

This International Student Edition is for use outside of the U.S.

# physical science

Twelfth Edition

Bill W. Tillery

Mc  
Graw  
Hill  
Education

## Conversion Factors

### Length

1 in = 2.54 cm  
 1 cm = 0.394 in  
 1 ft = 30.5 cm  
 1 m = 39.4 in = 3.281 ft  
 1 km = 0.621 mi  
 1 mi = 5,280 ft = 1.609 km  
 1 light-year =  $9.461 \times 10^{15}$  m

### Mass

1 lb = 453.6 g (where  $g = 9.8 \text{ m/s}^2$ )  
 1 kg = 2.205 lb (where  $g = 9.8 \text{ m/s}^2$ )  
 1 atomic mass unit  $u = 1.66061 \times 10^{-27}$  kg

### Volume

1 liter = 1.057 quarts  
 1 in<sup>3</sup> = 16.39 cm<sup>3</sup>  
 1 gallon = 3.786 liter  
 1 ft<sup>3</sup> = 0.02832 m<sup>3</sup>

### Energy

1 cal = 4.184 J  
 1 J = 0.738 ft·lb = 0.239 cal  
 1 ft·lb = 1.356 J  
 1 Btu = 252 cal = 778 ft·lb  
 1 kWh =  $3.60 \times 10^6$  J = 860 kcal  
 1 hp = 550 ft·lb/s = 746 W  
 1 W = 0.738 ft·lb/s  
 1 Btu/h = 0.293 W  
 Absolute zero (0K) =  $-273.15^\circ\text{C}$   
 1 J =  $6.24 \times 10^{18}$  eV  
 1 eV =  $1.6022 \times 10^{-19}$  J

### Speed

1 km/h = 0.2778 m/s = 0.6214 mi/h  
 1 m/s = 3.60 km/h = 2.237 mi/h = 3.281 ft/s  
 1 mi/h = 1.61 km/h = 0.447 m/s = 1.47 ft/s  
 1 ft/s = 0.3048 m/s = 0.6818 mi/h

### Force

1 N = 0.2248 lb  
 1 lb = 4.448 N

### Pressure

1 atm = 1.013 bar =  $1.013 \times 10^5$  N/m<sup>2</sup> = 14.7 lb/in<sup>2</sup>  
 1 lb/in<sup>2</sup> =  $6.90 \times 10^3$  N/m<sup>2</sup>

## Metric Prefixes

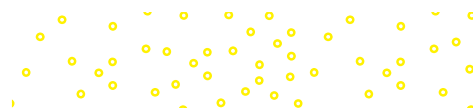
Prefix	Symbol	Meaning	Unit Multiplier
exa-	E	quintillion	$10^{18}$
peta-	P	quadrillion	$10^{15}$
tera-	T	trillion	$10^{12}$
giga-	G	billion	$10^9$
mega-	M	million	$10^6$
kilo-	k	thousand	$10^3$
hecto-	h	hundred	$10^2$
deka-	da	ten	$10^1$
<b>unit</b>			
deci-	d	one-tenth	$10^{-1}$
centi-	c	one-hundredth	$10^{-2}$
milli-	m	one-thousandth	$10^{-3}$
micro-	$\mu$	one-millionth	$10^{-6}$
nano-	n	one-billionth	$10^{-9}$
pico-	p	one-trillionth	$10^{-12}$
femto-	f	one-quadrillionth	$10^{-15}$
atto-	a	one-quintillionth	$10^{-18}$

## Physical Constants

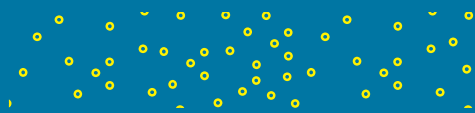
Quantity	Approximate Value
Gravity (Earth)	$g = 9.8 \text{ m/s}^2$
Gravitational law constant	$G = 6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$
Earth radius (mean)	$6.38 \times 10^6 \text{ m}$
Earth mass	$5.97 \times 10^{24} \text{ kg}$
Earth-Sun distance (mean)	$1.50 \times 10^{11} \text{ m}$
Earth-Moon distance (mean)	$3.84 \times 10^8 \text{ m}$
Fundamental charge	$1.60 \times 10^{-19} \text{ C}$
Coulomb law constant	$k = 9.00 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$
Electron rest mass	$9.11 \times 10^{-31} \text{ kg}$
Proton rest mass	$1.6726 \times 10^{-27} \text{ kg}$
Neutron rest mass	$1.6750 \times 10^{-27} \text{ kg}$
Bohr radius	$5.29 \times 10^{-11} \text{ m}$
Avogadro's number	$6.022045 \times 10^{23}/\text{mol}$
Planck's constant	$6.62 \times 10^{-34} \text{ J}\cdot\text{s}$
Speed of light (vacuum)	$3.00 \times 10^8 \text{ m/s}$
Pi	$\pi = 3.1415926536$

## Greek Letters

Alpha	A	$\alpha$	Nu	N	$\nu$
Beta	B	$\beta$	Xi	$\Xi$	$\xi$
Gamma	$\Gamma$	$\gamma$	Omicron	O	o
Delta	$\Delta$	$\delta$	Pi	$\Pi$	$\pi$
Epsilon	E	$\epsilon$	Rho	P	$\rho$
Zeta	Z	$\zeta$	Sigma	$\Sigma$	$\sigma$
Eta	H	$\eta$	Tau	T	$\tau$
Theta	$\Theta$	$\theta$	Upsilon	$\Upsilon$	$\upsilon$
Iota	I	$\iota$	Phi	$\Phi$	$\phi$
Kappa	K	$\kappa$	Chi	X	$\chi$
Lambda	$\Lambda$	$\lambda$	Psi	$\Psi$	$\psi$
Mu	M	$\mu$	Omega	$\Omega$	$\omega$







TWELFTH EDITION

# PHYSICAL SCIENCE

BILL W. TILLERY

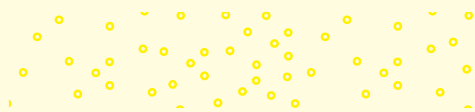
ARIZONA STATE UNIVERSITY

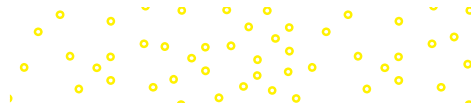
STEPHANIE J. SLATER

CENTER FOR ASTRONOMY & PHYSICS EDUCATION RESEARCH

TIMOTHY F. SLATER

UNIVERSITY OF WYOMING





## PHYSICAL SCIENCE

Published by McGraw-Hill Education, 2 Penn Plaza, New York, NY 10121. Copyright © 2020 by McGraw-Hill Education. All rights reserved. Printed in the United States of America. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of McGraw-Hill Education, including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LWI 21 20 19 18

ISBN 978-1-260-56592-8

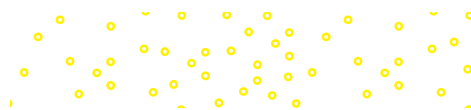
MHID 1-260-56592-0

Cover Image: ©Shutterstock/D K Grove

All credits appearing on page or at the end of the book are considered to be an extension of the copyright page

The Internet addresses listed in the text were accurate at the time of publication. The inclusion of a website does not indicate an endorsement by the authors or McGraw-Hill Education, and McGraw-Hill Education does not guarantee the accuracy of the information presented at these sites.

[mheducation.com/highered](http://mheducation.com/highered)



# BRIEF CONTENTS

Preface xiii

**1** What Is Science? 1

## PHYSICS

**2** Motion 25

**3** Energy 62

**4** Heat and Temperature 87

**5** Wave Motions and  
Sound 116

**6** Electricity 140

**7** Light 178

## CHEMISTRY

**8** Atoms and Periodic  
Properties 205

**9** Chemical Bonds 231

**10** Chemical Reactions 253

**11** Water and Solutions 276

**12** Organic Chemistry 300

**13** Nuclear Reactions 324

## ASTRONOMY

**14** The Universe 352

**15** The Solar System 377

**16** Earth in Space 405

## EARTH SCIENCE

**17** Rocks and Minerals 433

**18** Plate Tectonics 454

**19** Building Earth's  
Surface 477

**20** Shaping Earth's  
Surface 501

**21** Geologic Time 522

**22** The Atmosphere  
of Earth 543

**23** Weather and Climate 567

**24** Earth's Waters 600

Appendix **A** A-1

Appendix **B** A-9

Appendix **C** A-11

Appendix **D** A-13

Appendix **E** A-25

**Index** I-1

# CONTENTS

Preface xiii

## 1 What Is Science? 1

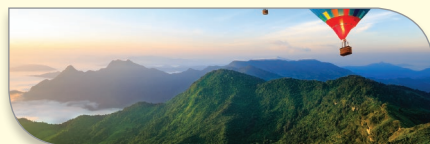


©Steve Satushek/Getty Images

- 1.1 Objects and Properties 2
- 1.2 Quantifying Properties 4
- 1.3 Measurement Systems 4
- 1.4 Standard Units for the Metric System 5
  - Length 5
  - Mass 5
  - Time 6
- 1.5 Metric Prefixes 6
- 1.6 Understandings from Measurements 7
  - Data 7
  - Ratios and Generalizations 7
  - The Density Ratio 8
  - Symbols and Equations 10
  - How to Solve Problems 12
- 1.7 The Nature of Science 13
  - The Scientific Method 14
  - Explanations and Investigations 14
- Science and Society: Basic and Applied Research 15**
  - Laws and Principles 17
  - Models and Theories 17
- Summary 19
- People Behind the Science: Florence Bascom (1862–1945) 20**
  - Key Terms* 21
  - Applying the Concepts* 21
  - Questions for Thought* 23
  - For Further Analysis* 24
  - Invitation to Inquiry* 24
  - Parallel Exercises* 24

## PHYSICS

## 2 Motion 25



©Patrick Foto/Shutterstock

- 2.1 Describing Motion 26
- 2.2 Measuring Motion 27
  - Speed 27
  - Velocity 29
  - Acceleration 29
- Science and Society: Transportation and the Environment 31**
  - Forces 32
- 2.3 Horizontal Motion on Land 34
- 2.4 Falling Objects 35
- A Closer Look: A Bicycle Racer's Edge 37**
- A Closer Look: Free Fall 38**
- 2.5 Compound Motion 38
  - Vertical Projectiles 39
  - Horizontal Projectiles 39
- 2.6 Three Laws of Motion 41
  - Newton's First Law of Motion 41
  - Newton's Second Law of Motion 42
  - Weight and Mass 44
  - Newton's Third Law of Motion 45
- 2.7 Momentum 47
  - Conservation of Momentum 47
  - Impulse 48
- 2.8 Forces and Circular Motion 49
- 2.9 Newton's Law of Gravitation 50
  - Earth Satellites 52
- A Closer Look: Gravity Problems 53**
  - Weightlessness 54
- People Behind the Science: Isaac Newton (1642–1727) 55**

- Summary 56
- Key Terms* 57
- Applying the Concepts* 57
- Questions for Thought* 60
- For Further Analysis* 60
- Invitation to Inquiry* 60
- Parallel Exercises* 60

## 3 Energy 62



©Glen Allison/Getty Images

- 3.1 Work 63
  - Units of Work 64
  - Power 65
- A Closer Look: Simple Machines 66**
- 3.2 Motion, Position, and Energy 68
  - Potential Energy 68
  - Kinetic Energy 69
- 3.3 Energy Flow 70
  - Work and Energy 71
  - Energy Forms 71
  - Energy Conversion 73
  - Energy Conservation 75
  - Energy Transfer 75
- 3.4 Energy Sources Today 76
  - Petroleum 76
- Science and Society: Grow Your Own Fuel? 77**
  - Coal 77
  - Moving Water 77
  - Nuclear 78
- People Behind the Science: James Prescott Joule (1818–1889) 78**
  - Conserving Energy 79
- 3.5 Energy Sources Tomorrow 80
  - Solar Technologies 80
  - Geothermal Energy 81
  - Hydrogen 81
- Summary 82

