

AN INTRODUCTION TO

Physical Science

Fourteenth Edition

SHIPMAN • WILSON • HIGGINS • TORRES

AN INTRODUCTION TO

Physical Science

Fourteenth Edition

This Fourteenth Edition
is dedicated to the
editors (in particular,
Brandi Kirksey, Alison
Eigel Zade, Malvine
Litten, and Rachel Morris)
who helped make the
textbook what it is today.

J. D. W., C. A. H., and O. T.

SHIPMAN • WILSON • HIGGINS • TORRES



© Tony Power 2010/Flickr/Getty Images

AN INTRODUCTION TO

Physical Science

Fourteenth Edition

JAMES T. SHIPMAN
Ohio University

JERRY D. WILSON
Lander University

CHARLES A. HIGGINS, Jr.
Middle Tennessee State University

OMAR TORRES
College of the Canyons



Australia • Brazil • Mexico • Singapore • United Kingdom • United States

This is an electronic version of the print textbook. Due to electronic rights restrictions, some third party content may be suppressed. Editorial review has deemed that any suppressed content does not materially affect the overall learning experience. The publisher reserves the right to remove content from this title at any time if subsequent rights restrictions require it. For valuable information on pricing, previous editions, changes to current editions, and alternate formats, please visit www.cengage.com/highered to search by ISBN#, author, title, or keyword for materials in your areas of interest.

**An Introduction to Physical Science,
Fourteenth Edition**

James T. Shipman
Jerry D. Wilson
Charles A. Higgins, Jr.
Omar Torres

Product Director: Mary Finch
Senior Product Manager: Charles Hartford
Content Developer: Peter McGahey
Associate Content Developer: Brandi Kirksey
Media Developer: John Wimer
Marketing Manager: Julie Schuster
Content Project Manager: Alison Eigel Zade
Senior Art Director: Cate Barr
Manufacturing Planner: Sandee Milewski
IP Analyst: Farah Fard
IP Project Manager: Christine Myaskovsky
Production Service/Project Manager:
Cenveo/Malvine Litten
PMG Photo Researcher: Venkat Narayanan
PMG Text Researchers: Sowmya Mathialagan
and Pinky Subi
Text & Cover Designer: Dare Porter, Real Time Design
Cover Image Credit: "Power Sources" © Tony Prower
2010/Flickr/Getty Images
Compositor: Cenveo® Publisher Services

© 2016, 2013, 2009 Cengage Learning

WCN: 02-200-203

ALL RIGHTS RESERVED. No part of this work covered by the copyright herein may be reproduced, transmitted, stored, or used in any form or by any means graphic, electronic, or mechanical, including but not limited to photocopying, recording, scanning, digitizing, taping, web distribution, information networks, or information storage and retrieval systems, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without the prior written permission of the publisher.

For product information and technology assistance, contact us at
Cengage Learning Customer & Sales Support, 1-800-354-9706

For permission to use material from this text or product,
submit all requests online at www.cengage.com/permissions.
Further permissions questions can be emailed to
permissionrequest@cengage.com

Library of Congress Control Number: 2014946327

Student Edition:

ISBN: 978-1-305-07913-7

Paper Edition:

ISBN: 978-1-305-07912-0

Cengage Learning

20 Channel Center Street
Boston, MA 02210
USA

Unless otherwise noted, all content is © Cengage Learning.

Cengage Learning is a leading provider of customized learning solutions with office locations around the globe, including Singapore, the United Kingdom, Australia, Mexico, Brazil and Japan. Locate your local office at international.cengage.com/region

Cengage Learning products are represented in Canada by Nelson Education, Ltd.

For your course and learning solutions, visit www.cengage.com

Purchase any of our products at your local college store or at our preferred online store www.cengagebrain.com

Instructors: Please visit login.cengage.com and log in to access instructor-specific resources.

Printed in the United States of America

Print Number: 01

Print Year: 2014

Brief Contents

Chapter 1	Measurement	1
Chapter 2	Motion	27
Chapter 3	Force and Motion	51
Chapter 4	Work and Energy	81
Chapter 5	Temperature and Heat	108
Chapter 6	Waves and Sound	141
Chapter 7	Optics and Wave Effects	165
Chapter 8	Electricity and Magnetism	199
Chapter 9	Atomic Physics	235
Chapter 10	Nuclear Physics	265
Chapter 11	The Chemical Elements	305
Chapter 12	Chemical Bonding	333
Chapter 13	Chemical Reactions	363
Chapter 14	Organic Chemistry	394
Chapter 15	Place and Time	423
Chapter 16	The Solar System	451
Chapter 17	Moons and Small Solar System Bodies	482
Chapter 18	The Universe	511
Chapter 19	The Atmosphere	546
Chapter 20	Atmospheric Effects	579
Chapter 21	Structural Geology and Plate Tectonics	615
Chapter 22	Minerals, Rocks, and Volcanoes	646
Chapter 23	Surface Processes	678
Chapter 24	Geologic Time	704

Contents

Preface xii

About the Authors xvii

Chapter 1 Measurement 1

- 1.1 The Physical Sciences 2
- 1.2 Scientific Investigation 3
- 1.3 The Senses 4
 - 1.1 HIGHLIGHT The “Face” on Mars 5
- 1.4 Standard Units and Systems of Units 6
 - 1.1 CONCEPTUAL Q&A Time and Time Again 10
- 1.5 More on the Metric System 12
- 1.6 Derived Units and Conversion Factors 14
 - 1.2 HIGHLIGHT Is Unit Conversion Important? It Sure Is. 19
- 1.7 Significant Figures 20
 - Key Terms 22, Matching 22, Multiple Choice 22, Fill In The Blank 23, Short Answer 23, Visual Connection 24, Applying Your Knowledge 24, Important Equation 24, Exercises 25

