (a) Determine the weight on the Moon of a person whose weight on the Earth is 150 lb. (b) What would be your weight on the Moon?
16. Suppose an astronaut has landed on Mars. Fully equipped, the astronaut has a mass of 125 kg, and when the astronaut gets on a scale, the reading is 49 N. What is the acceleration due to gravity on Mars?

3.6 Archimedes' Principle and Buoyancy

17. A child's cubic play block has a mass of 120 g and sides of 5.00 cm. When placed in a bathtub full of water, will the cube sink or float? (*Hint:* See Chapter 1.6.)
18. A ball with a radius of 8.00 cm and a mass of 600 g is thrown into a lake. Will the ball sink or float?
19. A student found a large rectangular wooden box that measures 2.0 m long, 1.0 m wide, and 0.50 m deep. He wants to invite a few friends to float in the river. How many 75-kg students can the boat safely carry? (The answer may surprise you, and then you would be creative to load these students.)
20. What is the weight of the ice cube in ● Fig. 3.28?

3.7 Momentum

21. Calculate the linear momentum of a pickup truck that has a mass of 1000 kg and is traveling eastward at 20 m/s.
22. A small car with a mass of 900 kg travels northward at 30 m/s. Does the car have more or less momentum than the truck in Exercise 19, and how much more or less? (Is direction a factor in this exercise?)
23. Two ice skaters stand together as illustrated in ● Fig. 3.29. They "push off" and travel directly away from each other, the boy with a velocity of 0.50 m/s to the left. If the boy weighs 750 N and the girl weighs 550 N, what is the girl's velocity after they push off? (Consider the ice to be frictionless.)
24. For the couple in Fig. 3.29, suppose you do not know the girl's mass but observed she moves at 0.65 m/s in the opposite direction. What is her mass?
25. A comet goes around the Sun in an elliptical orbit. At its farthest point, 600 million miles from the Sun, it is traveling with a speed of 15,000 mi/h. How fast is it traveling at its closest approach to the Sun, at a distance of 100 million miles?
26. Taking the density of air to be 1.29 kg/m^3, what is the magnitude of the angular momentum of a cubic meter of air moving with a wind speed of 75 mi/h in a hurricane? Assume the air is 50 km from the center of the hurricane "eye."

Work and Energy

CHAPTER

4

Cedar Point Amusement Park/Resort, Sandusky Ohio

Courtesy Cedar Point Amusement Park/Resort, Sandusky Ohio

I like work; it fascinates me. I can sit and look at it for hours.

•

Jerome K. Jerome
(1859–1927)

< A lot of work going up, and a lot of energy at the top. The roller coaster at Cedar Point Amusement Park in Sandusky, Ohio, is shown here. The roller coaster reaches speeds of 120 miles per hour within 4 seconds

Did You Know?	Section
In walking, no work is done against friction and the frictional force is in the direction of the motion.	4.1
It is possible to have zero kinetic energy along with zero potential energy.	4.2
Energy cannot be created or destroyed.	4.5

Chapter Outline

4.1 Work 82
4.2 Kinetic Energy and Potential Energy 84
Conceptual Q&A 4.1 Double Zero 89
4.3 Conservation of Energy 89
Conceptual Q&A 4.2 The Race Is On 91
4.4 Power 92
Conceptual Q&A 4.3 Payment for Power 95
4.5 Forms of Energy and Consumption 95
4.6 Alternative and Renewable Energy Sources 97
Physical Science Today 4.1 Light Bulbs That Last 50,000 Hours? 101

The commonly used terms *work* and *energy* have general meanings for most people. For example, work is done to accomplish some task or job. To get the work done, energy is expended. Hence, work and energy are related. After a day's work, one is usually tired and requires rest and food to regain one's energy.

The scientific meaning of work is quite different from the common meaning. A student standing and holding an overloaded book bag is technically doing no work, yet he or she will feel tired after a time. Why does the student do no work? As will be learned in this chapter, mechanical work involves force *and* motion.

Energy, one of the cornerstones of science, is more difficult to define. Matter and energy make up the universe. Matter is easily understood; in general, we can touch it and feel it. Energy is not actually tangible; it is a concept. We are aware of energy only when it is being used or transformed, such as when it is used to do work. For this reason, energy is sometimes described as stored work.

Our main source of energy on Earth is the Sun, which constantly radiates enormous amounts of energy into space. Only a small portion of this energy is

PHYSICS FACTS

- *Energy* comes from the Greek *energeia*, meaning "activity."
- The United States has about 5% of the world's population and consumes about 26% of the world's energy supply.
- Muscles are used to propel the human body by turning stored (potential) energy into motion (kinetic energy).
- The human body operates within the limits of the conservation of total energy. The sum of dietary input energy minus the energy expended in the work of daily activities, internal activities, and system heat losses equals zero.

received by the Earth, where much of it goes into sustaining plant and animal life. On the Earth, energy exists in various forms, including chemical, electrical, nuclear, and gravitational energies. However, a basic form of interest is mechanical energy, which is associated with the motion and position of objects. This may be classified more specifically as *kinetic energy* (energy of motion) and *potential energy* (energy of position). There's a lot of interesting aspects of energy. Read on.