*Key Terms* 82  
*Applying the Concepts* 82  
*Questions for Thought* 84  
*For Further Analysis* 84  
*Invitation to Inquiry* 85  
*Parallel Exercises* 85

## 4 Heat and Temperature 87



©Frank Rossbach/Media Bakery

- 4.1 The Kinetic Molecular Theory 88
  - Molecules 88
  - Molecules Interact 89
  - Phases of Matter 89
  - Molecules Move 90
- 4.2 Temperature 91
  - Thermometers 91
  - Temperature Scales 92
- A Closer Look: Goose Bumps and Shivering 94**
- 4.3 Heat 94
  - Heat as Energy Transfer 95
  - Measures of Heat 96
  - Specific Heat 96
  - Heat Flow 98
- Science and Society: Require Insulation? 99**
- 4.4 Energy, Heat, and Molecular Theory 100
  - Phase Change 101
- A Closer Look: Passive Solar Design 103**
  - Evaporation and Condensation 105
- 4.5 Thermodynamics 106
  - The First Law of Thermodynamics 107
  - The Second Law of Thermodynamics 108
  - The Second Law and Natural Processes 108
- People Behind the Science: Count Rumford (Benjamin Thompson) (1753–1814) 109**
  - Summary 110
  - Key Terms* 111
  - Applying the Concepts* 111
  - Questions for Thought* 114
  - For Further Analysis* 114
  - Invitation to Inquiry* 114
  - Parallel Exercises* 114

## 5 Wave Motions and Sound 116



©Medioimages/PunchStock/Getty Images

- 5.1 Forces and Elastic Materials 117
  - Forces and Vibrations 117
  - Describing Vibrations 118
- 5.2 Waves 119
  - Kinds of Mechanical Waves 120
  - Waves in Air 120
- 5.3 Describing Waves 121
- 5.4 Sound Waves 123
  - Sound Waves in Air and Hearing 123
  - Medium Required 123
- A Closer Look: Hearing Problems 124**
  - Velocity of Sound in Air 124
  - Refraction and Reflection 125
  - Interference 127
- 5.5 Energy of Waves 128
  - How Loud Is That Sound? 128
  - Resonance 129
- 5.6 Sources of Sounds 130
  - Vibrating Strings 130
- Science and Society: Laser Bug 132**
  - Sounds from Moving Sources 132
- People Behind the Science: Johann Christian Doppler (1803–1853) 133**
  - Case Study: Doppler Radar 134**
    - Summary 134
    - Key Terms* 135
    - Applying the Concepts* 135
    - Questions for Thought* 138
    - For Further Analysis* 138
    - Invitation to Inquiry* 138
    - Parallel Exercises* 138

## 6 Electricity 140



©CWellsPhotography/Getty Images

- 6.1 Concepts of Electricity 141
  - Electron Theory of Charge 141
  - Measuring Electrical Charges 144

- Electrostatic Forces 145
- Force Fields 145
- Electric Potential 147
- 6.2 Electric Current 147
  - The Electric Circuit 148
  - The Nature of Current 149
  - Electrical Resistance 151
  - Electrical Power and Electrical Work 152

### **People Behind the Science: Benjamin Franklin (1706–1790) 155**

- 6.3 Magnetism 156
  - Magnetic Poles 156
  - Magnetic Fields 156
  - The Source of Magnetic Fields 157
- 6.4 Electric Currents and Magnetism 159
  - Current Loops 159
  - Applications of Electromagnets 160
- 6.5 Electromagnetic Induction 162
- A Closer Look: Current War 163**
  - Generators 163
  - Transformers 163
- 6.6 Circuit Connections 165
  - Voltage Sources in Circuits 165
- Science and Society: Blackout Reveals Pollution 167**
  - Resistances in Circuits 167
- A Closer Look: Solar Cells 168**
  - Household Circuits 170
- Summary 171
- Key Terms* 172
- Applying the Concepts* 173
- Questions for Thought* 175
- For Further Analysis* 175
- Invitation to Inquiry* 176
- Parallel Exercises* 176

## 7 Light 178



©Photodisc/SuperStock

- 7.1 Sources of Light 179
- Case Study: Bioluminescent 180**
- 7.2 Properties of Light 181
  - Light Interacts with Matter 181
  - Reflection 183
  - Refraction 184
- A Closer Look: Optics 186**
  - Dispersion and Color 189



## A Closer Look: The Rainbow 190

- 7.3 Evidence for Waves 191
  - Interference 191
  - Polarization 191

## A Closer Look: Optic Fibers 192

## A Closer Look: Lasers 193

## A Closer Look: Why Is the Sky Blue? 194

- 7.4 Evidence for Particles 194
  - Photoelectric Effect 194
  - Quantization of Energy 195
- 7.5 The Present Theory 196
- 7.6 Relativity 196
  - Special Relativity 197

## People Behind the Science:

### James Clerk Maxwell (1831–1879) 198

- General Theory 199
- Relativity Theory Applied 199
- Summary 199
- Key Terms 200
- Applying the Concepts 200
- Questions for Thought 203
- For Further Analysis 203
- Invitation to Inquiry 203
- Parallel Exercises 203

## CHEMISTRY

## 8 Atoms and Periodic Properties 205



©McGraw-Hill Education/Charles D. Winters, photographer

- 8.1 Atomic Structure
  - Discovered 206
  - Discovery of the Electron 207

### Case Study: Discovery of the Electron 208

- The Nucleus 208

### Case Study: Oil Drop Experiment 209

- 8.2 The Bohr Model 211
  - The Quantum Concept 211
  - Atomic Spectra 211
  - Bohr's Theory 212
- 8.3 Quantum Mechanics 214
  - Matter Waves 215
  - Wave Mechanics 216
  - The Quantum Mechanics Model 216

## Science and Society:

### Atomic Research 217

- 8.4 Electron Configuration 218
- 8.5 The Periodic Table 219
- 8.6 Metals, Nonmetals, and Semiconductors 221

## A Closer Look: The Rare Earths 222

## People Behind the Science:

### Dmitri Ivanovich Mendeleev (1834–1907) 223

## A Closer Look: Semiconductors 224

- Summary 224
- Key Terms 225
- Applying the Concepts 226
- Questions for Thought 228
- For Further Analysis 228
- Invitation to Inquiry 228
- Parallel Exercises 229

## 9 Chemical Bonds 231



©McGraw-Hill Education

- 9.1 Compounds and Chemical Change 232
- 9.2 Valence Electrons and Ions 234
- 9.3 Chemical Bonds 235
  - Ionic Bonds 235
  - Covalent Bonds 238
- 9.4 Bond Polarity 240
- Case Study: Electronegativity 242
- 9.5 Composition of
  - Compounds 242
  - Ionic Compound Names 243
  - Ionic Compound Formulas 243
  - Covalent Compound Names 244

## Science and Society:

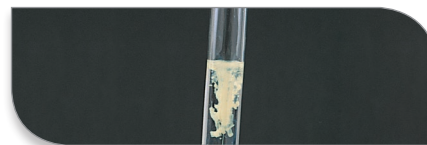
### Microwave Ovens and Molecular Bonds 245

- Covalent Compound Formulas 246

## People Behind the Science: Linus Carl Pauling (1901–1994) 247

- Summary 247
- Key Terms 248
- Applying the Concepts 248
- Questions for Thought 251
- For Further Analysis 251
- Invitation to Inquiry 251
- Parallel Exercises 251

## 10 Chemical Reactions 253



©McGraw-Hill Education/Terry Wild Studio, photographer

- 10.1 Chemical Formulas 254
  - Molecular and Formula Weights 255
  - Percent Composition of Compounds 255
- 10.2 Chemical Equations 257
  - Balancing Equations 257
- Case Study: Conservation of Mass 261
  - Generalizing Equations 261
- 10.3 Types of Chemical Reactions 262
  - Combination Reactions 263
  - Decomposition Reactions 263
  - Replacement Reactions 264
  - Ion Exchange Reactions 265
- 10.4 Information from Chemical Equations 266
  - Units of Measurement used with Equations 267
- Science and Society: The Catalytic Converter 269
  - Quantitative Uses of Equations 269
- People Behind the Science: Emma Perry Carr (1880–1972) 270
  - Summary 271
  - Key Terms 271
  - Applying the Concepts 271
  - Questions for Thought 274
  - For Further Analysis 274
  - Invitation to Inquiry 274
  - Parallel Exercises 274

## 11 Water and Solutions 276

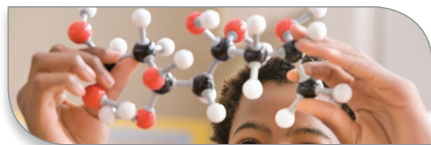


©Digital Archive Japan/Alamy Stock Photo

- 11.1 Household Water 277
- Science and Society: Who Has the Right? 278
- 11.2 Properties of Water 278
  - Structure of Water Molecules 278

- The Dissolving Process 280
- Concentration of Solutions 281
- A Closer Look: Decompression Sickness 284**
- Solubility 284
- Science and Society: What Is BPA? 285**
- 11.3 Properties of Water
  - Solutions 285
  - Electrolytes 285
  - Boiling Point 286
  - Freezing Point 287
- 11.4 Acids, Bases, and Salts 288
  - Properties of Acids and Bases 288
  - Explaining Acid-Base Properties 289
  - Strong and Weak Acids and Bases 290
  - The pH Scale 291
  - Properties of Salts 291
  - Hard and Soft Water 292
- A Closer Look: Acid Rain 293**
- People Behind the Science: Johannes Nicolaus Brønsted (1879–1947) 294**
- Summary 295
- Key Terms 295*
- Applying the Concepts 295*
- Questions for Thought 298*
- For Further Analysis 298*
- Invitation to Inquiry 298*
- Parallel Exercises 298*

## 12 Organic Chemistry 300

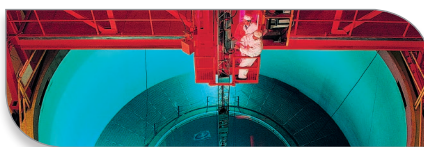


©Fuse/Getty Images

- 12.1 Organic Compounds 301
- 12.2 Hydrocarbons 302
  - Alkenes and Alkynes 304
  - Cycloalkanes and Aromatic Hydrocarbons 304
- 12.3 Petroleum 305
- 12.4 Hydrocarbon Derivatives 307
  - Alcohols 308
  - Ethers, Aldehydes, and Ketones 310
  - Organic Acids and Esters 310
- Science and Society: Aspirin, a Common Organic Compound 311**
- 12.5 Organic Compounds of Life 312
  - Proteins 312

- Carbohydrates 313
- Fats and Oils 314
- Synthetic Polymers 315
- A Closer Look: How to Sort Plastic Bottles for Recycling 317**
- People Behind the Science: Alfred Bernhard Nobel (1833–1896) 318**
- Summary 319
- Key Terms 319*
- Applying the Concepts 320*
- Questions for Thought 322*
- For Further Analysis 322*
- Invitation to Inquiry 322*
- Parallel Exercises 323*