Chapter 2 Motion 27

- 2.1 Defining Motion 28
- 2.2 Speed and Velocity 29
- 2.3 Acceleration 33
 - 2.1 CONCEPTUAL Q&A Putting the Pedal to the Metal 36
 - 2.1 HIGHLIGHT Galileo and the Leaning Tower of Pisa 37
 - 2.2 CONCEPTUAL Q&A And the Winner Is . . . 39
 - 2.2 HIGHLIGHT Terminal Velocity—Don’t Fail Me Now! 40
- 2.4 Acceleration in Uniform Circular Motion 40
- 2.5 Projectile Motion 43
 - 2.3 CONCEPTUAL Q&A Hanging in There 44
 - Key Terms 46, Matching 46, Multiple Choice 46, Fill In The Blank 47, Short Answer 47, Visual Connection 48, Applying Your Knowledge 48, Important Equations 49, Exercises 49

Chapter 3 Force and Motion 51

- 3.1 Force and Net Force 52
- 3.2 Newton’s First Law of Motion 53
 - 3.1 CONCEPTUAL Q&A You Go Your Way, I’ll Go Mine 55
- 3.3 Newton’s Second Law of Motion 56
 - 3.2 CONCEPTUAL Q&A Fundamental is Fundamental 58
- 3.4 Newton’s Third Law of Motion 61
 - 3.1 HIGHLIGHT The Automobile Air Bag 63
- 3.5 Newton’s Law of Gravitation 63
 - 3.3 CONCEPTUAL Q&A A Lot of Mass 65
- 3.6 Archimedes’ Principle and Buoyancy 67
 - 3.4 CONCEPTUAL Q&A Float the Boat 68

- 3.7 Momentum 68
 - 3.2 HIGHLIGHT Surface Tension, Water Striders, and Soap Bubbles 69
 - Key Terms 75, Matching 75, Multiple Choice 75, Fill In The Blank 76, Short Answer 76, Visual Connection 77, Applying Your Knowledge 78, Important Equations 78, Exercises 79

Chapter 4 Work and Energy 81

- 4.1 Work 82
- 4.2 Kinetic Energy and Potential Energy 84
 - 4.1 CONCEPTUAL Q&A Double Zero 89
- 4.3 Conservation of Energy 89
 - 4.2 CONCEPTUAL Q&A The Race Is On 91
- 4.4 Power 92
 - 4.3 CONCEPTUAL Q&A Payment for Power 95
- 4.5 Forms of Energy and Consumption 95
 - 4.1 HIGHLIGHT Ice That Burns 97
- 4.6 Alternative and Renewable Energy Sources 98
 - 4.2 HIGHLIGHT Hybrids and Hydrogen 102
 - Key Terms 103, Matching 103, Multiple Choice 103, Fill In The Blank 104, Short Answer 104, Visual Connection 105, Applying Your Knowledge 106, Important Equations 106, Exercises 106

Chapter 5 Temperature and Heat 108

- 5.1 Temperature 109
 - 5.1 CONCEPTUAL Q&A Shake It Down 110
 - 5.1 HIGHLIGHT Human Body Temperature 113
 - 5.2 CONCEPTUAL Q&A The Easy Approximation 113
- 5.2 Heat 113
 - 5.2 HIGHLIGHT Freezing from the Top Down 115
- 5.3 Specific Heat and Latent Heat 116
 - 5.3 CONCEPTUAL Q&A Under Pressure 122
- 5.4 Heat Transfer 123
 - 5.4 CONCEPTUAL Q&A Hug the Rug 124
- 5.5 Phases of Matter 125
- 5.6 The Kinetic Theory of Gases 127
- 5.7 Thermodynamics 130
 - 5.3 HIGHLIGHT Hot Gases: Aerosol Cans and Popcorn 131
 - 5.5 CONCEPTUAL Q&A Common Descriptions 133
 - Key Terms 135, Matching 135, Multiple Choice 136, Fill In The Blank 136, Short Answer 136, Visual Connection 138, Applying Your Knowledge 138, Important Equations 139, Exercises 139

Chapter 6 Waves and Sound 141

- 6.1 Waves and Energy Propagation 141
- 6.2 Wave Properties 143

- 6.3 Light Waves 146
- 6.4 Sound Waves 148
- 6.1 CONCEPTUAL Q&A A Tree Fell 151
- 6.1 HIGHLIGHT Noise Exposure Limits 152
- 6.5 The Doppler Effect 154
- 6.2 CONCEPTUAL Q&A Faster Than Sound 155
- 6.6 Standing Waves and Resonance 157
- 6.3 CONCEPTUAL Q&A It Can Be Shattering 159
- Key Terms 160, Matching 161, Multiple Choice 161, Fill In The Blank 162, Short Answer 162, Visual Connection 163, Applying Your Knowledge 163, Important Equations 163, Exercises 164