4.1 Work

Key Questions

- Is work a vector quantity? In other words, does it need a direction associated with it?
- What are the units of work?

Mechanically, work involves force and motion. One can apply a force all day long, but if there is no motion, then there is technically no work. The work done by a *constant force* F is defined as follows:

The **work** *done by a constant force F acting on an object is the product of the magnitude of the force (or parallel component of the force) and the parallel distance d through which the object moves while the force is applied.*

In equation form,

$$\text{work} = \text{force} \times \text{parallel distance}$$
$$W = Fd \qquad 4.1$$

In this form, it is easy to see that work involves motion. If $d = 0$, then the object has not moved and no work is done.

Figures 4.1 and 4.2 illustrate the difference between the application of force without work resulting and the application of force that results in work. In Fig. 4.1, a force is being applied to the wall, but no work is done because the wall doesn't move. After a while the man may become quite tired, but no mechanical work is done. Figure 4.2 shows an object being moved through a distance d by an applied force F. Note that the force and the directed distance are parallel to each other and that the force F acts through the parallel distance d. The work is then the product of the force and distance, $W = Fd$.

Another important consideration is shown in Fig. 4.3. When the force and the distance are not parallel to each other, only a component or part of the force acts through the parallel distance. When a lawn mower is pushed at an angle to the horizontal, only the component of the force that is parallel to the level lawn (horizontal component F_h) moves through a parallel distance and does work ($W = F_h d$). The vertical component

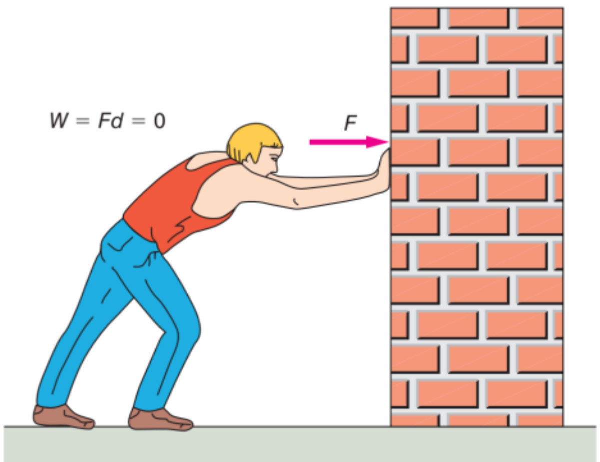

Figure 4.1 No Work Done A force is applied to the wall, but no work is done because there is no motion ($d = 0$).

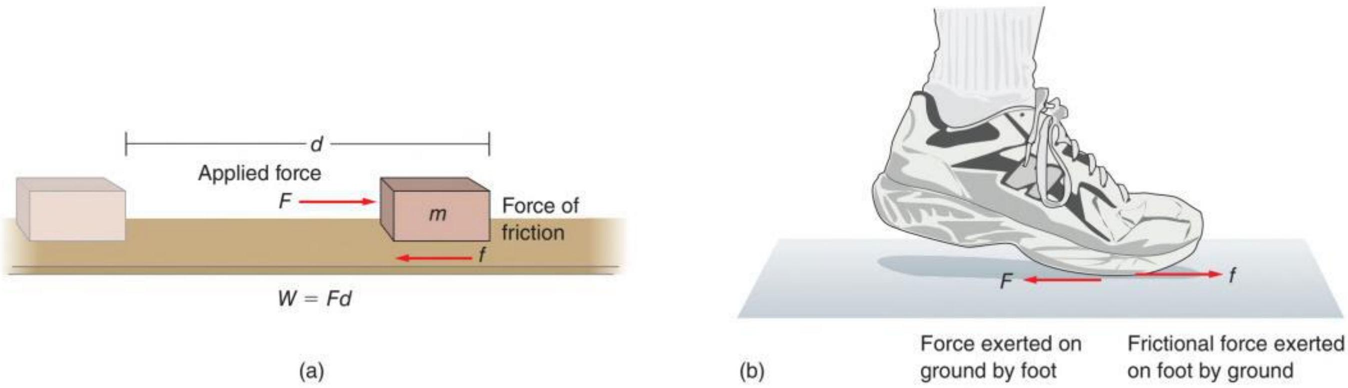

Figure 4.4 Work and No Work Done against Friction (a) The mass is moved to the right with a constant velocity by a force *F*, which is equal and opposite to the frictional force *f*. See text for description. (b) When you are walking, there is friction between your feet and the floor. This example is a static case, and the frictional force prevents the foot from moving or slipping. No motion, no work.

The work done by the frictional force is then $-fd = -W$; that is, it is negative work. The negative frictional work is equal to the positive work done by the applied force, so the total work is zero, $W_t = Fd - fd = 0$. Otherwise, there would be net work and an energy transfer such that the block would not move with a constant velocity. If the applied force were removed, then the block would slow down (decrease in energy) and eventually stop because of frictional work.