## 13 Nuclear Reactions 324



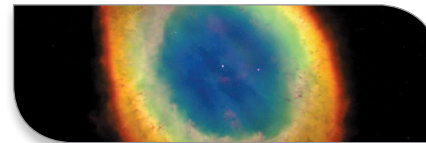
©Digital Vision/Getty Images

- 13.1 Natural Radioactivity 325
  - Nuclear Equations 326
  - The Nature of the Nucleus 327
  - Types of Radioactive Decay 328
  - Radioactive Decay Series 330
- 13.2 Measurement of Radiation 332
  - Measurement Methods 332
- A Closer Look: How Is Half-Life Determined? 333**
- Radiation Units 333
- A Closer Look: Carbon Dating 334**
- Radiation Exposure 334
- 13.3 Nuclear Energy 335
- A Closer Look: Radiation and Food Preservation 336**
- Nuclear Fission 337
- A Closer Look: Nuclear Medicine 338**
- Nuclear Power Plants 338
- Nuclear Fusion 341
- A Closer Look: Three Mile Island, Chernobyl, and Fukushima I 342**
- A Closer Look: Nuclear Waste 344**
- Science and Society: High-Level Nuclear Waste 345**
- The Source of Nuclear Energy 345
- People Behind the Science: Marie Curie (1867–1934) 346**
- Summary 347
- Key Terms 347*
- Applying the Concepts 347*

- Questions for Thought 350*
- For Further Analysis 350*
- Invitation to Inquiry 350*
- Parallel Exercises 350*

## ASTRONOMY

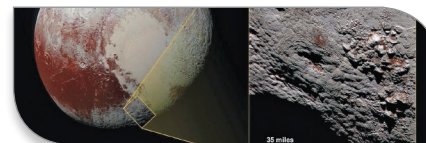
### 14 The Universe 352



Source: NASA/ESA

- 14.1 The Night Sky 353
- 14.2 Stars 355
  - Origin of Stars 355
  - Brightness of Stars 357
  - Star Temperature 358
  - Star Types 359
  - The Life of a Star 360
- A Closer Look: Observing with New Technology 363**
- Science and Society: Light Pollution 364**
- 14.3 Galaxies 364
- A Closer Look: Extraterrestrials? 365**
- The Milky Way Galaxy 365
- People Behind the Science: Jocelyn (Susan) Bell Burnell (1943– ) 366**
- Other Galaxies 367
- 14.4 The Universe 367
- A Closer Look: Dark Energy 368**
- A Closer Look: Dark Matter 370**
- Summary 371
- Key Terms 372*
- Applying the Concepts 372*
- Questions for Thought 374*
- For Further Analysis 375*
- Invitation to Inquiry 375*
- Parallel Exercises 375*

### 15 The Solar System 377



Source: NASA/JHUAPL/SwRI

- 15.1 Planets Near the Sun 378
  - Mercury 380
  - Venus 381
  - Mars 382

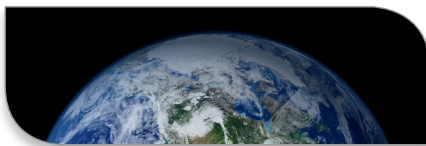
**Case Study: Worth the Cost? 385**

- 15.2 Planets Far from the Sun 386
  - Jupiter 386
  - Saturn 388
  - Uranus and Neptune 389
- 15.3 Small Bodies of the Solar System 390
  - Comets 390
  - Asteroids 392
  - Meteors and Meteorites 393
- 15.4 Origin of the Solar System 394
  - Stage A 395
  - Stage B 395
  - Stage C 396
- 15.5 Ideas About the Solar System 396
  - The Geocentric Model 396
  - The Heliocentric Model 397

**People Behind the Science: Gerard Peter Kuiper (1905–1973) 400**

- Summary 400
- Key Terms* 401
- Applying the Concepts* 401
- Questions for Thought* 403
- For Further Analysis* 403
- Invitation to Inquiry* 403
- Parallel Exercises* 404

## 16 Earth in Space 405



Source: NASA GSFC image by Robert Simmon and Reto Stockli.

- 16.1 Shape and Size of Earth 406
- 16.2 Motions of Earth 408
  - Orbit 408
  - Rotation 410
  - Precession 411
- 16.3 Place and Time 412
  - Identifying Place 412
  - Measuring Time 413

**Science and Society: Saving Time? 417**

- 16.4 The Moon 420
  - Composition and Features 421
  - History of the Moon 423
- 16.5 The Earth-Moon System 423
  - Phases of the Moon 423
  - Eclipses of the Sun and Moon 424
  - Tides 425

**People Behind the Science: Carl Edward Sagan (1934–1996) 426**

- Summary 427
- Key Terms* 428
- Applying the Concepts* 428
- Questions for Thought* 430
- For Further Analysis* 431
- Invitation to Inquiry* 431
- Parallel Exercises* 431

## EARTH SCIENCE

### 17 Rocks and Minerals 433



©Lissa Harrison

- 17.1 Solid Earth Materials 434
- 17.2 Minerals 435
  - Crystal Structures 436
  - Silicates and Nonsilicates 436
  - Physical Properties of Minerals 438
- 17.3 Mineral-Forming Processes 441
- 17.4 Rocks 441
  - Igneous Rocks 442
  - Sedimentary Rocks 443

**A Closer Look: Asbestos 445**

**Science and Society: Using Mineral Resources 446**

**People Behind the Science: Victor Moritz Goldschmidt (1888–1947) 447**

- Metamorphic Rocks 447
- 17.5 The Rock Cycle 449
- Summary 449
- Key Terms* 449
- Applying the Concepts* 450
- Questions for Thought* 451
- For Further Analysis* 452
- Invitation to Inquiry* 452
- Parallel Exercises* 452

### 18 Plate Tectonics 454



Source: Library of Congress Prints and Photographs Division [LC-DIG-ppmsca-18014]

- 18.1 History of Earth's Interior 455
- 18.2 Earth's Internal Structure 456
  - Body Waves 456

- Surface Waves 456
- The Crust 457
- The Mantle 458
- The Core 458
- A More Detailed Structure 459

**A Closer Look: Seismic Tomography 460**

- 18.3 Theory of Plate Tectonics 460
  - Evidence from Earth's Magnetic Field 461
  - Evidence from the Ocean 461
  - Lithosphere Plates and Boundaries 463

**A Closer Look: Measuring Plate Movement 465**

- Present-Day Understandings 467

**People Behind the Science: Harry Hammond Hess (1906–1969) 468**

**Science and Society: Geothermal Energy 469**

- Summary 470
- Key Terms* 471
- Applying the Concepts* 471
- Questions for Thought* 474
- For Further Analysis* 474
- Invitation to Inquiry* 474
- Parallel Exercises* 474

### 19 Building Earth's Surface 477



©Dr. Parvinder Sethi

- 19.1 Interpreting Earth's Surface 478
- 19.2 Earth's Changing Features 479
  - Stress and Strain 479
  - Folding 480
  - Joints and Faults 481
- 19.3 Earthquakes 484
  - Causes of Earthquakes 484
  - Locating and Measuring Earthquakes 485
  - Measuring Earthquake Strength 487

**A Closer Look: Earthquake Safety 488**

- 19.4 Origin of Mountains 489
  - Folded and Faulted Mountains 489
  - Volcanic Mountains 490



**A Closer Look: Volcanoes Change the World** 493  
**People Behind the Science: James Hutton (1726–1797)** 494  
 Summary 495  
*Key Terms* 495  
*Applying the Concepts* 495  
*Questions for Thought* 498  
*For Further Analysis* 498  
*Invitation to Inquiry* 498  
*Parallel Exercises* 499

## 20 Shaping Earth's Surface 501



©Doug Sherman/Geofile

20.1 Weathering, Erosion, and Transportation 503  
 20.2 Weathering 503  
 20.3 Soils 506  
 20.4 Erosion 506  
   Mass Movement 506  
   Running Water 508  
   Glaciers 510  
   Wind 513  
**Science and Society: Acid Rain** 514  
**People Behind the Science: John Wesley Powell (1834–1902)** 515  
 20.5 Development of  
   Landscapes 515  
   Rock Structure 515  
   Weathering and Erosion Processes 515  
   Stage of Development 515  
 Summary 516  
*Key Terms* 517  
*Applying the Concepts* 517  
*Questions for Thought* 519  
*For Further Analysis* 519  
*Invitation to Inquiry* 519  
*Parallel Exercises* 520

## 21 Geologic Time 522



©Zoonar GmbH/Alamy Stock Photo

21.1 Fossils 523  
   Early Ideas about Fossils 524  
   Types of Fossilization 524  
 21.2 Reading Rocks 526  
   Arranging Events in Order 527  
   Correlation 528  
 21.3 Geologic Time 530  
   Early Attempts at Earth Dating 530  
   Modern Techniques 531  
   The Geologic Time Scale 532  
   Geologic Periods and Typical Fossils 534

**People Behind the Science: Eduard Suess (1831–1914)** 535  
 Mass Extinctions 535  
 Interpreting Geologic History—A Summary 536  
 Summary 537  
*Key Terms* 537  
*Applying the Concepts* 537  
*Questions for Thought* 540  
*For Further Analysis* 540  
*Invitation to Inquiry* 540  
*Parallel Exercises* 540

## 22 The Atmosphere of Earth 543



©Stephanie J. Slater

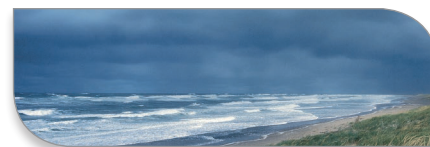
22.1 The Atmosphere 544  
   Composition of the Atmosphere 545  
   Atmospheric Pressure 546  
   Warming the Atmosphere 547

**A Closer Look: Hole in the Ozone Layer?** 548  
   Structure of the Atmosphere 549  
 22.2 The Winds 550  
**A Closer Look: The Windchill Factor** 552  
   Local Wind Patterns 552

**Science and Society: Use Wind Energy?** 553  
   Global Wind Patterns 554  
 22.3 Water and the Atmosphere 555  
   Evaporation and Condensation 556

**People Behind the Science: James Ephraim Lovelock (1919–)** 559  
   Fog and Clouds 560  
 Summary 562  
*Key Terms* 562  
*Applying the Concepts* 562  
*Questions for Thought* 565  
*For Further Analysis* 565  
*Invitation to Inquiry* 565  
*Parallel Exercises* 565

## 23 Weather and Climate 567



©Ingram Publishing/age fotostock

23.1 Clouds and Precipitation 568  
   Cloud-Forming Processes 569  
   Origin of Precipitation 571  
 23.2 Weather Producers 571  
   Air Masses 572  
   Weather Fronts 573

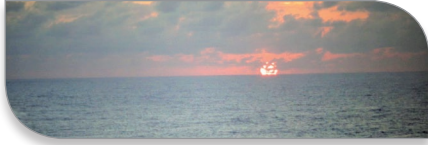
**Science and Society: Urban Heat Islands** 575

  Waves and Cyclones 575  
   Major Storms 576  
 23.3 Weather Forecasting 581  
   Climate 582  
   Major Climate Groups 582  
   Regional Climatic Influence 584  
   Describing Climates 585  
 23.4 Climate Change 588  
   Causes of Global Climate Change 589

**Case Study: El Niño** 590  
   Global Warming 591  
**People Behind the Science: Vilhelm Firman Koren Bjerknes (1862–1951)** 592

Summary 593  
Key Terms 593  
Applying the Concepts 593  
Questions for Thought 596  
For Further Analysis 596  
Invitation to Inquiry 596  
Parallel Exercises 596

## 24 Earth's Waters 600



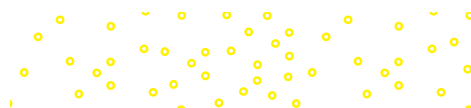
©Timothy F. Slater

24.1 Water on Earth 601  
Freshwater 602  
**Science and Society: Water  
Quality 603**

Surface Water 603  
Groundwater 605  
Freshwater as a  
Resource 607  
**A Closer Look: Water Quality  
and Wastewater Treatment 608**  
24.2 Seawater 610  
Oceans and Seas 611  
The Nature of Seawater 612  
Movement of Seawater 613  
**A Closer Look: Estuary  
Pollution 614**  
**A Closer Look: Rogue  
Waves 617**  
**People Behind the Science:  
Rachel Louise Carson  
(1907–1964) 618**  
24.3 The Ocean Floor 620  
Summary 621  
Key Terms 621  
Applying the Concepts 622

*Questions for Thought* 624  
*For Further Analysis* 624  
*Invitation to Inquiry* 624  
*Parallel Exercises* 624

**Appendix A** A-1  
**Appendix B** A-9  
**Appendix C** A-11  
**Appendix D** A-13  
**Appendix E** A-25  
**Index** I-1



# PREFACE

*Physical Science* is a straightforward, easy-to-read but substantial introduction to the fundamental behavior of matter and energy. It is intended to serve the needs of nonscience majors who are required to complete one or more physical science courses. It introduces basic concepts and key ideas while providing opportunities for students to learn reasoning skills and a new way of thinking about their environment. No prior work in science is assumed. The language, as well as the mathematics, is as simple as can be practical for a college-level science course.