Chapter 7 Optics and Wave Effects 165

- 7.1 Reflection 166
- 7.1 CONCEPTUAL Q&A No Can See 167
- 7.2 CONCEPTUAL Q&A Nighttime Mirror 168
- 7.2 Refraction and Dispersion 169
- 7.3 CONCEPTUAL Q&A Twinkle, Twinkle 171
- 7.1 HIGHLIGHT The Rainbow: Dispersion and Internal Reflection 176
- 7.3 Spherical Mirrors 178
- 7.4 CONCEPTUAL Q&A Up and Down 182
- 7.4 Lenses 182
- 7.5 CONCEPTUAL Q&A Right-Side Up from Upside-Down 185
- 7.5 Polarization 187
- 7.2 HIGHLIGHT Liquid Crystal Displays (LCDs) 189
- 7.6 Diffraction and Interference 190
- Key Terms 194, Matching 194, Multiple Choice 195, Fill In The Blank 195, Short Answer 196, Visual Connection 197, Applying Your Knowledge 197, Important Equations 197, Exercises 198

Chapter 8 Electricity and Magnetism 199

- 8.1 Electric Charge, Electric Force, and Electric Field 200
- 8.1 CONCEPTUAL Q&A Defying Gravity 202
- 8.2 Current, Voltage, and Electrical Power 204
- 8.1 HIGHLIGHT United States and Europe: Different Voltages 209
- 8.3 Simple Electric Circuits and Electrical Safety 209
- 8.2 CONCEPTUAL Q&A Series or Parallel 212
- 8.3 CONCEPTUAL Q&A More Resistance, More Current 213
- 8.2 HIGHLIGHT Electrical Effects on Humans 216
- 8.4 Magnetism 217
- 8.4 CONCEPTUAL Q&A Coin Magnet 220
- 8.3 HIGHLIGHT Magnetic North Pole 223
- 8.5 Electromagnetism 224
- 8.5 CONCEPTUAL Q&A No Transformation 227
- Key Terms 230, Matching 230, Multiple Choice 231, Fill In The Blank 231, Short Answer 231, Visual Connection 233, Applying Your Knowledge 233, Important Equations 233, Exercises 234

Chapter 9 Atomic Physics 235

- 9.1 Early Concepts of the Atom 236
- 9.2 The Dual Nature of Light 237
- 9.1 CONCEPTUAL Q&A Step Right Up 239
- 9.1 HIGHLIGHT Albert Einstein 241
- 9.3 Bohr Theory of the Hydrogen Atom 242
- 9.4 Microwave Ovens, X-Rays, and Lasers 249
- 9.2 CONCEPTUAL Q&A Can't Get Through 250
- 9.2 HIGHLIGHT X-Ray CAT Scan and MRI 251
- 9.5 Heisenberg's Uncertainty Principle 254
- 9.6 Matter Waves 255
- 9.3 CONCEPTUAL Q&A A Bit Too Small 256
- 9.7 The Electron Cloud Model of the Atom 257
- 9.3 HIGHLIGHT Electron Microscopes 258
- Key Terms 260, Matching 261, Multiple Choice 261, Fill In The Blank 262, Short Answer 262, Visual Connection 263, Applying Your Knowledge 263, Important Equations 263, Exercises 264

Chapter 10 Nuclear Physics 265

- 10.1 Symbols of the Elements 265
- 10.2 The Atomic Nucleus 267
- 10.3 Radioactivity and Half-Life 271
- 10.1 HIGHLIGHT The Discovery of Radioactivity 272
- 10.1 CONCEPTUAL Q&A A Misprint? 275
- 10.4 Nuclear Reactions 280
- 10.2 CONCEPTUAL Q&A Around the House 282
- 10.5 Nuclear Fission 284
- 10.3 CONCEPTUAL Q&A Out of Control 289
- 10.2 HIGHLIGHT Pebble-Bed Gas Reactor 289
- 10.6 Nuclear Fusion 290
- 10.7 Effects of Radiation 294
- 10.3 HIGHLIGHT Nuclear Power and Waste Disposal 296
- 10.8 Elementary Particles 296
- 10.4 CONCEPTUAL Q&A *Star Trek* Adventure 299
- Key Terms 299, Matching 300, Multiple Choice 300, Fill In The Blank 301, Short Answer 301, Visual Connection 302, Applying Your Knowledge 302, Important Equations 303, Exercises 303

Chapter 11 The Chemical Elements 305

- 11.1 Classification of Matter 306
- 11.1 CONCEPTUAL Q&A A Compound Question 307
- 11.2 Discovery of the Elements 309
- 11.3 Occurrence of the Elements 311
- 11.1 HIGHLIGHT Are There Really 98 Naturally Occurring Elements? 311
- 11.2 HIGHLIGHT Berzelius and How New Elements Are Named 312
- 11.4 The Periodic Table 316
- 11.5 Naming Compounds 322
- 11.2 CONCEPTUAL Q&A A Table of Compounds? 322
- 11.6 Groups of Elements 325

Key Terms 328, Matching 328, Multiple Choice 329, Fill In The Blank 329, Short Answer 330, Visual Connection 331, Applying Your Knowledge 331, Exercises 331

Chapter 12 Chemical Bonding 333

- 12.1 Law of Conservation of Mass 334
 12.1 HIGHLIGHT Lavoisier, “The Father of Chemistry” 335
- 12.2 Law of Definite Proportions 335
- 12.3 Dalton’s Atomic Theory 338
- 12.4 Ionic Bonding 339
 12.2 HIGHLIGHT Photochromic Sunglasses 344
- 12.5 Covalent Bonding 346
 12.1 CONCEPTUAL Q&A A Matter of Purity 353
- 12.6 Hydrogen Bonding 355
 12.2 CONCEPTUAL Q&A Hydrogen Bond Highways 356
- Key Terms 357, Matching 358, Multiple Choice 358, Fill In The Blank 359, Short Answer 359, Visual Connection 360, Applying Your Knowledge 360, Important Equations 360, Exercises 361