When walking, there must be friction between our feet and the floor; otherwise, we would slip. In this case, though, no work is done against friction because the frictional force prevents the foot from slipping (Fig. 4.4b). No motion of the foot, no work. Of course, other (muscle) forces do work because there is motion in walking. It is interesting to note in Fig. 4.4b that to walk forward, one exerts a backward force on the floor. The frictional force is in the direction of the walking motion and opposes the motion (slipping) of the foot on the ground.

Did You Learn?

- Work is a scalar quantity. Both force and parallel distance (actually, displacement) have directions associated with them, but their product, work, does not.
- Work $= F \times d$ and so has the units newton-meter (N · m), which is called a joule (J). In the British system this would be pound · foot, but is commonly written as foot · pound (ft · lb).

4.2 Kinetic Energy and Potential Energy

Key Questions

- By what process is energy transferred from one object to another?
- To find the difference in gravitational potential energies, the difference in heights is used. What is used to find the difference in kinetic energies?

When work is done on an object, what happens? When work is done against gravity, an object's height is changed, and when work is done against friction, heat is produced. Note that in these examples some physical quantity changes when work is done.

The concept of energy helps unify all the possible changes. Basically, when work is done there is a change in energy, and the amount of work done is equal to the change in energy. But what is energy? Energy is somewhat difficult to define because it is abstract. Like force, it is a concept: easier to describe in terms of what it can do rather than in terms of what it is.

EXAMPLE 4.1 Finding the Change in Kinetic Energy

A 1.0-kg ball is fired from a cannon. What is the change in the ball's kinetic energy when it accelerates from 4.0 m/s to 8.0 m/s?

Thinking It Through

Once the initial and final velocities of the ball are known, the change in the kinetic energy can be easily found; remember that it is the difference in each kinetic energy and not the difference in velocities.

Solution

Given: $m = 1.0$ kg and $v_1 = 4.0$ m/s
$v_2 = 8.0$ m/s

Equation 4.3 can be used directly to compute the change in kinetic energy. Notice that the kinetic energy is calculated for each velocity.

$$\Delta E_k = E_{k_2} - E_{k_1} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$$
$$= \frac{1}{2}(1.0\text{ kg})(8.0\text{ m/s})^2 - \frac{1}{2}(1.0\text{ kg})(4.0\text{ m/s})^2$$
$$= 32\text{ J} - 8.0\text{ J} = 24\text{ J}$$

Confidence Exercise 4.1

In working the preceding example, suppose a student first subtracts the velocities and says $\Delta E_k = \frac{1}{2}m(v_2 - v_1)^2$. What would the answer be, and would it be correct? Explain and show your work.

The answers to Confidence Exercises may be found at the back of the book.

If an object is initially at rest ($v_1 = 0$), then the change in kinetic energy is equal to the kinetic energy of the object. Also keep in mind that to find the change in kinetic energy, you must first find the kinetic energy for each velocity and then subtract, *not* find the change or difference in velocities and then compute the change in kinetic energy.

Work is done in getting a stationary object moving, and the object then has kinetic energy. Suppose you wanted to stop a moving object such as an automobile. Work must be done here, too, and the amount of work needed to stop the automobile is equal to its change in kinetic energy. The work is generally supplied by brake friction.

In bringing an automobile to a stop, we are sometimes concerned about the braking distance, which is the distance the car travels after the brakes are applied. On a level road the work done to stop a moving car is equal to the braking force (f) times the braking distance ($W = fd$). As has been noted, the required work is equal to the kinetic energy of the car ($fd = \frac{1}{2}mv^2$). Assuming that the braking force is constant, the braking distance is directly proportional to the square of the velocity ($d \propto v^2$).

Squaring the velocity makes a big difference in the braking distances for different speeds. For example, if the speed is doubled, then the braking distance is increased by a factor of 4. (What happens to the braking distance if the speed is tripled?)

This concept of braking distance explains why school zones have relatively low speed limits, commonly 32 km/h (20 mi/h). The braking distance of a car traveling at this speed is about 8.0 m (26 ft). For a car traveling twice the speed, 64 km/h (40 mi/h), the braking distance is four times that distance, or $4 \times 8.0\text{ m} = 32\text{ m}$ (105 ft). See ● Fig. 4.6.

The driver's reaction time is also a consideration. This simple calculation shows that if a driver exceeds the speed limit in a school zone, then he or she may not be able to stop in time to avoid hitting a child who darts into the street. Remember v^2 the next time you are driving through a school zone.