## ORGANIZATION

The *Physical Science* sequence of chapters is flexible, and the instructor can determine topic sequence and depth of coverage as needed. The materials are also designed to support a conceptual approach or a combined conceptual and problem-solving approach. With laboratory studies, the text contains enough material for the instructor to select a sequence for a two-semester course. It can also serve as a text in a one-semester astronomy and earth science course or in other combinations.

## MEETING STUDENT NEEDS

*Physical Science* is based on two fundamental assumptions arrived at as the result of years of experience and observation from teaching the course: (1) that students taking the course often have very limited background and/or aptitude in the natural sciences; and (2) that these types of student will better grasp the ideas and principles of physical science that are discussed with minimal use of technical terminology and detail. In addition, it is critical for the student to see relevant applications of the material to everyday life. Most of these everyday-life applications, such as environmental concerns, are not isolated in an arbitrary chapter; they are discussed where they occur naturally throughout the text.

Each chapter presents historical background where appropriate, uses everyday examples in developing concepts, and follows a logical flow of presentation. The historical chronology, of special interest to the humanistically inclined nonscience major, serves to humanize the science being presented. The use of everyday examples appeals to the nonscience major, typically accustomed to reading narration, not scientific technical writing, and also tends to bring relevancy to the material being presented. The logical flow of presentation is helpful to students not accustomed to thinking about relationships between what is being read and previous knowledge learned, a useful



©Corbis/VCG/Getty Images

skill in understanding the physical sciences. Worked examples help students to integrate concepts and understand the use of relationships called equations. These examples also serve as a model for problem solving; consequently, special attention is given to *complete* unit work and to the clear, fully expressed use of mathematics. Where appropriate, chapters contain one or more activities, called *Concepts Applied*, that use everyday materials rather than specialized laboratory equipment. These activities are intended to bring the science concepts closer to the world of the student. The activities are supplemental and can be done as optional student activities or as demonstrations.

## A STUDENT-FOCUSED REVISION

For the twelfth edition, real student data points and input, derived from thousands of our LearnSmart users, were used to guide the revision. LearnSmart Heat Maps provided a quick visual snapshot of usage of portions of the text and the relative difficulty students experienced in mastering the content. With these data, the text content was honed:

- If the data indicated that the subject covered was more difficult than other parts of the book, as evidenced by a high proportion of students responding incorrectly to LearnSmart probes, the text content was substantively revised or reorganized to be as clear and illustrative as possible.
- When the data showed that a smaller percentage of the students had difficulty learning the material, the text was revised to provide a clearer presentation by rewriting the section or providing additional example problems to strengthen student problem-solving skills.

This process was used to direct the revision of this new edition, along with other instructor and student feedback. The following “New to This Edition” summary lists the more major additions and refinements.

## NEW TO THIS EDITION

Numerous revisions have been made to the text to update the content on current events and to make the text even more user-friendly and relevant for students.

The list below provides chapter-specific updates:

- Throughout the text, issues and illustrations surrounding science, technology and society have been significantly updated, replacing descriptions of out-of-date technologies and replacing them with newer, more relevant ones.
- Photographs and illustrations have received a major face-lift. More than 80 new photographs and illustrations have been included.
- All chapters have been revised to increase readability of the text, figure and illustrations.
- The revised Chapter 15 includes completely revised information related to Mercury, Venus and Mars based upon information from the latest space missions.
- Chapter 23 includes the most recent IPCC information on Earth’s changing climate and its causes.

## THE LEARNING SYSTEM

*Physical Science* has an effective combination of innovative learning aids intended to make the student’s study of science more effective and enjoyable. This variety of aids is included to help students clearly understand the concepts and principles that serve as the foundation of the physical sciences.

## OVERVIEW

Chapter 1 provides an *overview* or orientation to what the study of physical science in general and this text in particular are all about. It discusses the fundamental methods and techniques used by scientists to study and understand the world around us. It also explains the problem-solving approach used throughout the text so that students can more effectively apply what they have learned.

## CHAPTER OPENING TOOLS

### Core Concept and Supporting Concepts

Core and supporting concepts integrate the chapter concepts and the chapter outline. The core and supporting concepts outline and emphasize the concepts at a chapter level. The concepts list is designed to help students focus their studies by identifying the most important topics in the chapter outline.

### Chapter Outline

The chapter outline includes all the major topic headings and subheadings within the body of the chapter. It gives you a quick glimpse of the chapter’s contents and helps you locate sections dealing with particular topics.

## Chapter Overview

Each chapter begins with an introductory overview. The overview previews the chapter’s contents and what you can expect to learn from reading the chapter. It adds to the general outline of the chapter by introducing you to the concepts to be covered, facilitating the integration of topics, and helping you to stay focused and organized while reading the chapter for the first time. After you read the introduction, browse through the chapter, paying particular attention to the topic headings and illustrations so that you get a feel for the kinds of ideas included within the chapter.

## EXAMPLES

Each topic discussed within the chapter contains one or more concrete, worked *Examples* of a problem and its solution as it applies to the topic at hand. Through careful study of these examples, students can better appreciate the many uses of problem solving in the physical sciences.

## APPLYING SCIENCE TO THE REAL WORLD

### Concepts Applied

Each chapter also includes one or more *Concepts Applied* boxes. These activities are simple investigative exercises that students can perform at home or in the classroom to demonstrate important concepts and reinforce understanding of them. This feature also describes the application of those concepts to everyday life.

### Closer Look

One or more boxed *Closer Look* features can be found in each chapter of *Physical Science*. These readings present topics of special human or environmental concern (the use of seat belts, acid rain, and air pollution, for example). In addition to environmental concerns, topics are presented on interesting technological applications (passive solar homes, solar cells, catalytic converters, etc.) or on the cutting edge of scientific research (for example, El Niño and dark energy). All boxed features are informative materials that are supplementary in nature. The *Closer Look* readings serve to underscore the relevance of physical science in confronting the many issues we face daily.

### Science Sketches

This feature found in each chapter of the 12th edition text, engages students in creating their own explanations and analogies by challenging them to create visual representations of concepts.

### Science and Society

These readings relate the chapter’s content to current societal issues. Many of these boxes also include Questions to Discuss that provide an opportunity to discuss issues with your peers.

### Myths, Mistakes, and Misunderstandings

These brief boxes provide short, scientific explanations to dispel a societal myth or a home experiment or project that enables you to dispel the myth on your own.

## People Behind the Science

Many chapters also have fascinating biographies that spotlight well-known scientists, past or present. From these *People Behind the Science* biographies, students learn about the human side of the science: physical science is indeed relevant, and real people do the research and make the discoveries. These readings present physical science in real-life terms that students can identify with and understand.

## END-OF-CHAPTER FEATURES

At the end of each chapter, students will find the following materials:

- **Summary:** highlights the key elements of the chapter.
- **Summary of Equations:** reinforces retention of the equations presented.
- **Key Terms:** gives page references for finding the terms defined within the context of the chapter reading.
- **Applying the Concepts:** tests comprehension of the material covered with a multiple-choice quiz.
- **Questions for Thought:** challenges students to demonstrate their understanding of the topics.
- **Parallel Exercises:** reinforce problem-solving skills. There are two groups of parallel exercises, Group A and Group B. The Group A parallel exercises have complete solutions worked out, along with useful comments, in appendix E. The Group B parallel exercises are similar to those in Group A but do not contain answers in the text. By working through the Group A parallel exercises and checking the solutions in appendix E, students will gain confidence in tackling the parallel exercises in Group B and thus reinforce their problem-solving skills.
- **For Further Analysis:** includes exercises containing analysis or discussion questions, independent investigations, and activities intended to emphasize critical thinking skills and societal issues and to develop a deeper understanding of the chapter content.
- **Invitation to Inquiry:** includes exercises that consist of short, open-ended activities that allow you to apply investigative skills to the material in the chapter.

## END-OF-TEXT MATERIALS

Appendices providing math review, additional background details, solubility and humidity charts, solutions for the in-chapter follow-up examples, and solutions for the Group A Parallel Exercises can be found at the back of the text. There is also a Glossary of all key terms, an index, and special tables printed on the inside covers for reference use.

## SUPPLEMENTARY MATERIAL

### Presentation Tools

*Complete set of electronic book images and assets for instructors.*

*Build instructional materials wherever, whenever, and however you want!*

Accessed from your textbook's Connect Instructor's Resources, **Presentation Tools** is an online collection of photos, artwork, and animations that can be used to create customized lectures, visually enhanced tests and quizzes, compelling course websites, or attractive printed support materials. All assets are copyrighted by McGraw-Hill Higher Education but can be used by instructors for classroom purposes. The visual resources in this collection include:

- **Art and Photo Library:** Full-color digital files of all of the illustrations and many of the photos in the text can be readily incorporated into lecture presentations, exams, or custom-made classroom materials.
- **Worked Example Library, Table Library, and Numbered Equations Library:** Access the worked examples, tables, and equations from the text in electronic format for inclusion in your classroom resources.
- **Animations Library:** Files of animations and videos covering the many topics in *Physical Science* are included so that you can easily make use of these animations in a lecture or classroom setting.

Also residing on your textbook's website are

- **PowerPoint Slides:** For instructors who prefer to create their lectures from scratch, all illustrations, photos, and tables are preinserted by chapter into blank PowerPoint slides.
- **Lecture Outlines:** Lecture notes, incorporating illustrations, examples, and tables, have been written to the twelfth edition text. They are provided in PowerPoint format so that you may use these lectures as written or customize them to fit your lecture.

## Laboratory Manual

The *laboratory manual*, written and classroom tested by the author, presents a selection of laboratory exercises specifically written for the interests and abilities of nonscience majors. There are laboratory exercises that require measurement, data analysis, and thinking in a more structured learning environment, while alternative exercises that are open-ended "Invitations to Inquiry" are provided for instructors who would like a less structured approach. When the laboratory manual is used with *Physical Science*, students will have an opportunity to master basic scientific principles and concepts, learn new problem-solving and thinking skills, and understand the nature of scientific inquiry from the perspective of hands-on experiences. The *instructor's edition of the laboratory manual* can be found on the *Physical Science* Connect Instructor's Resources.





# connect®

Students—study more efficiently, retain more and achieve better outcomes. Instructors—focus on what you love—teaching.

## SUCCESSFUL SEMESTERS INCLUDE CONNECT

### FOR INSTRUCTORS

#### You're in the driver's seat.

Want to build your own course? No problem. Prefer to use our turnkey, prebuilt course? Easy. Want to make changes throughout the semester? Sure. And you'll save time with Connect's auto-grading too.