Chapter 13 Chemical Reactions 363

- 13.1 Balancing Chemical Equations 364
- 13.2 Energy and Rate of Reaction 368
 13.1 HIGHLIGHT The Chemistry of Air Bags 370
 13.1 CONCEPTUAL Q&A Burning Iron! 372
 13.2 CONCEPTUAL Q&A No Pineapple 373
- 13.3 Acids and Bases 374
 13.3 CONCEPTUAL Q&A Crying Time 377
 13.2 HIGHLIGHT The Chemistry of Tooth Decay 378
 13.4 CONCEPTUAL Q&A Odors, Be Gone! 379
- 13.4 Single-Replacement Reactions 382
- 13.5 Avogadro’s Number 385
- Key Terms 388, Matching 388, Multiple Choice 389, Fill In The Blank 390, Short Answer 390, Visual Connection 391, Applying Your Knowledge 391, Important Equation 392, Exercises 392

Chapter 14 Organic Chemistry 394

- 14.1 Bonding in Organic Compounds 395
- 14.2 Aromatic Hydrocarbons 396
- 14.3 Aliphatic Hydrocarbons 398
 14.1 HIGHLIGHT Octane Rating 402
- 14.4 Derivatives of Hydrocarbons 406
- 14.5 Synthetic Polymers 410
 14.1 CONCEPTUAL Q&A Keep It in Place 411
- 14.6 Biochemistry 413
 14.2 CONCEPTUAL Q&A My Twisted Double Helix 414
 14.3 CONCEPTUAL Q&A Carbohydrates and You 415
 14.2 HIGHLIGHT Veggie Gasoline? 417

Key Terms 418, Matching 418, Multiple Choice 418, Fill In The Blank 419, Short Answer 419, Visual Connection 420, Applying Your Knowledge 420, Exercises 421

Chapter 15 Place and Time 423

- 15.1 Cartesian Coordinates 424
 15.1 CONCEPTUAL Q&A 3-D Coordinates 425
- 15.2 Latitude and Longitude 425
 15.2 CONCEPTUAL Q&A Parallels and Perpendiculars 426
 15.1 HIGHLIGHT Global Positioning System (GPS) 428
- 15.3 Time 429
 15.2 HIGHLIGHT Time Traveler 432
 15.3 CONCEPTUAL Q&A Polar Time 433
- 15.4 Determining Latitude and Longitude 434
- 15.5 The Seasons and the Calendar 440
 15.4 CONCEPTUAL Q&A Equal Days and Nights 441
 15.5 CONCEPTUAL Q&A Hot and Cold Weather 442
 15.3 HIGHLIGHT A Brief History of the Calendar 444
- 15.6 Precession of the Earth’s Axis 445
- Key Terms 446, Matching 447, Multiple Choice 447, Fill In The Blank 448, Short Answer 448, Visual Connection 449, Applying Your Knowledge 449, Important Equation 450, Exercises 450

Chapter 16 The Solar System 451

- 16.1 The Solar System and Planetary Motion 452
- 16.2 Major Planet Classifications and Orbits 455
- 16.3 The Planet Earth 457
 16.1 CONCEPTUAL Q&A Another Foucault Pendulum 460
- 16.4 The Terrestrial Planets 461
- 16.5 The Jovian Planets 465
 16.2 CONCEPTUAL Q&A Gaseous Planet Rotations 466
 16.1 HIGHLIGHT Solar System Exploration: Gravity Assists 469
- 16.6 The Dwarf Planets 471
- 16.7 The Origin of the Solar System 475
- 16.8 Other Planetary Systems 476
 16.2 HIGHLIGHT The Kepler Mission: Searching for Planets 477
- Key Terms 478, Matching 478, Multiple Choice 478, Fill In The Blank 479, Short Answer 480, Visual Connection 480, Applying Your Knowledge 481, Important Equation 481, Exercises 481

Chapter 17 Moons and Small Solar System Bodies 482

- 17.1 Structure, Origin, and Features of the Earth’s Moon 483
 17.1 CONCEPTUAL Q&A No Magnetic Field 484
- 17.2 Lunar Motion Effects: Phases, Eclipses, and Tides 487

- 17.1 HIGHLIGHT Seeing Only One Side of the Moon 488
 17.2 CONCEPTUAL Q&A A Phase for Every Eclipse 491
 17.3 CONCEPTUAL Q&A Copper Moon 492
- 17.3 Moons of the Terrestrial Planets 495
 17.4 Moons of the Jovian Planets 495
 17.5 Moons of the Dwarf Planets 499
 17.6 Small Solar System Bodies: Asteroids, Meteoroids, Comets, and Interplanetary Dust 500
 17.2 HIGHLIGHT Trans-Neptunian Objects (TNOs) 505
- Key Terms 506, Matching 506, Multiple Choice 507, Fill In The Blank 508, Short Answer 508, Visual Connection 509, Applying Your Knowledge 510, Exercises 510