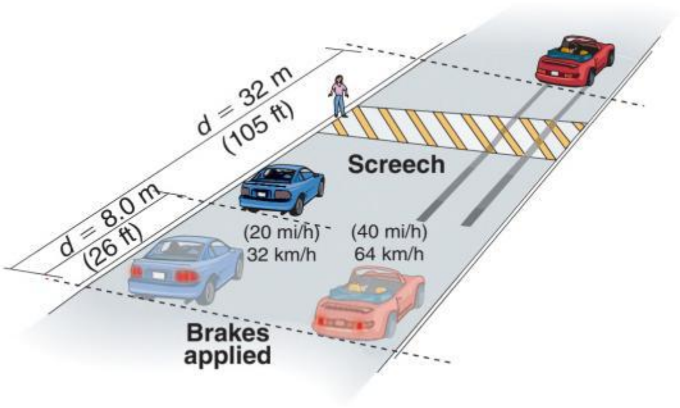

Figure 4.6 Energy and Braking Distance Given a constant braking force, if the braking distance of a car traveling 32 km/h (20 mi/h) is 8.0 m (26 ft), then for a car traveling twice as fast, or 64 km/h (40 mi/h), the braking distance is four times greater, or 32 m (105 ft), that is, $d \propto v^2$.

Potential Energy

An object doesn't have to be in motion to have energy. It also may have energy by virtue of where it is. **Potential energy** *is the energy an object has because of its position or location, or more simply, it is the energy of position.* Work is done in changing the position of an object; hence, there is a change in energy.

For example, when an object is lifted at a slow constant velocity, there is no net force on it because it is not accelerating. The weight mg of the object acts downward, and there is an equal and opposite upward force. The distance parallel to the applied upward force is the height h to which the object is lifted (● Fig. 4.7). Thus, the *work done against gravity* is, in equation form,

$$\begin{aligned} \text{work} &= \text{weight} \times \text{height} \\ W &= mgh \\ (W &= Fd) \end{aligned} \qquad 4.4$$

Suppose you lift a 1.0-kg book from the floor to a tabletop 1.0 m high. The amount of work done in lifting the book is

$$\begin{aligned} W &= mgh \\ &= (1.0 \text{ kg})(9.8 \text{ m/s}^2)(1.0 \text{ m}) = 9.8 \text{ J} \end{aligned}$$

With work being done, the energy of the book changes (increases), and the book on the table has energy and the ability to do work because of its height or position. This energy

Nathan King/Alamy Stock Photo

Figure 4.7 Work against Gravity In lifting weights (mg) to a height h, a weight lifter applies an upward lifting force F. The work done in lifting the weights is mgh. While standing there with the weights overhead, is the weight lifter doing any work?

is called **gravitational potential energy**. If the book were allowed to fall back to the floor, it could do work; for example, crush something.

As another example, the water stored behind a dam has potential energy because of its position. This gravitational potential energy is used to generate electrical energy. Also, when walking up stairs to a classroom, you are doing work. On the upper floor you have more gravitational potential energy than does a person on the lower floor. (Call down and tell the person so.)

The gravitational potential energy E_p is equal to the work done, and this is equal to the weight of the object multiplied by the height (Eq. 4.4). That is,

$$\text{gravitational potential energy} = \text{weight} \times \text{height}$$
$$E_p = mgh \tag{4.5}$$

When work is done by or against gravity, the potential energy changes, and

$$\begin{aligned} \text{work} &= \text{change in potential energy} \\ &= E_{p_2} - E_{p_1} \\ &= mgh_2 - mgh_1 \\ &= mg(h_2 - h_1) \\ &= mg\,\Delta h \end{aligned}$$

Similar to an object having kinetic energy for a particular velocity, an object has a potential energy for each particular height or position. When work is done there is a *change* in position, so the (Δh) is really a height *difference*. The h in Eqs. 4.4 and. 4.5 is also a height difference, with $h_1 = 0$.

The value of the gravitational potential energy at a particular position depends on the reference point or the reference or zero point from which the height is measured. Near the surface of the Earth, where the acceleration due to gravity (g) is relatively constant, the designation of the zero position or height is arbitrary. Any point will do. Using an arbitrary zero point is like using a point other than the zero mark on a meterstick to measure length (● Fig. 4.8). This practice may give rise to negative positions, such as the minus (−) positions on a Cartesian graph.

Heights (actually, displacements or directed lengths) may be positive or negative relative to the zero reference point. However, note that the height *difference*, or change in the potential energy between two positions, is the same in any case. For example, in Fig. 4.8 the top ball is at a height of $h = y_2 - y_1 = 50$ cm − 0 cm = 50 cm according to the scale on the left, and $h = 100$ cm − 50 cm = 50 cm according to the meterstick on the right. Basically, you can't change a length or height by just changing scales.

A negative (–) h gives a *negative* potential energy. A negative potential energy is analogous to a position in a hole or a well shaft because we usually designate $h = 0$ at the Earth's surface. Negative energy "wells" will be important in the discussion of atomic theory in Chapter 9.3.