©McGraw-Hill Education



# 65%

## Less Time Grading

#### They'll thank you for it.

Adaptive study resources like SmartBook® help your students be better prepared in less time. You can transform your class time from dull definitions to dynamic debates. Hear from your peers about the benefits of Connect at [www.mheducation.com/highered/connect](http://www.mheducation.com/highered/connect)

#### Make it simple, make it affordable.

Connect makes it easy with seamless integration using any of the major Learning Management Systems—Blackboard®, Canvas, and D2L, among others—to let you organize your course in one convenient location. Give your students access to digital materials at a discount with our inclusive access program. Ask your McGraw-Hill representative for more information.



©Hill Street Studios/Tobin Rogers/Blend Images LLC



#### Solutions for your challenges.

A product isn't a solution. Real solutions are affordable, reliable, and come with training and ongoing support when you need it and how you want it. Our Customer Experience Group can also help you troubleshoot tech problems—although Connect's 99% uptime means you might not need to call them. See for yourself at [status.mheducation.com](http://status.mheducation.com)

# FOR STUDENTS

## Effective, efficient studying.

Connect helps you be more productive with your study time and get better grades using tools like SmartBook, which highlights key concepts and creates a personalized study plan. Connect sets you up for success, so you walk into class with confidence and walk out with better grades.



©Shutterstock/wavebreakmedia

“I really liked this app—it made it easy to study when you don't have your textbook in front of you.”

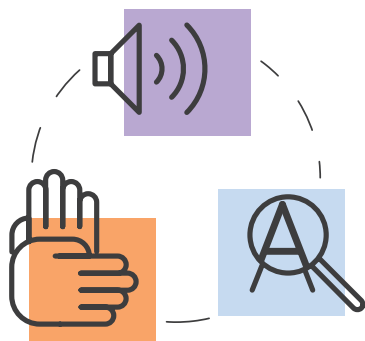
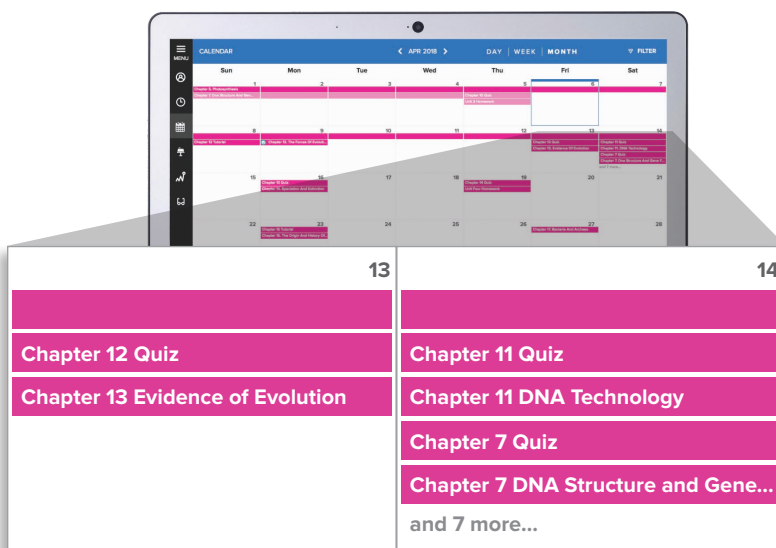
- Jordan Cunningham,  
Eastern Washington University

## Study anytime, anywhere.

Download the free ReadAnywhere app and access your online eBook when it's convenient, even if you're offline. And since the app automatically syncs with your eBook in Connect, all of your notes are available every time you open it. Find out more at [www.mheducation.com/readanywhere](http://www.mheducation.com/readanywhere)

## No surprises.

The Connect Calendar and Reports tools keep you on track with the work you need to get done and your assignment scores. Life gets busy; Connect tools help you keep learning through it all.



## Learning for everyone.

McGraw-Hill works directly with Accessibility Services Departments and faculty to meet the learning needs of all students. Please contact your Accessibility Services office and ask them to email [accessibility@mheducation.com](mailto:accessibility@mheducation.com), or visit [www.mheducation.com/about/accessibility.html](http://www.mheducation.com/about/accessibility.html) for more information.

## ACKNOWLEDGMENTS

We are indebted to the reviewers of the previous editions for their constructive suggestions, new ideas, and invaluable advice. Special thanks and appreciation goes out to our reviewers:

Adedoyin Adeyiga, *Cheyney University of Pennsylvania*  
James E. Baxter, *Harrisburg Area Community College*  
C. Eric Boswell, *Troy University*  
Corina Brown, *University of Northern Colorado*  
Amy Burks, *Northeast Mississippi Community College*  
Aslam H. Chowdhury, *University of Arkansas at Pine Bluff*  
Jose D'Arruda, *University of North Carolina Pembroke*  
Carlos Ize, *Tulsa Community College*  
Sapna Jain, *Alabama State University*  
David Manning, *Harrisburg Area Community College*  
Gregory E. Osborne, *Northeast State Community College*  
Eddie C. Red, *Morehouse College*  
Alan Rowe, *Norfolk State University*  
Walid Shihabi, *Tulsa Community College*  
R. Seth Smith, *Francis Marion University*  
Kevin Storr, *Prairie View A&M University*  
Maria E. Tarafa, *Miami Dade College*  
Keith M. Vogelsang, *Ivy Tech Community College*  
Nicholas L. Wolff, *Lane College*  
Raymond Zich, *Illinois State University*

The following individuals helped write and review learning goal-oriented content for **LearnSmart for Physical Science**:

Stephanie J. Slater, *CAPER Center for Astronomy & Physics Education Research*  
Timothy F. Slater, *University of Wyoming*  
Gina Seegers Szablewski, *University of Wisconsin - Milwaukee*

The authors of the text, Stephanie and Timothy Slater, revised the PowerPoint Lecture Outlines, the Instructor's Manual, and the Test Bank for the twelfth edition.

## MEET THE AUTHORS

### BILL W. TILLERY

Bill W. Tillery is professor emeritus of Physics at Arizona State University, where he was a member of the faculty from 1973 to 2006. He earned a bachelor's degree at Northeastern State University and master's and doctorate degrees from the University of Northern Colorado. Before moving to Arizona State University, he served as director of the Science and Mathematics Teaching Center at the University of Wyoming and as an assistant professor at Florida State University. Bill served on numerous councils, boards, and committees, and he was honored as the "Outstanding University Educator" at the University of Wyoming. He was elected the "Outstanding Teacher" in the Department of Physics and Astronomy at Arizona State University.

During his time at Arizona State, Bill taught a variety of courses, including general education courses in science and

society, physical science, and introduction to physics. He received more than forty grants from the National Science Foundation, the U.S. Office of Education, private industry (Arizona Public Service), and private foundations (The Flinn Foundation) for science curriculum development and science teacher in-service training. In addition to teaching and grant work, Bill authored or coauthored more than sixty textbooks and many monographs and served as editor of three separate newsletters and journals.

### STEPHANIE J. SLATER

Stephanie Slater is the Director of the CAPER Center for Astronomy & Physics Education Research. After undergraduate studies at Massachusetts Institute of Technology and graduate work at Montana State University, Dr. Slater earned her Ph.D. from the University of Arizona in the Department of Teaching, Learning and Sociocultural Studies studying how undergraduate research experiences influence the professional career pathways of women scientists. Dr. Slater was selected as the American Physical Society's Woman Physicist of the Month in December 2013 and received both NASA Top Star and NASA Gold Star Education awards.

With more than twenty years of teaching experience, Dr. Slater has written science textbooks for undergraduate classes and books on education research design and methods for graduate courses. Her work on educational innovations has been funded by the National Science Foundation and NASA and she has served on numerous science education and outreach committees for the American Association of Physics Teachers, the American Physical Society, the American Geophysical Union, and the American Institute of Physics, among others. She is also a frequent lecturer at science fiction conventions, illustrating how science fiction books, television series, and movies describe how humans interact at the intersection of science and culture.

### TIMOTHY F. SLATER

Tim Slater has been the University of Wyoming Excellence in Higher Education Endowed Professor of Science Education since 2008. Prior to joining the faculty at the University of Wyoming, he was an astronomer at the University of Arizona from 2001 to 2008 where he was the first professor in the United States to earn tenure in a top-ranked Astronomy Department on the basis of his scholarly publication and grant award record in astronomy education research. From 1996 to 2001, he was a research professor of physics at Montana State University.

Dr. Slater earned a Ph.D. at the University of South Carolina, an MS at Clemson University, and two Bachelor's degrees at Kansas State University. He is widely known as the "professor's professor" because of the hundreds of college teaching talks and workshops he has given to thousands of professors on innovative teaching methods. Dr. Slater serves as the Editor-in-Chief of the *Journal of Astronomy & Earth Sciences Education* and was the initial U.S. Chairman of the International Year of Astronomy. An avid motorcycle rider, he is the author of thirteen books, has written more than one hundred peer-reviewed journal articles, and been the recipient of numerous teaching awards.



# 1

## What Is Science?



Physical science is concerned with your physical surroundings and your concepts and understanding of these surroundings.  
©Steve Satushek/Getty

### CORE CONCEPT

Science is a way of thinking about and understanding your environment.

### OUTLINE

#### Objects and Properties

Properties are qualities or attributes that can be used to describe an object or event.

#### Data

Data is measurement information that can be used to describe objects, conditions, events, or changes.

#### Scientific Method

Science investigations include collecting observations, developing explanations, and testing explanations.

#### Laws and Principles

Scientific laws describe relationships between events that happen time after time, describing *what* happens in nature.

- 1.1 Objects and Properties
- 1.2 Quantifying Properties
- 1.3 Measurement Systems
- 1.4 Standard Units for the Metric System
  - Length
  - Mass
  - Time
- 1.5 Metric Prefixes
- 1.6 Understandings from Measurements

- Data
  - Ratios and Generalizations
  - The Density Ratio
  - Symbols and Equations
    - Symbols
    - Equations
    - Proportionality Statements
  - How to Solve Problems
- 1.7 The Nature of Science

- The Scientific Method
  - Explanations and Investigations
  - Testing a Hypothesis

#### Science and Society: Basic and Applied Research

- Accept Results?
- Other Considerations
- Pseudoscience

- Laws and Principles
- Models and Theories

#### People Behind the Science: Florence Bascom

#### Quantifying Properties

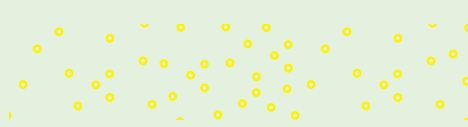
Measurement is used to accurately describe properties of objects or events.

#### Symbols and Equations

An equation is a statement of a relationship between variables.

#### Models and Theories

A scientific theory is a broad working hypothesis based on extensive experimental evidence, describing *why* something happens in nature.



# OVERVIEW

Have you ever thought about your thinking and what you know? On a very simplified level, you could say that everything you know came to you through your senses. You see, hear, and touch things of your choosing, and you can also smell and taste things in your surroundings. Information is gathered and sent to your brain by your sense organs. Somehow, your brain processes all this information in an attempt to find order and make sense of it all. Finding order helps you understand the world and what may be happening at a particular place and time. Finding order also helps you predict what may happen next, which can be very important in a lot of situations.

This is a book on thinking about and understanding your physical surroundings. These surroundings range from the obvious, such as the landscape (Figure 1.1) and the day-to-day weather, to the not so obvious, such as how atoms are put together. You will learn how to think about your surroundings, whatever your previous experience with thought-demanding situations. This first chapter is about “tools and rules” that you will use in the thinking process.