Chapter 18 The Universe 511

- 18.1 The Celestial Sphere 512
 18.1 CONCEPTUAL Q&A Celestial Coordinates 514
- 18.2 The Sun: Our Closest Star 515
 18.3 Classifying Stars 519
 18.4 The Life Cycle of Low-Mass Stars 522
 18.5 The Life Cycle of High-Mass Stars 524
 18.2 CONCEPTUAL Q&A Black Hole Sun 527
- 18.6 Galaxies 528
 18.1 HIGHLIGHT Determining Astronomical Distances 532
- 18.7 Cosmology 535
 18.3 CONCEPTUAL Q&A The Expanding Universe 537
 18.2 HIGHLIGHT The Age of the Universe 539
- Key Terms 541, Matching 541, Multiple Choice 542, Fill In The Blank 542, Short Answer 543, Visual Connection 544, Applying Your Knowledge 544, Important Equations 544, Exercises 544

Chapter 19 The Atmosphere 546

- 19.1 Atmospheric Composition and Structure 547
 19.2 Atmospheric Energy Content 551
 19.1 CONCEPTUAL Q&A Hot Time 553
 19.1 HIGHLIGHT Blue Skies and Red Sunsets 554
 19.2 HIGHLIGHT The Greenhouse Effect 556
 19.2 CONCEPTUAL Q&A Violet Sky 557
- 19.3 Atmospheric Measurements and Observations 558
 19.3 CONCEPTUAL Q&A Not Dense Enough 559
 19.4 CONCEPTUAL Q&A Slurp It Up 560
 19.3 HIGHLIGHT Human Body Pressures: Blood and Intraocular 561
- 19.4 Air Motion 566
 19.5 Clouds 570
 19.4 HIGHLIGHT Cloud Families and Types 572
- Key Terms 575, Matching 575, Multiple Choice 575, Fill In The Blank 576, Short Answer 576, Visual Connection 577, Applying Your Knowledge 578, Important Equation 578, Exercises 578

Chapter 20 Atmospheric Effects 579

- 20.1 Condensation and Precipitation 580
 20.2 Air Masses 583
 20.1 HIGHLIGHT El Niño (the Little Boy) and La Niña (the Little Girl) 587
- 20.3 Storms 587
 20.1 CONCEPTUAL Q&A What a Thundersnow! 589
 20.2 HIGHLIGHT Wind Chill Temperature Index 591
 20.2 CONCEPTUAL Q&A Snowy Cold 592
 20.3 CONCEPTUAL Q&A There She Blows 596
- 20.4 Atmospheric Pollution 599
 20.3 HIGHLIGHT Naming Hurricanes 600
 20.4 CONCEPTUAL Q&A A Laughing Matter 603
- 20.5 Climate and Pollution 607
 20.5 CONCEPTUAL Q&A Ruminating Up Some CH₄ 609
 20.4 HIGHLIGHT The Ozone Hole and Global Warming 610
- Key Terms 610, Matching 612, Multiple Choice 612, Fill In The Blank 613, Short Answer 613, Visual Connection 614, Applying Your Knowledge 614, Exercises 614

Chapter 21 Structural Geology and Plate Tectonics 615

- 21.1 The Earth's Interior Structure 616
 21.1 CONCEPTUAL Q&A The Earth's Interior Boundaries 617
- 21.2 Continental Drift and Seafloor Spreading 618
 21.3 Plate Tectonics 623
 21.2 CONCEPTUAL Q&A Continents in Balance 625
 21.1 HIGHLIGHT Crustal Motion on Other Planets and Moons 626
- 21.4 Plate Motion and Volcanoes 629
 21.5 Earthquakes 631
 21.3 CONCEPTUAL Q&A Los Angeles Meets San Francisco 633
 21.2 HIGHLIGHT Earthquake Risk in North America 634
 21.4 CONCEPTUAL Q&A The 2010 Big Shake in Haiti 636
- 21.6 Crustal Deformation and Mountain Building 637
 21.3 HIGHLIGHT Deadly Tsunamis 638
- Key Terms 642, Matching 642, Multiple Choice 643, Fill In The Blank 644, Short Answer 644, Visual Connection 645, Applying Your Knowledge 645

Chapter 22 Minerals, Rocks, and Volcanoes 646

- 22.1 Minerals 647
 22.1 CONCEPTUAL Q&A Cutting Diamonds 651
- 22.2 Rocks 653

- 22.2 CONCEPTUAL Q&A Energy for the Rock Cycle 655
 - 22.3 Igneous Rocks 655
 - 22.4 Igneous Activity and Volcanoes 658
 - 22.1 HIGHLIGHT Making Gold in an Active Volcano 659
 - 22.5 Sedimentary Rocks 665
 - 22.6 Metamorphic Rocks 669
 - 22.3 CONCEPTUAL Q&A Name That Metamorphic Process 672
- Key Terms 673, Matching 673, Multiple Choice 674, Fill In The Blank 675, Short Answer 675, Visual Connection 676, Applying Your Knowledge 676

Chapter 23 Surface Processes 678

- 23.1 Weathering 679
 - 23.1 CONCEPTUAL Q&A Moon Weathering 681
 - 23.2 Erosion 683
 - 23.3 Groundwater 689
 - 23.1 HIGHLIGHT The Earth's Largest Crystals 690
 - 23.2 CONCEPTUAL Q&A Powering the Hydrologic Cycle 690
 - 23.4 Shoreline and Seafloor Topography 694
 - 23.2 HIGHLIGHT The Highest Tides in the World 696
- Key Terms 700, Matching 701, Multiple Choice 701, Fill In The Blank 702, Short Answer 702, Visual Connection 703, Applying Your Knowledge 703