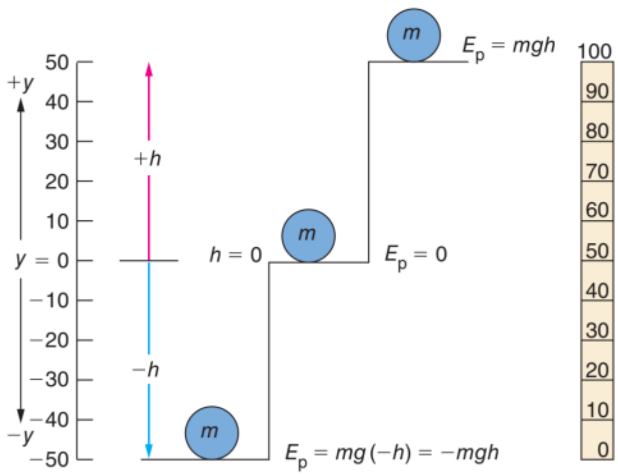

Figure 4.8 Reference Point The reference point for measuring height is arbitrary. For example, the zero reference point may be that on a Cartesian axis (*left*) or that at one end of the meterstick (*right*). For positions below the chosen zero reference point on the Cartesian *y*-axis, the potential energy is negative because of negative displacement. However, the potential-energy values measured from the zero end of the meterstick would be positive. The important point is that the energy *differences* are the same for any reference.

Conceptual Question and Answer 4.1

Double Zero

Q. A fellow student tells you that she has both zero kinetic energy and zero gravitational potential energy. Is this possible?

A. Yes. If she is sitting motionless ($v = 0$), then her kinetic energy is zero. The value of the gravitational potential energy depends on the reference or zero point. If this point is taken at the student's position ($h = 0$), then she will have both zero kinetic and potential energies. (Some work would change the situation.)

There are other types of potential energy besides gravitational. For example, when a spring is compressed or stretched, work is done (against the spring force) and the spring has potential energy as a result of the change in length (position). Also, work is done when a bowstring is drawn back. The bow and the bowstring bend and acquire potential energy. This potential energy is capable of doing work on an arrow, thus producing motion and kinetic energy. *Note again that work is a process of transferring energy*.

Did You Learn?

- Energy is the ability or capability to do work, and work is the process by which energy is transferred from one object to another.
- To find the difference in kinetic energies, the difference in the squares of the velocity is taken, $\Delta E = \frac{1}{2} m(v_2^2 - v_1^2)$, *not* the difference in velocities squared $(v_2 - v_1)^2$.

4.3 Conservation of Energy

Key Questions

- Overall, can energy be created or destroyed?
- What is the difference between total energy and mechanical energy?

Energy may change from one form to another and does so without a net loss or net gain. That is to say, energy is *conserved*, and the total amount remains constant. The study of energy transformations has led to one of the most basic scientific principles, the law of conservation of energy. Although the meaning is the same, the *law of conservation of energy* (or simply the conservation of energy) can be stated in different ways. For example, "energy can be neither created nor destroyed" and "in changing from one form to another, energy is always conserved" are both ways of stating this law.

The law of **conservation of total energy** may also be conveniently stated as follows:

The total energy of an isolated system remains constant.

Thus, although energy may be changed from one form to another, energy is not lost from the system, and so it is conserved. A *system* is something enclosed within boundaries, which may be real or imaginary, and *isolated* means that nothing from the outside affects the system (and vice versa).

For example, the students in a classroom might be considered a system. They may move around in the room, but if no one leaves or enters, then the number of students is conserved (the "law of conservation of students"). It is sometimes said that the total energy of the universe is conserved, which is true. The universe is the largest system of which we can think, and all the energy that has ever been in the universe is still there somewhere in some form or other.

Note from Table 4.2 that as the stone falls, the potential energy becomes less (decreasing h) and the kinetic energy becomes greater (increasing v). Potential energy is converted into kinetic energy. Just before the stone hits the ground ($h = 0$), all the energy is kinetic, and the velocity is a maximum. (What happens to the energy when the stone hits the ground?)

This relationship can be used to compute the magnitude of the velocity, or the speed, of a falling object released from rest. The potential energy lost is $mg\Delta h$, where Δh is the change or decrease in height measured *from the release point down*. This is converted into kinetic energy, $\frac{1}{2}mv^2$. By the conservation of mechanical energy, these quantities are equal:

$$\frac{1}{2}mv^2 = mg\Delta h$$

Then, canceling the m's and solving for v, the *speed of a dropped object after it has fallen a distance h from the point of release* is

$$v = \sqrt{2g\Delta h} \qquad 4.7$$

This equation was used to compute the v's in Table 4.2. For example, at a height of 3.0 m, $\Delta h = 10\text{ m} - 3.0\text{ m} = 7.0\text{ m}$ (a decrease of 7.0 m), and

$$v = \sqrt{2g\Delta h} = \sqrt{2(9.8\text{ m/s}^2)(7.0\text{ m})} = 12\text{ m/s}$$

Conceptual Question and Answer 4.2

The Race Is On

Q. They're off! Two identical balls are released simultaneously from the same height on individual tracks, as shown in ● Fig. 4.10. Which ball will reach the end of its track first (or do they arrive together)?

A. The Track B ball finishes first and wins the race. Obviously, the B ball has a longer distance to travel, so how can this be? Although the B ball must travel farther, it gains greater speed by giving up potential energy for kinetic energy on the downslope, which allows it to cover a greater distance in a shorter time. The B ball has a greater average speed on both the lower downslope and upslope of the track, and so it pulls ahead of the Track A ball and gets to the finish line first. (On the upslope, ball B is decelerating, but it is still traveling faster than ball A.)