## 1.1 OBJECTS AND PROPERTIES

Physical science is concerned with making sense out of the physical environment. The early stages of this “search for sense” usually involve *objects* in the environment, things that can be seen or touched. These could be objects you see every day, such as a glass of water, a moving automobile, or a blowing flag. They could be quite large, such as the Sun, the Moon, or even the solar system, or invisible to the unaided human eye. Physical scientists are usually focused on studying nonliving things, leaving the domain of living things for life scientists.

As you were growing up, you learned to form a generalized mental image of objects called a *concept*. Your concept of an object is an idea of what it is, in general, or what it should be according to your idea. You usually have a word stored away in your mind that represents a concept. The word *chair*, for example, probably evokes an idea of “something to sit on.” Your generalized mental image for the concept that goes with the word *chair* probably includes a four-legged object with a backrest. Upon close inspection, most of your (and everyone else’s) concepts are found to be somewhat vague. For example, if the word *chair* brings forth a mental image of something with four legs and a backrest (the concept), what is the difference between a “high chair” and a “bar stool”? When is a chair a chair and not a stool (Figure 1.2)? These kinds of questions can be troublesome for many people.

Not all of your concepts are about material objects. You also have concepts about intangibles such as time, motion, and relationships between events. As was the case with concepts of material objects, words represent the existence of intangible concepts. For example, the words *second*, *hour*, *day*, and *month* represent concepts of time. A concept of the pushes and pulls that come with changes of motion during an airplane flight might be represented with such words as *accelerate* and *falling*. Intangible concepts might seem to be more abstract since they do not represent material objects.



**FIGURE 1.1** Your physical surroundings include naturally occurring things in the landscape as well as things people have made.

©John Giustina/Getty Images/Photodisc



**FIGURE 1.2** What is your concept of a chair? Is this a picture of a chair or is it a stool? Most people have concepts, or ideas of what things in general should be, that are loosely defined. The concept of a chair is one example, and this is a picture of a swivel office chair with arms.  
©Ingram Publishing

By the time you reach adulthood, you have literally thousands of words to represent thousands of concepts. But most, you would find on inspection, are somewhat ambiguous and not at all clear-cut. That is why you find it necessary to talk about certain concepts for a minute or two to see if the other person has the same “concept” for words as you do. That is why when one person says, “Boy, was it hot!” the other person may respond, “How hot was it?” The meaning of *hot* can be quite different for two people, especially if one is from Arizona and the other from Alaska!

The problem with words, concepts, and mental images can be illustrated by imagining a situation involving you and another person. Suppose that you have found a rock that you believe would make a great bookend. Suppose further that you are talking to the other person on the telephone, and you want to discuss the suitability of the rock as a bookend, but you do not know the name of the rock. If you knew the name, you would simply state that you found a “\_\_\_\_\_.” Then you would probably discuss the rock for a minute or so to see if the other person really understood what you were talking about. But not knowing the name of the rock and wanting to communicate about the suitability of the object as a bookend, what would you do? You would probably describe the characteristics, or **properties**, of the rock. Properties are the qualities or attributes that, taken together, are usually peculiar to an object. Since you commonly determine properties with your senses (smell, sight, hearing, touch, and taste), you could say that the properties of an object are the effect the object has on your senses. For example, you might say that the rock is a “big, yellow, smooth rock with shiny gold cubes on one side.” But consider the mental image that the other person on the telephone forms when you describe these



**FIGURE 1.3** Could you describe this rock to another person over the telephone so that the other person would know *exactly* what you see? This is not likely with everyday language, which is full of implied comparisons, assumptions, and inaccurate descriptions. ©McGraw-Hill Education/Bill Tillery, photographer

properties. It is entirely possible that the other person is thinking of something very different from what you are describing (Figure 1.3)!

As you can see, the example of describing a proposed bookend by listing its properties in everyday language leaves much to be desired. The description does not really help the other person form an accurate mental image of the rock. One problem with the attempted communication is that the description of any property implies some kind of *referent*. The word **referent** means that you *refer to*, or think of, a given property in terms of another, more familiar object. Colors, for example, are sometimes stated with a referent. Examples are “sky blue,” “grass green,” or “lemon yellow.” The referents for the colors blue, green, and yellow are, respectively, the sky, living grass, and a ripe lemon.

Referents for properties are not always as explicit as they are for colors, but a comparison is always implied. Since the comparison is implied, it often goes unspoken and leads to assumptions in communications. For example, when you stated that the rock was “big,” you assumed that the other person knew that you did not mean as big as a house or even as big as a bicycle. You assumed that the other person knew that you meant that the rock was about as large as a book, perhaps a bit larger.

Another problem with the listed properties of the rock is the use of the word *smooth*. The other person would not know if you meant that the rock *looked* smooth or *felt* smooth. After all, some objects can look smooth and feel rough. Other objects can look rough and feel smooth. Thus, here is another assumption, and probably all of the properties lead to implied comparisons, assumptions, and a not-very-accurate communication. This is the nature of your everyday language and the nature of most attempts at communication.

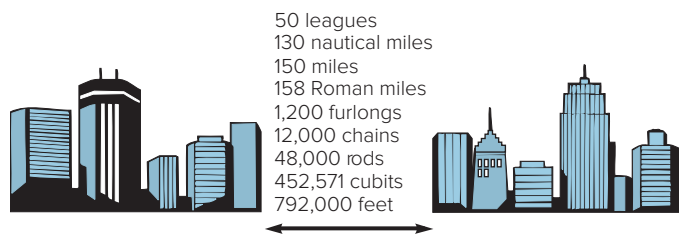
## 1.2 QUANTIFYING PROPERTIES

Typical day-to-day communications are often vague and leave much to be assumed. A communication between two people, for example, could involve one person describing some person, object, or event to a second person. The description is made by using referents and comparisons that the second person may or may not have in mind. Thus, such attributes as “long” fingernails or “short” hair may have entirely different meanings to different people involved in a conversation. Assumptions and vagueness can be avoided by using **measurement** in a description. Measurement is a process of comparing a property to a well-defined and agreed-upon referent. The well-defined and agreed-upon referent is used as a standard called a **unit**. The measurement process involves three steps: (1) *comparing* the referent unit to the property being described, (2) following a *procedure*, or operation, that specifies how the comparison is made, and (3) *counting* how many standard units describe the property being considered.

The measurement process uses a defined referent unit, which is compared to a property being measured. The *value* of the property is determined by counting the number of referent units. The name of the unit implies the procedure that results in the number. A measurement statement always contains a *number* and *name* for the referent unit. The number answers the question “How much?” and the name answers the question “Of what?” Thus, a measurement always tells you “how much of what.” You will find that using measurements will sharpen your communications. You will also find that using measurements is one of the first steps in understanding your physical environment.

## 1.3 MEASUREMENT SYSTEMS

Measurement is a process that brings precision to a description by specifying the “how much” and “of what” of a property in a particular situation. A number expresses the value of the property, and the name of a unit tells you what the referent is as well as implies the procedure for obtaining the number. Referent units must be defined and established, however, if others are to understand and reproduce a measurement. When standards are established, the referent unit is called a **standard unit** (Figure 1.4). The use of standard units makes it possible to communicate and duplicate measurements. Standard units are usually defined and established by governments and their agencies that are created for that purpose. In the United States, the agency

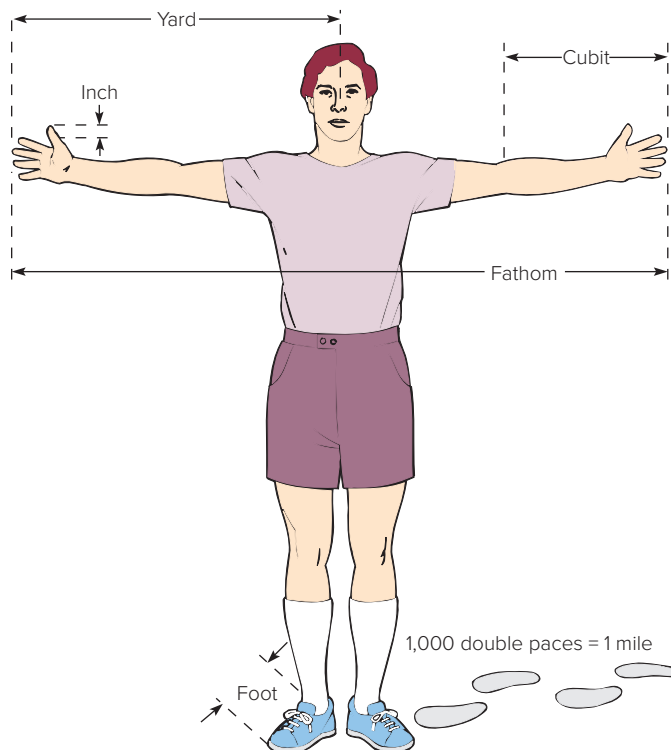


**FIGURE 1.4** Which of the listed units should be used to describe the distance between these hypothetical towns? Is there an advantage to using any of the units? Any could be used, and when one particular unit is officially adopted, it becomes known as the *standard unit*.

concerned with measurement standards is the National Institute of Standards and Technology. In Canada, the Standards Council of Canada oversees the National Standard System.

There are two major *systems* of standard units in use today, the *English system* and the *metric system*. The metric system is used throughout the world except in the United States, where both systems are in use. The continued use of the English system in the United States presents problems in international trade, so there is pressure for a complete conversion to the metric system. More and more metric units are being used in everyday measurements, but a complete conversion will involve an enormous cost. Appendix A contains a method for converting from one system to the other easily. Consult this section if you need to convert from one metric unit to another metric unit or to convert from English to metric units or vice versa. Conversion factors are listed inside the front cover.

People have used referents to communicate about properties of things throughout human history. The ancient Greek civilization, for example, used units of *stadia* to communicate about distances and elevations. The *stadium* was a unit of length of the racetrack at the local stadium (*stadia* is the plural of *stadium*), based on a length of 125 paces. Later civilizations, such as the ancient Romans, adopted the stadia and other referent units from the ancient Greeks. Some of these same referent units were later adopted by the early English civilization, which eventually led to the **English system** of measurement. Some adopted units of the English system were originally based on parts of the human body, presumably because you always had these referents with you (Figure 1.5). The inch, for example,



**FIGURE 1.5** Many early units for measurement were originally based on the human body. Some of the units were later standardized by governments to become the basis of the English system of measurement.

**TABLE 1.1**
**The SI Base Units**

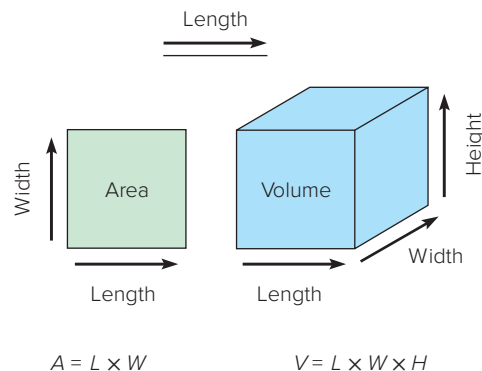
Property	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

used the end joint of the thumb for a referent. A foot, naturally, was the length of a foot, and a yard was the distance from the tip of the nose to the end of the fingers on an arm held straight out. A cubit was the distance from the end of an elbow to the fingertip, and a fathom was the distance between the fingertips of two arms held straight out. As you can imagine, there were problems with these early units because everyone had different-sized body parts. Beginning in the 1300s, the sizes of the various units were gradually standardized by English kings.

The **metric system** was established by the French Academy of Sciences in 1791. The academy created a measurement system that was based on invariable referents in nature, not human body parts. These referents have been redefined over time to make the standard units more reproducible. The *International System of Units*, abbreviated *SI*, is a modernized version of the metric system. Today, the SI system has seven base units that define standards for the properties of length, mass, time, electric current, temperature, amount of substance, and light intensity (Table 1.1). All units other than the seven basic ones are *derived* units. Area, volume, and speed, for example, are all expressed with derived units. Units for the properties of length, mass, and time are introduced in this chapter. The remaining units will be introduced in later chapters as the properties they measure are discussed.