Chapter 24 Geologic Time 704

- 24.1 Fossils 705
 - 24.1 HIGHLIGHT How Fossils Were Formed 707
 - 24.1 CONCEPTUAL Q&A Fossilized Jellyfish 708
 - 24.2 Relative Geologic Time 708
 - 24.3 Radiometric Dating 713
 - 24.2 CONCEPTUAL Q&A Dinosaur Dating 718
 - 24.4 The Age of the Earth 719
 - 24.5 The Geologic Time Scale 720
 - 24.2 HIGHLIGHT The K-T Event: The Disappearance of the Dinosaurs 724
- Key Terms 725, Matching 726, Multiple Choice 726, Fill In The Blank 727, Short Answer 727, Visual Connection 728, Applying Your Knowledge 729, Exercises 729

Appendixes A-1

Answers to Confidence Exercises A-21

Answers to Selected Questions A-24

Glossary G-1

Index I-1

Preface

Science and technology are the driving forces of change in our world today. They revolutionize all aspects of our lives, including communication, transportation, medical care, the environment, politics, and education. To understand and fully participate in this transformation, it is important that today's students advance their knowledge of science. In addition to increasing their understanding of the principles of science, it is imperative that students know how science is truly conducted, and when, where, and to what science is applied. Equipped with this knowledge, they can better adapt to their environment and make informed decisions that ultimately affect their lives and the lives of others.

The primary goal of the fourteenth edition of *An Introduction to Physical Science* is in keeping with that of previous editions: to stimulate students' interest in science and to build a solid foundation of general knowledge in the physical sciences. Additionally, we continue to present the content in such a way that students develop the critical reasoning and problem-solving skills that are needed in our ever-changing technological world.

An Introduction to Physical Science, Fourteenth Edition, is intended for an introductory course for college nonscience majors. The five divisions of physical science are covered: physics, chemistry, astronomy, meteorology, and geology. Each division of physical science is discussed in the context of real-world examples. The textbook is readily adaptable to either a one- or two-semester course, or a two- to three-quarter course, allowing the instructor to select topics of his or her choice.

Approach

One of the outstanding features of this textbook continues to be its emphasis on fundamental concepts. These concepts are built on as we progress through the chapters. For example, Chapter 1, which introduces the concepts of measurement, is followed by chapters on the basic topics of physics: motion, force, energy, heat, wave motion, electricity and magnetism, atomic physics, and nuclear physics. This foundation in physics is useful in developing the principles of chemistry, astronomy, meteorology, and geology in the chapters that follow. We hope that this will lead to more students choosing careers in the sciences, engineering, and mathematics.

Organizational Updates in the Fourteenth Edition

The fourteenth edition of *An Introduction to Physical Science* retains its 24-chapter format. Each chapter contains a new Did You Know? feature identifying especially interesting science facts to engage a student's interest in the material they are preparing to read. You will also still find the Conceptual Questions and Answers, highlighting important material and important mathematical concepts as well. All Highlight boxes and Conceptual Question and Answer boxes are now numbered within each chapter and can be referenced in the Chapter Outline. All of the chapters contain many new photographs that are relatable to the current physical sciences student.

Chapter 2 has a new Highlight, "Terminal Velocity—Don't Fail Me Now!" showcasing Felix Baumgartner's jump from the stratosphere. Chapter 5 has new text on thermometers and their applications, including an accompanying Conceptual Question and Answer. There is also a new Highlight, "Human Body Temperature," discussing "normal" human body temperature, as well as its extremes. Chapter 10 features a new Highlight, "Pebble-Bed Gas Reactor," discussing possibly the next generation of nuclear reactors and how they work. Section 10.8 on Elementary Particles has been amended to include the Higgs boson and the resulting Nobel Prize award to Peter Higgs.

Chapter 11 features a new Highlight, "Are There Really 98 Naturally Occurring Elements?" to better explain this question to students. Chapter 12 has a new table,

“Predicted Molecular Shapes Using VSEPR,” summarizing various molecular geometries. Chapter 14 features a new discussion on 2,2,4-Trimethylpentane, including a new Highlight, “Octane Rating.”

Chapter 14 has a new Conceptual Question and Answer to clarify 3-D coordinates and some new text on geographic poles. Chapter 15 also has a new Highlight, “Time Traveler,” to explain the International Date Line. Chapter 16 contains updates to information on Mars according to recent explorations, and Chapter 17 is also updated with recent discoveries, especially relating to the moons of Saturn and Pluto, and features the latest photo of the nucleus of a comet. Chapter 18 contains astronomical updates, including changes to Hubble’s constant and the estimated age of the universe.

Chapter 19 has a new Highlight, “Human Body Pressures: Blood and Intraocular,” as part of the discussion of pressure measurements. Chapter 20 contains new material on recent meteorological events and a discussion of the hurricane rating system.

Chapter 21 has new information on the interior structure of the Earth based on recent studies, as well as a revised explanation of the forces involved in plate tectonics. Chapter 22 has a new Conceptual Question and Answer on cutting diamonds and features an updated figure with an expanded view of the rock cycle. Chapter 24 has a few updates on the geologic time calendar.

Math Coverage and Support

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

The level of mathematics in the textbook continues to be no greater than that of general high school math. Appendixes A through G provide a review of the math skills needed to deal with the mathematical exercises in this textbook. It may be helpful for students to begin their study by reading through these seven appendixes. This will help identify and remediate any mathematical weaknesses and thereby build confidence and ability for working the mathematical exercises in the textbook. Practice Exercises for mathematical concepts and skills appear in Cengage Learning’s CourseMate.