Question: Are their speeds the same at the finish line? *Hint*: Look at their overall changes in potential energies. Did you get it? Note that the balls overall have the same decrease in height. Hence, they have the same decrease in potential energy and the same increase in kinetic energy, and they arrive at the finish line with the same speed.

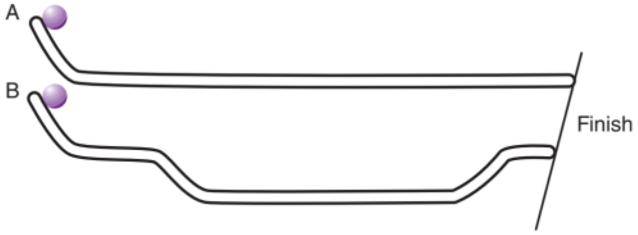

Figure 4.10 The Race Is On Two identical balls are released simultaneously from the same height on individual tracks. Which ball will reach the end of its track first?

Table 4.3 SI Units of Force, Work, Energy, and Power

Quantity	Unit	Symbol	Equivalent Units
Force	newton	N	$kg \cdot m/s^2$
Work	joule	J	N · m
Energy	joule	J	N · m
Power	watt	W	J/s

One should be careful not to be confused by the two meanings of the capital letter W. In the equation $P = W/t$, the (italic) W stands for work. In the statement $P = 25$ W, the (roman) W stands for watts. In equations, letters that stand for variable quantities are in italic type, whereas letters used as abbreviations for units are in regular (roman) type.

In the British system, the unit of work is the foot-pound and the unit of power is the foot-pound per second (ft · lb/s). A larger unit, the **horsepower** (hp), is commonly used to rate the power of motors and engines, and

$$1 \text{ horsepower (hp)} = 550 \text{ ft} \cdot \text{lb/s} = 746 \text{ W}$$

The horsepower unit was originated by James Watt, after whom the SI unit of power is named. In the 1700s horses were used in coal mines to bring coal to the surface and to power water pumps. In trying to sell his improved steam engine to replace horses, Watt cleverly rated the engines in horsepower to compare the rates at which work could be done by an engine and by an average horse.

The greater the power of an engine or motor, the faster it can do work; that is, it can do more work in a given time. For instance, a 2-hp motor can do twice as much work as a 1-hp motor in the same amount of time, or a 2-hp motor can do the same amount of work as a 1-hp motor in half the time.

Example 4.3 shows how power is calculated.

EXAMPLE 4.3 Calculating Power

A constant force of 150 N is used to push a student's stalled motorcycle 10 m along a flat road in 20 s. Calculate the power expended in watts.

Thinking It Through

Power is the work per time $P = W/t$, so computing the work done $W = Fd$ and dividing by the time gives the power expended in pushing the motorcycle.

Solution

First, we list the given data and what is to be found in symbol form:

Given: $F = 150$ N   *Wanted*: P (power)
$d = 10$ m
$t = 20$ s

Equation 4.9 can be used to find the power with the work expressed explicitly as Fd:

$$P = \frac{W}{t} = \frac{Fd}{t} = \frac{(150 \text{ N})(10 \text{ m})}{20 \text{ s}} = 75 \text{ W}$$

Notice that the units are consistent, N · m/s = J/s = W. The given units are all SI, so the answer will have the SI unit of power, the watt.

Confidence Exercise 4.3

A student expends 7.5 W of power in lifting a textbook 0.50 m in 1.0 s with a constant velocity. (a) How much work is done, and (b) How much does the book weigh (in newtons)?

The answers to Confidence Exercises may be found at the back of the book.


Ikonoklast Fotografie/Shutterstock.com

Figure 4.12 Energy Consumption Electrical energy is consumed as the motor of the grinder does work and turns the grinding wheel. Notice the flying sparks and that the operator wisely is wearing a face shield. An electric *power* company is actually charging for *energy* in units of kilowatt-hours (kWh).

As we have seen, work produces a change in energy. Thus *power may be thought of as energy produced or consumed divided by the time taken to do so*. That is,

$$\text{power} = \frac{\text{energy produced or consumed}}{\text{time taken}}$$

or

$$P = \frac{E}{t} \qquad 4.10$$

Rearranging the equation yields

$$E = Pt \qquad 4.10a$$

Equation 4.10a is useful in computing the amount of electrical energy consumed in the home. Because energy is power times time ($P \times t$), it has units of watt-second ($W \cdot s$). Using the larger units of kilowatt (kW) and hour (h) gives the larger unit of **kilowatt-hour** (kWh).

When paying the power company for electricity, in what units are you charged? That is, what do you pay for? If you check an electric bill, you will find that the bill is for so many kilowatt-hours (kWh). Hence, people actually pay the power company for the amount of energy consumed, which is used to do work (● Fig. 4.12). Example 4.4 illustrates how the energy consumed can be calculated when the power rating is known.

EXAMPLE 4.4 Computing Energy Consumed

A 1.0-hp electric motor runs for 10 hours. How much energy is consumed (in kilowatt-hours)?