## 1.4 >> STANDARD UNITS FOR THE METRIC SYSTEM

If you consider all the properties of all the objects and events in your surroundings, the number seems overwhelming. Yet, close inspection of how properties are measured reveals that some properties are combinations of other properties (Figure 1.6). Volume, for example, is described by the three length measurements of length, width, and height. Area, on the other hand, is described by just the two length measurements of length and width. Length, however, cannot be defined in simpler terms of any other property. There are four properties that cannot be described in simpler terms, and all other properties are combinations of these four. For this reason, they are called the **fundamental properties**. A fundamental property cannot be



**FIGURE 1.6** Area, or the extent of a surface, can be described by two length measurements. Volume, or the space that an object occupies, can be described by three length measurements. Length, however, can be described only in terms of how it is measured, so it is called a *fundamental property*.

defined in simpler terms other than to describe how it is measured. These four fundamental properties are (1) *length*, (2) *mass*, (3) *time*, and (4) *charge*. Used individually or in combinations, these four properties will describe or measure what you observe in nature. Metric units for measuring the fundamental properties of length, mass, and time will be described next. The fourth fundamental property, charge, is associated with electricity, and a unit for this property will be discussed in chapter 6.

### LENGTH

The standard unit for length in the metric system is the **meter** (the symbol or abbreviation is m). The meter is defined as the distance that light travels in a vacuum during a certain time period, 1/299,792,458 second. The important thing to remember, however, is that the meter is the metric *standard unit* for length. A meter is slightly longer than a yard, 39.3 inches. It is approximately the distance from your left shoulder to the tip of your right hand when your arm is held straight out. Many door-knobs are about 1 meter above the floor. Think about these distances when you are trying to visualize a meter length.

### MASS

The standard unit for mass in the metric system is the **kilogram** (kg). The kilogram is defined as the mass of a particular cylinder made of platinum and iridium, kept by the International Bureau of Weights and Measures in France. This is the only standard unit that is still defined in terms of an object. The property of mass is sometimes confused with the property of weight since they are directly proportional to each other at a given location on the surface of Earth. They are, however, two completely different properties and are measured with different units. All objects tend to maintain their state of rest or straight-line motion, and this property is called “inertia.” The *mass* of an object is a measure of the inertia of an object. The *weight* of the object is a measure of the force of gravity on it. This distinction between weight and mass will be discussed in detail in chapter 2. For now, remember that weight and mass are not the same property.



## TIME

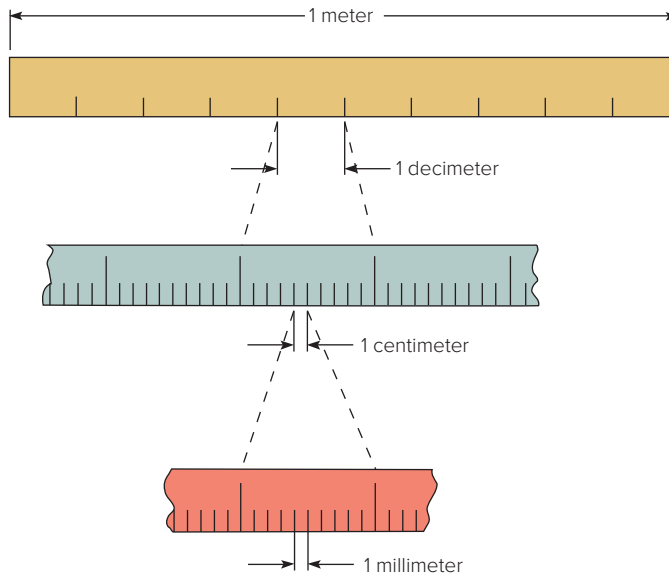
The standard unit for time is the **second** (s). The second was originally defined as  $1/86,400$  of a solar day ( $1/60 \times 1/60 \times 1/24$ ). Earth's spin was found not to be as constant as thought, so this old definition of one second had to be revised. Adopted in 1967, the new definition is based on a high-precision device known as an *atomic clock*. An atomic clock has a referent for a second that is provided by the characteristic vibrations of the cesium-133 atom. The atomic clock that was built at the National Institute of Standards and Technology in Boulder, Colorado, will neither gain nor lose a second in 20 million years!

## 1.5 METRIC PREFIXES

The metric system uses prefixes to represent larger or smaller amounts by factors of 10. Some of the more commonly used prefixes, their abbreviations, and their meanings are listed in Table 1.2. Suppose you wish to measure something smaller than the standard unit of length, the meter. The meter is subdivided into 10 equal-sized subunits called *decimeters*. The prefix *deci-* has a meaning of “one-tenth of,” and it takes 10 decimeters (dm) to equal the length of 1 meter.

For even smaller measurements, each decimeter is divided into 10 equal-sized subunits called *centimeters*. It takes 10 centimeters (cm) to equal 1 decimeter and 100 centimeters to equal 1 meter. In a similar fashion, each prefix up or down the metric scale represents a simple increase or decrease by a factor of 10 (Figure 1.7).

When the metric system was established in 1791, the standard unit of mass was defined in terms of the mass of a certain volume of water. One cubic decimeter ( $1 \text{ dm}^3$ ) of pure water at  $4^\circ\text{C}$  was



**FIGURE 1.7** Compare the units shown here. How many millimeters fit into the space occupied by 1 centimeter? How many millimeters fit into the space of 1 decimeter? How many millimeters fit into the space of 1 meter? Can you express all these as multiples of 10?

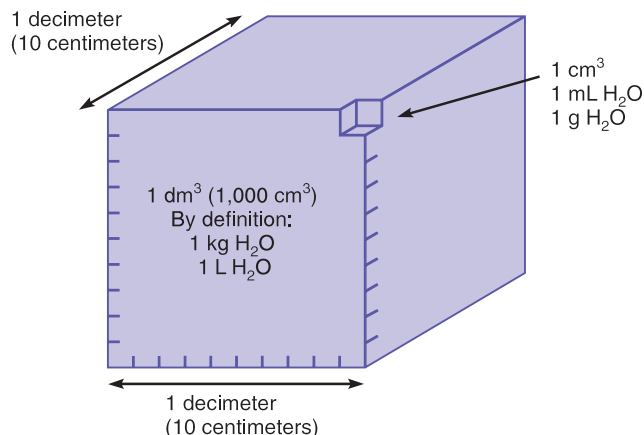
*defined* to have a mass of 1 kilogram (kg). This definition was convenient because it created a relationship between length, mass, and volume. As illustrated in Figure 1.8, a cubic decimeter is 10 cm on each side. The volume of this cube is therefore  $10 \text{ cm} \times 10 \text{ cm} \times 10 \text{ cm}$ , or 1,000 cubic centimeters (abbreviated as cc or  $\text{cm}^3$ ). Thus, a volume of  $1,000 \text{ cm}^3$  of water has a mass of 1 kg. Since 1 kg is 1,000 g,  $1 \text{ cm}^3$  of water has a mass of 1 g.

The volume of  $1,000 \text{ cm}^3$  also defines a metric unit that is commonly used to measure liquid volume, the **liter** (L). For smaller amounts of liquid volume, the milliliter (mL) is used. The relationship between liquid volume, volume, and mass of water is therefore

$$1.0 \text{ L} \Rightarrow 1.0 \text{ dm}^3 \text{ and has a mass of } 1.0 \text{ kg}$$

or, for smaller amounts,

$$1.0 \text{ mL} \Rightarrow 1.0 \text{ cm}^3 \text{ and has a mass of } 1.0 \text{ g}$$



**FIGURE 1.8** A cubic decimeter of water ( $1,000 \text{ cm}^3$ ) has a liquid volume of 1 L ( $1,000 \text{ mL}$ ) and a mass of 1 kg ( $1,000 \text{ g}$ ). Therefore,  $1 \text{ cm}^3$  of water has a liquid volume of 1 mL and a mass of 1 g.

**TABLE 1.2**

**Some Metric Prefixes**

Prefix	Symbol	Meaning	Unit Multiplier
exa-	E	quintillion	$10^{18}$
peta-	P	quadrillion	$10^{15}$
tera-	T	trillion	$10^{12}$
giga-	G	billion	$10^9$
mega-	M	million	$10^6$
kilo-	k	thousand	$10^3$
hecto-	h	hundred	$10^2$
deka-	da	ten	$10^1$
deci-	d	one-tenth	$10^{-1}$
centi-	c	one-hundredth	$10^{-2}$
milli-	m	one-thousandth	$10^{-3}$
micro-	$\mu$	one-millionth	$10^{-6}$
nano-	n	one-billionth	$10^{-9}$
pico-	p	one-trillionth	$10^{-12}$
femto-	f	one-quadrillionth	$10^{-15}$
atto-	a	one-quintillionth	$10^{-18}$

## 1.6 UNDERSTANDINGS FROM MEASUREMENTS

One of the more basic uses of measurement is to *describe* something in an exact way that everyone can understand. For example, if a friend in another city tells you that the weather has been “warm,” you might not understand what temperature is being described. A statement that the air temperature is 70°F carries more exact information than a statement about “warm weather.” The statement that the air temperature is 70°F contains two important concepts: (1) the numerical value of 70 and (2) the referent unit of degrees Fahrenheit. Note that both a numerical value and a unit are necessary to communicate a measurement correctly. Thus, weather reports describe weather conditions with numerically specified units; for example, 70° Fahrenheit for air temperature, 5 miles per hour for wind speed, and 0.5 inch for rainfall (Figure 1.9). When such numerically specified units are used in a description, or a weather report, everyone understands *exactly* the condition being described.

### DATA

Measurement information used to describe something is called **data**. Data can be used to describe objects, conditions, events, or changes that might be occurring. You really do not know if the weather is changing much from year to year until you compare the yearly weather data. The data will tell you, for example, if the weather is becoming hotter or dryer or is staying about the same from year to year.

Let’s see how data can be used to describe something and how the data can be analyzed for further understanding. The cubes illustrated in Figure 1.10 will serve as an example. Each cube can be described by measuring the properties of size and surface area.

First, consider the size of each cube. Size can be described by **volume**, which means *how much space something occupies*. The volume of a cube can be obtained by measuring and multiplying the length, width, and height. The data are

volume of cube <i>a</i>	1 cm <sup>3</sup>
volume of cube <i>b</i>	8 cm <sup>3</sup>
volume of cube <i>c</i>	27 cm <sup>3</sup>

Weather Report	
Friday (24 hours ended at 5 P.M.)	
Highs—airport	73°F, downtown 76°F
Lows—airport	68°F, downtown 70°F
Rainfall .....	0.26 in
Average wind speed .....	5.2 mph
Relative humidity .....	High 85%
	Low 75%
Rainfall ± normal to date.....	+0.94 in

**FIGURE 1.9** A weather report gives exact information, data that describe the weather by reporting numerically specified units for each condition being described.