Assistance is also offered to students by means of in-text worked *Examples* and follow-up *Confidence Exercises* (with answers at the end of the book). However, the relative emphasis, whether descriptive or quantitative, is left to the discretion of the instructor. For instance, the end-of-chapter material may be selected according to the instructor’s preferences. To maintain a more descriptive approach, the *Exercises* may be omitted, and the other end-of-chapter sections may be used for assignments.

Outstanding Pedagogical Features in the Fourteenth Edition

- *New Did You Know?* feature. Interesting scientific concepts and details with section references to encourage exploration within the chapter. Listed at the beginning of each chapter.
- *Conceptual Questions and Answers* throughout every chapter. Conceptual in nature (no mathematics), the questions are designed to pique student interest in associated chapter material—and answers are given at the back of the book. A few example questions (see text for answers):
 - At night, a glass windowpane acts as a mirror when viewed from inside a lighted room. Why isn’t it a mirror during the day?

- Why do wet clothes or water spots on clothes appear to be a darker color? Does the color change?
- Microwave glass oven doors have a metal mesh with holes. What is the purpose of this?
- Each chapter begins with a list of *Facts*—a brief description of interesting, pertinent, and user-friendly items regarding concepts and topics to be covered in the chapter.
- Each section begins with *Preview Questions* that ask about principles and concepts that should be learned in studying the section. The questions are also designed to introduce important topics to pique the curiosity of the student.
- Each section ends with *Did You Learn?* statements that remind and emphasize the answers to the *Preview Questions* and important section topics that should have been noted.
- The acclaimed *Highlight* feature has been retained. The fourteenth edition has seven new Highlights, each with photos and description to relate science to its various applications.
- All worked-out *Examples* within a chapter give step-by-step solutions and are followed by related *Confidence Exercises* that give students immediate practice in solving that specific type of problem. *Answers to Confidence Exercises* may be found at the back of the book, so students can judge immediately their degree of comprehension.
- Nine *Appendixes* and a back-of-the-book *Glossary* of all chapter Key Terms and other associated terms are included to further aid student learning.

End-of-Chapter Features

For the fourteenth edition, the end-of-chapter material continues to include important features in the following order:

1. *Key Terms* that summarize the important boldface chapter terms, all of which are defined in the back-of-the-book *Glossary*.
2. *Matching Questions* following the *Key Terms* are designed to test students' ability to match an appropriate statement with each key term. For immediate feedback, answers to these questions are provided at the back of the book.
3. *Multiple-Choice Questions* follow the Matching Questions. The questions are keyed to the appropriate chapter section should the student need help, and the answers are given at the back of the book.
4. Next come *Fill-in-the-Blank Questions*. These questions are keyed to the appropriate chapter section should the student need help, and the answers are given at the back of the book.
5. *Short Answer Questions* test students' knowledge of important concepts by section.
6. In addition to new questions and problems in the end-of-chapter sections, all chapters contain a new *Visual Connection*. This feature has been reimagined in a different format, with an unlabeled illustrated concept and "blanks" in which the student gives names to the various parts of the visual idea. This new format is to promote a student's translation of what they see into the new terms they have learned in the chapter.
7. Next is the *Applying Your Knowledge* section. These questions involve conceptual and practical applications of material covered in the chapter and everyday topics relevant to the subject matter and challenge the student to apply the concepts learned.
8. When the chapter contains mathematical equations, a list of *Important Equations* is given as a helpful review tool for students and for quick reference when needed in working Exercises.
9. The *Exercises* section follows, but only for those chapters with mathematical content. As in previous editions, these exercises are paired, with the answer being provided to the first exercise (odd number) of each pair.

Design, Photo, and Illustration Program

Recognizing that many students are visual learners, we have increased the visual appeal and accessibility of this edition with new and more color photos and an updated art program.

Complete Text Support Package

CourseMate with eBook Interested in a simple way to complement your text and course content with study and practice materials? Cengage Learning's CourseMate brings course concepts to life with interactive learning, study, and exam preparation tools that support the printed textbook. Watch student comprehension soar as your class works with the printed textbook and the textbook-specific website.

CourseMate goes beyond the book to deliver what you need!



Enhanced WebAssign for Shipman, Wilson, Higgins, Torres's *An Introduction to Physical Science, 14th Edition* Exclusively from Cengage Learning, Enhanced WebAssign® combines the exceptional mathematics, physics, and astronomy content that you know and love with the most powerful online homework solution, WebAssign. Enhanced WebAssign engages students with immediate feedback and an interactive eBook, helping students to develop a deeper conceptual understanding of their subject matter. Online assignments can be built by selecting from hundreds of text-specific problems or supplemented with problems from any Cengage Learning textbook.

Enhanced WebAssign includes the Cengage YouBook: an engaging and customizable new eBook that lets you tailor the textbook to fit your course and connect with your students. You can remove and rearrange chapters in the table of contents and tailor assigned readings that match your syllabus exactly. Powerful editing tools let you change as much as you'd like—or leave it just like it is. You can highlight key passages or add sticky notes to pages to comment on a concept in the reading, and then share any of these individual notes and highlights with your students, or keep them personal. You can also edit narrative content in the textbook by adding a text box or striking out text. With a handy link tool, you can drop in an icon at any point in the eBook that lets you link to your own lecture notes, audio summaries, video lectures, or other files on a personal website or anywhere on the web. A simple YouTube widget lets you easily find and embed videos from YouTube directly into eBook pages.