Thinking It Through

Power is energy per time, $P = E/t$, so given the power and time the energy consumed can be found, $E = Pt$. However, energy in kilowatt-hours is wanted and the power of the motor is given in horsepower, so a unit conversion is necessary.

Solution

Given: $P = 1.0$ hp, $t = 10$ h *Wanted:* E (energy in kWh)

Note that the time is given in hours, which is what is wanted, but the power needs to be converted to kilowatts. With 1 hp = 746 W, we have

$$\begin{aligned} 1.0 \text{ hp} &= 746 \text{ W } (1 \text{ kW}/1000 \text{ W}) = 0.746 \text{ kW} \\ &= 0.75 \text{ kW (rounding)} \end{aligned}$$

Then, using Eq. 4.10a,

$$E = Pt = (0.75 \text{ kW})(10 \text{ h}) = 7.5 \text{ kWh}$$

This is the electrical energy consumed when the motor is running (doing work).

We often complain about our electric bills. In the United States, the average cost of electricity is about 13¢ per kWh. Thus, running the motor for 10 hours at a rate of 13¢ per kWh costs 98¢. That's pretty cheap for 10 hours of work output. (Electrical energy is discussed further in Chapter 8.2.)

Confidence Exercise 4.4

A household uses 2.00 kW of power each day for 1 month (30 days). If the charge for electricity is 8¢ per kWh, how much is the electric bill for the month?

The answers to Confidence Exercises may be found at the back of the book.

Conceptual Question and Answer 4.3

Payment for Power

Q. Some factory workers are paid by the hour. Others are paid on a piecework basis (paid according to the number of pieces or items they process or produce). Is there a power consideration in either of these methods of payment?

A. For hourly payment, there is little consideration for worker incentive or power consumed. A worker gets paid no matter how much work or power is expended. For piecework, on the other hand, the more work done in a given time or the more power expended, the more items produced and the greater the pay.

Did You Learn?

- A 2-hp engine can do twice as much work as a 1-hp engine in the same time, or the same amount of work in half the time.
- The kilowatt-hour (kWh) is a unit of energy ($E = Pt$).

4.5 Forms of Energy and Consumption

Key Questions

- How many common forms of energy are there, and what are they?
- What are the two leading fuels consumed in the United States, and which is used more in the generation of electricity?

Forms of Energy

We commonly talk about various forms of energy such as chemical energy and electrical energy. Many forms of energy exist, but the main unifying concept is the conservation of energy. *Energy cannot be created or destroyed, but it can change from one form to another*.

In considering the conservation of energy to its fullest, there has to be an accounting for all the energy. Consider a swinging pendulum. The kinetic and potential energies of the pendulum bob change at each point in the swing. Ideally, the *sum* of the kinetic and potential energies—the total mechanical energy—would remain constant at each point in the swing and the pendulum would swing indefinitely.

In the real world, however, the pendulum will eventually come to a stop. Where did the energy go? Of course, friction is involved. In most practical situations, the kinetic and potential energies of objects eventually end up as heat. *Heat*, or *thermal energy*, will be examined at some length in Chapter 5.2, but for now let's just say that heat is transferred energy that becomes associated with kinetic and potential energies on a molecular level.

We have already studied *gravitational potential energy*. The gravitational potential energy of water is used to generate electricity in hydroelectric plants. Electricity may be described in terms of electrical force and *electrical energy* (Chapter 8.2). This energy is associated with the motions of electric charges (electric currents). It is electrical energy that runs numerous appliances and machines that do work for us.

Electrical forces hold or bond atoms and molecules together, and there is potential energy in these bonds. When fuel is burned (a chemical reaction), a rearrangement of the electrons and atoms in the fuel occurs, and energy—*chemical energy*—is released. Our main fossil fuels (wood, coal, petroleum, and natural gas) are indirectly the result of

Table 4.4 Common Forms of Energy

Chemical energy
Electrical energy
Gravitational (potential) energy
Nuclear energy
Radiant (electromagnetic) energy
Thermal energy

the Sun's energy. This *radiant energy*, or light from the Sun, is electromagnetic radiation. When electrically charged particles are accelerated, electromagnetic waves are "radiated" (Chapter 6.3). Visible light, radio waves, TV waves, and microwaves are examples of electromagnetic waves.

A more recent entry into the energy sweepstakes is *nuclear energy*. Nuclear energy is the source of the Sun's energy. Fundamental nuclear forces are involved, and the rearrangement of nuclear particles to form different nuclei results in the release of energy as some of the mass of the nuclei is converted into energy. In this case mass is considered to be a form of energy (Chapter 10). See ● Table 4.4 for a summary of the common forms of energy.

As we go about our daily lives, each of us is constantly using and giving off energy from body heat. The source of this energy is food (● Fig. 4.13). An average adult radiates heat energy at about the same rate as a 100-W light bulb. This explains why it can become uncomfortably warm in a crowded room. In winter extra clothing helps keep our body heat from escaping. In summer the evaporation of perspiration helps remove heat and cool our bodies.