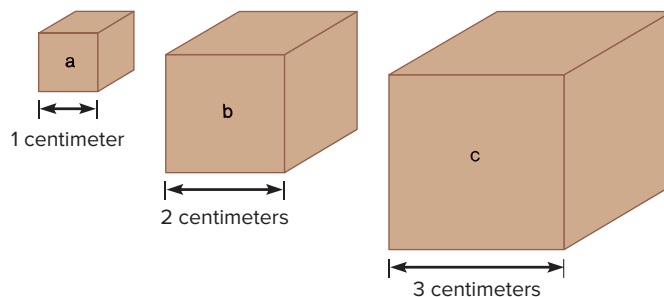
Now consider the surface area of each cube. **Area** means *the extent of a surface*, and each cube has six surfaces, or faces (top, bottom, and four sides). The area of any face can be obtained by measuring and multiplying length and width. The data for the three cubes describe them as follows:

	Volume	Surface Area
cube <i>a</i>	1 cm <sup>3</sup>	6 cm <sup>2</sup>
cube <i>b</i>	8 cm <sup>3</sup>	24 cm <sup>2</sup>
cube <i>c</i>	27 cm <sup>3</sup>	54 cm <sup>2</sup>

### RATIOS AND GENERALIZATIONS

Data on the volume and surface area of the three cubes in Figure 1.10 describe the cubes, but whether they say anything about a relationship between the volume and surface area of a cube is difficult to tell. Nature seems to have a tendency to camouflage relationships, making it difficult to extract meaning from raw data. Seeing through the camouflage requires the use of mathematical techniques to expose patterns. Let’s see how such techniques can be applied to the data on the three cubes and what the pattern means.

One mathematical technique for reducing data to a more manageable form is to expose patterns through a **ratio**. A ratio is a relationship between two numbers that is obtained when one number is divided by another number. Suppose, for example, that an instructor has 50 sheets of graph paper for a laboratory group of 25 students. The relationship, or ratio, between the number of sheets and the number of students is 50 papers to 25 students, and this can be written as 50 papers/25 students. This ratio is *simplified* by dividing 25 into 50, and the ratio becomes 2 papers/1 student. The 1 is usually understood (not stated), and the ratio is written as simply 2 papers/student. It is read as 2 papers “for each” student, or 2 papers “per” student. The concept of simplifying with a ratio is an important one, and you will see it time and again throughout science. It is important that you understand the meaning of *per* and *for each* when used with numbers and units.



**FIGURE 1.10** Cube *a* is 1 centimeter on each side, cube *b* is 2 centimeters on each side, and cube *c* is 3 centimeters on each side. These three cubes can be described and compared with data, or measurement information, but some form of analysis is needed to find patterns or meaning in the data.

Applying the ratio concept to the three cubes in Figure 1.10, the ratio of surface area to volume for the smallest cube, cube *a*, is  $6 \text{ cm}^2$  to  $1 \text{ cm}^3$ , or

$$\frac{6 \text{ cm}^2}{1 \text{ cm}^3} = 6 \frac{\text{cm}^2}{\text{cm}^3}$$

meaning there are 6 square centimeters of area *for each* cubic centimeter of volume.

The middle-sized cube, cube *b*, had a surface area of  $24 \text{ cm}^2$  and a volume of  $8 \text{ cm}^3$ . The ratio of surface area to volume for this cube is therefore

$$\frac{24 \text{ cm}^2}{8 \text{ cm}^3} = 3 \frac{\text{cm}^2}{\text{cm}^3}$$

meaning there are 3 square centimeters of area *for each* cubic centimeter of volume.

The largest cube, cube *c*, had a surface area of  $54 \text{ cm}^2$  and a volume of  $27 \text{ cm}^3$ . The ratio is

$$\frac{54 \text{ cm}^2}{27 \text{ cm}^3} = 2 \frac{\text{cm}^2}{\text{cm}^3}$$

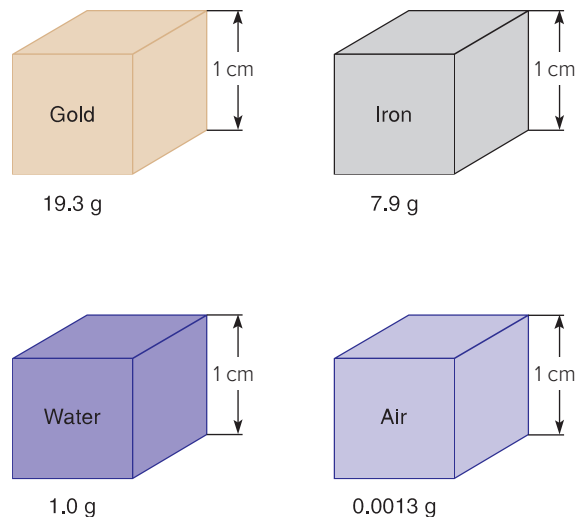
or 2 square centimeters of area *for each* cubic centimeter of volume. Summarizing the ratio of surface area to volume for all three cubes, you have

small cube	$a - 6:1$
middle cube	$b - 3:1$
large cube	$c - 2:1$

Now that you have simplified the data through ratios, you are ready to generalize about what the information means. You can generalize that the surface-area-to-volume ratio of a cube *decreases* as the volume of a cube becomes larger. Reasoning from this generalization will provide an explanation for a number of related observations. For example, why does crushed ice melt faster than a single large block of ice with the same volume? The explanation is that the crushed ice has a larger surface-area-to-volume ratio than the large block, so more surface is exposed to warm air. If the generalization is found to be true for shapes other than cubes, you could explain why a log chopped into small chunks burns faster than the whole log. Further generalizing might enable you to predict if large potatoes would require more or less peeling than the same weight of small potatoes. When generalized explanations result in predictions that can be verified by experience, you gain confidence in the explanation. Finding patterns of relationships is a satisfying intellectual adventure that leads to understanding and generalizations that are frequently practical.

## THE DENSITY RATIO

The power of using a ratio to simplify things, making explanations more accessible, is evident when you compare the simplified ratio 6 to 3 to 2 with the hodgepodge of numbers that you would have to consider without using ratios. The power of using the ratio technique is also evident when considering other properties of matter. Volume is a property that is sometimes confused



**FIGURE 1.11** Equal volumes of different substances do not have the same mass, as these cube units show. Calculate the densities in  $\text{g}/\text{cm}^3$ . Do equal volumes of different substances have the same density? Explain.

with mass. Larger objects do not necessarily contain more matter than smaller objects. A large balloon, for example, is much larger than this book, but the book is much more massive than the balloon. The simplified way of comparing the mass of a particular volume is to find the ratio of mass to volume. This ratio is called **density**, which is defined as *mass per unit volume*. The *per* means “for each” as previously discussed, and *unit* means one, or each. Thus, “mass per unit volume” literally means the “mass of one volume” (Figure 1.11). The relationship can be written as

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

or

$$\rho = \frac{m}{V}$$

( $\rho$  is the symbol for the Greek letter rho.)

### equation 1.1

As with other ratios, density is obtained by dividing one number and unit by another number and unit. Thus, the density of an object with a volume of  $5 \text{ cm}^3$  and a mass of 10 g is

$$\text{density} = \frac{10 \text{ g}}{5 \text{ cm}^3} = 2 \frac{\text{g}}{\text{cm}^3}$$

The density in this example is the ratio of 10 g to  $5 \text{ cm}^3$ , or  $10 \text{ g}/5 \text{ cm}^3$ , or 2 g to  $1 \text{ cm}^3$ . Thus, the density of the example object is the mass of *one* volume (a unit volume), or 2 g *for each*  $\text{cm}^3$ .

Any unit of mass and any unit of volume may be used to express density. The densities of solids, liquids, and gases are usually expressed in grams per cubic centimeter ( $\text{g}/\text{cm}^3$ ), but the densities of liquids are sometimes expressed in grams per milliliter ( $\text{g}/\text{mL}$ ). Using SI standard units, densities are expressed as  $\text{kg}/\text{m}^3$ . Densities of some common substances are shown in Table 1.3.

**TABLE 1.3**
**Densities ( $\rho$ ) of Some Common Substances**

	$\text{g/cm}^3$
Aluminum	2.70
Copper	8.96
Iron	7.87
Lead	11.4
Water	1.00
Seawater	1.03
Mercury	13.6
Gasoline	0.680

If matter is distributed the same throughout a volume, the *ratio* of mass to volume will remain the same no matter what mass and volume are being measured. Thus, a teaspoonful, a cup, and a lake full of freshwater at the same temperature will all have a density of about  $1 \text{ g/cm}^3$  or  $1 \text{ kg/L}$ . A given material will have its own unique density; example 1.1 shows how density can be used to identify an unknown substance. For help with significant figures, see appendix A (p. A3).

## CONCEPTS *Applied*



### Density Matters—Sharks and Cola Cans

What do a shark and a can of cola have in common? Sharks are marine animals that have an internal skeleton made entirely of cartilage. These animals have no swim bladder to adjust their body density in order to maintain their position in the water; therefore, they must constantly swim or they will sink. The bony fish, on the other hand, have a skeleton composed of bone, and most also have a swim bladder. These fish can regulate the amount of gas in the bladder to control their density. Thus, the fish can remain at a given level in the water without expending large amounts of energy.

Have you ever noticed the different floating characteristics of cans of the normal version of a carbonated cola beverage and a diet version? The surprising result is that the normal version usually sinks and the diet version usually floats. This has nothing to do with the amount of carbon dioxide in the two drinks. It is a result of the increase in density from the sugar added to the normal version, while the diet version has much less of an artificial sweetener that is much sweeter than sugar. So, the answer is that sharks and regular cans of cola both sink in water.

### EXAMPLE 1.1

Two blocks are on a table. Block A has a volume of  $30.0 \text{ cm}^3$  and a mass of  $81.0 \text{ g}$ . Block B has a volume of  $50.0 \text{ cm}^3$  and a mass of  $135 \text{ g}$ . Which block has the greater density? If the two blocks have the same density, what material are they? (See Table 1.3.)

### SOLUTION

Density is defined as the ratio of the mass of a substance per unit volume. Assuming the mass is distributed equally throughout the volume, you could assume that the ratio of mass to volume is the same no matter what quantities of mass and volume are measured. If you can accept this assumption, you can use equation 1.1 to determine the density.

#### Block A

$$\begin{aligned} \text{mass } (m) &= 81.0 \text{ g} \\ \text{volume } (V) &= 30.0 \text{ cm}^3 \\ \text{density} &= ? \end{aligned}$$

$$\begin{aligned} \rho &= \frac{m}{V} \\ &= \frac{81.0 \text{ g}}{30.0 \text{ cm}^3} \\ &= 2.70 \frac{\text{g}}{\text{cm}^3} \end{aligned}$$

#### Block B

$$\begin{aligned} \text{mass } (m) &= 135 \text{ g} \\ \text{volume } (V) &= 50.0 \text{ cm}^3 \\ \text{density} &= ? \end{aligned}$$

$$\begin{aligned} \rho &= \frac{m}{V} \\ &= \frac{135 \text{ g}}{50.0 \text{ cm}^3} \\ &= 2.70 \frac{\text{g}}{\text{cm}^3} \end{aligned}$$

As you can see, both blocks have the same density. Inspecting Table 1.3, you can see that aluminum has a density of  $2.70 \text{ g/cm}^3$ , so both blocks must be aluminum.

### EXAMPLE 1.2

A rock with a volume of  $4.50 \text{ cm}^3$  has a mass of  $15.0 \text{ g}$ . What is the density of the rock? (Answer:  $3.33 \text{ g/cm}^3$ )

## CONCEPTS *Applied*



### A Dense Textbook?

What is the density of this book? Measure the length, width, and height of this book in cm, then multiply to find the volume in  $\text{cm}^3$ . Use a scale to find the mass of this book in grams. Compute the density of the book by dividing the mass by the volume. Compare the density in  $\text{g/cm}^3$  with other substances listed in Table 1.3.



## Myths, Mistakes, & Misunderstandings

### Tap a Can?

Some people believe that tapping on the side of a can of carbonated beverage will prevent it from foaming over when the can is opened. Is this true or a myth? Set up a controlled experiment (see p. 15) to compare opening cold cans of carbonated beverage that have been tapped with cans that have not been tapped. Are you sure you have controlled all the other variables?