The commercial sources of energy on a national scale are mainly coal, oil (petroleum), and natural gas. Nuclear and hydroelectric energies are about the only other significant commercial sources. ● Figure 4.14 shows the current percentage of energy supplied by each of these resources. About a quarter of the oil consumption in the United States comes from imported oil. The United States does have large reserves of coal, but there are some pollution problems with this resource (see Chapter 20.4). Even so, it is still a major energy source for the generation of electricity along with natural gas, which has come into increasing use (● Fig. 4.15).

Perhaps you're wondering where all this energy goes and who consumes it. ● Figure 4.16 gives a general breakdown of energy use by economic sector.

Energy Consumption

All these forms of energy go into satisfying a growing demand. Although the United States has less than 5% of the world's population, it accounts for approximately 26% of the world's annual energy consumption of fossil fuels: coal, oil, and natural gas. With increasing world population (now over 7.8 billion), there is an ever-increasing demand for energy. Where will it come from?

Of course, fossil fuels and nuclear processes will continue to be used, but increasing use gives rise to pollution and environmental concerns. Fossil fuels contribute to


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Fgure 4.13 Refueling The source of human energy is food. Food is the fuel our bodies convert into energy that is used in performing tasks and carrying out body functions. Also, energy is given off as heat and may be stored for later use.

Figure 4.17 Grand Coulee Dam The potential energy of dammed water can be used to generate electricity. Shown here, the Grand Coulee Dam across the Columbia River in Washington state is the largest facility in the United States producing hydroelectric power and the fifth largest in the world.

Harald Sund/Photographer's Choice/Getty Images

- *Hydropower* Hydropower is used widely to produce electricity (● Fig. 4.17). We would like to increase this production because falling water generates electricity cleanly and efficiently. However, most of the best sites for dams have already been developed. There are over 2000 hydroelectric dams in the United States. The damming of rivers usually results in the loss of agricultural land and alters ecosystems.
- *Wind power* Wind applications have been used for centuries. If you drive north from Los Angeles into the desert, you will suddenly come upon acres and acres of wind turbines (● Fig. 4.18). Windmills for pumping water were once common on American farms. There have been significant advances in wind technology, and modern wind turbines generate electricity directly. The wind is free and nonpolluting. However, the limited availability of sites with sufficient wind (at least 20 km/h or 12 mi/h) prevents widespread development of wind power. And the wind does not blow continuously.

  One projected solution is a wind farm of floating wind turbines offshore in the ocean. This technology requires the development of an undersea power cable network to bring the electricity ashore.
- *Solar power* The Sun is our major source of energy and one of the most promising sources of energy for the future. Solar power is currently put to use, but more can be done. Solar heating and cooling systems are used in some homes and businesses, and other technologies focus on concentrating solar radiation for energy production.

Figure 4.18 Wind Energy Wind turbines near Tehachapi Pass, California, generate electricity using the desert wind.

Greg Randles/Shutterstock.com


DOE/NREL

Figure 4.20 The Geysers Located 72 miles north of San Francisco, the "Geysers" is a naturally occurring steam field reservoir below the Earth's surface used to generate electricity. As the largest complex of geothermal power plants in the world, the net generation capacity is enough to provide electricity for 750,000 homes.


markferguson2/Alamy Stock Photo

Figure 4.21 Wave-Action Electrical Generation The Aguçadoura wave in Peru converts the energy of ocean surface waves into electrical power. The snake-like structures float in the water, where they arc and bend, forcing oil to be pumped through high-pressure motors that in turn drive electrical generators. The power is then transferred to shore. (Underwater turbine generators also take advantage of the in-and-out motions of ocean water due to the daily rise and fall of tides.)

Marmaduke St. John/Alamy Stock Photo

Figure 4.22 Take Your Choice A sign advertising gasoline (3 grades), ethanol, diesel, biodiesel, natural gas, and propane at a San Diego (CA) filling station.

by strong tides going in and out of the Rance River. Underwater generators are planned to take advantage of the tide going in and out. Surface generators are also being developed to take advantage of surface wave action (● Fig. 4.21).

- *Biofuels* Because of the agricultural capacity of the United States, large amounts of corn can be produced, from which ethanol (an alcohol) is made. A mixture of gasoline and ethanol, called "gasohol," is used to run cars. Ethanol is advertised as reducing air pollution (less carbon dioxide) when mixed and burned with gasoline. Some pollution is reduced, but there are still emissions. Also, there is the disposal of waste by-products from the ethanol production to consider, and more fossil-fuel energy is actually used in ethanol production than the use of ethanol saves.

In some places a variety of biofuels are available. ● Figure 4.22 shows a filling station in San Diego, California, advertising fuel choices, including ethanol and biodiesel. (Biodiesel is typically made by chemically reacting vegetable oil with an alcohol.)

Work is being done on algae-based biofuels. Algae are organisms that grow in aquatic environments. A green layer of algae is commonly seen on ponds in the summer. Algae use photosynthesis (Chapter 19.1) to produce energy for rapid growth