The Cengage YouBook helps students go beyond just reading the textbook. Students can also highlight the text, add their own notes, and bookmark the text. Animations and videos play right on the page at the point of learning so that they're not speed bumps to reading but true enhancements.



PowerLecture for Shipman, Wilson, Higgins, Torres's *An Introduction To Physical Science, 14th Edition* This DVD provides the instructor with dynamic media tools for teaching. This dual-platform digital library and presentation tool provides text art, photos, and tables in a variety of easily exportable electronic formats. This enhanced DVD also contains animations to supplement your lectures, as well as lecture outlines. In addition, you can customize your presentations by importing your personal lecture slides or any other material you choose. Microsoft® PowerPoint® lecture slides and figures from the book are also included on this DVD. Turn your lectures into an interactive learning environment that promotes conceptual understanding with “clicker” content. With these slides you can pose text-specific questions to a large group, gather results, and display students' answers seamlessly. Using Cognero, instructors have all of the tools they need to create, author/edit, customize, and deliver multiple types of tests. Instructors can import questions directly from the test bank, create their own questions, or edit existing algorithmic questions, all within Cognero's powerful electronic platform.



Acknowledgments

We wish to thank our colleagues and students for the many contributions they continue to make to this textbook through correspondence, questionnaires, and classroom testing of the material. We would also like to thank all those who have helped us greatly in shaping this text over the years and the recent reviewers of this title:

Jennifer Cash, South Carolina State University
Richard Holland, Southeastern Illinois College
Mark Holycross, Spartanburg Methodist College
Trecia Markes, University of Nebraska—Kearney
Eric C. Martell, Millikin University
Robert Mason, Illinois Eastern Community College
Edgar Newman, Coastal Carolina University
Michael J. O'Shea, Kansas State University
Kendra Sibbersen, Metropolitan Community College
Todd Vaccaro, Francis Marion University

While they are not official reviewers for the book, we would like to acknowledge the contributions to the chemistry chapters by Lynn Deanhardt, Lander University, and Allison Wind, Middle Tennessee State University.

We are grateful to those individuals and organizations who contributed photographs, illustrations, and other information used in the text. We are also indebted to the Cengage Learning staff and several others for their dedicated and conscientious efforts in the production of *An Introduction to Physical Science*. We especially would like to thank Mary Finch, Product Director; Charlie Hartford, Senior Product Manager; Brandi Kirksey, Content Developer; Alison Eigel Zade, Content Project Manager; Julie Schuster, Marketing Development Manager; and Cate Barr, Senior Art Director.

As in previous editions, we continue to welcome comments from students and instructors of physical science and invite you to send us your impressions and suggestions.

About the Authors

With the Fourteenth Edition of *An Introduction to Physical Science*, first published nationally in 1971, the textbook has had a long run of 44 years. This accomplishment reflects the contributions over the years of several authors who are now deceased. In paying tribute to them, we have *James T. Shipman*, originator of the text and contributing to Editions 1–9. (Being known as the “Shipman” book, his name is retained on the authors’ list.) *Jerry L. Adams*, Editions 1–5, and *Aaron W. Todd*, Editions 7–11. Their contributions remain an integral part of *An Introduction to Physical Science*.

That being said, we have for the current edition:

Jerry D. Wilson received his physics degrees from: B.S., Ohio University; M.S., Union College (Schenectady, NY); and Ph.D., Ohio University. He is one of the original authors of the first edition of *An Introduction to Physical Science* and has several physical science and physics textbooks to his credit. In addition, Wilson has for over 30 years written a weekly question and answer column, the *Curiosity Corner* (originally the *Science Corner*), published in several area newspapers. He is currently Emeritus Professor of Physics at Lander University, Greenwood, SC. Email: jwilson@greenwood.net

Charles A. (Chuck) Higgins received his B.S. degree in physics from the University of Alabama in Huntsville and his M.S. and Ph.D. degrees in astronomy from the University of Florida. Areas of interest and research include planetary radio astronomy, astronomy education, and public outreach. He is currently Associate Professor in the Department of Physics and Astronomy at Middle Tennessee State University in Murfreesboro, Tennessee. Email: chiggins@mtsu.edu

Omar Torres received his chemistry degrees from: B.S., Texas A&M University; and M.S., the University of California at Los Angeles. He is currently the Dean of Mathematics, Sciences, and Engineering as well as a Professor in the Department of Chemistry at College of the Canyons in Santa Clarita, California. Torres also has another chemistry textbook to his credit. Email: omar.torres@canyons.edu

Measurement

CHAPTER

1



AP Images/Kevin Terrell

It is a capital mistake to theorize before one has data. Insensibly one begins to twist the facts to suit the theories, instead of the theories to suit the facts.

•
Sherlock Holmes
(Arthur Conan Doyle,
1859–1930)

< Bring in the chain for a measurement. No first and 10!

Did You Know?

Section

There are five divisions in physical science.

1.1

Mass and weight are related, but mass is the fundamental quantity.

1.4

Density describes the compactness of matter or mass per unit volume of a substance.

1.6

Science is concerned with the description and understanding of our environment. A first step in understanding our environment is to measure and describe the physical world. Over the centuries, humans have developed increasingly sophisticated methods of measurement, and scientists make use of the most advanced of these.

We are continually making measurements in our daily lives. Watches and clocks are used to measure the time it takes for events to take place. A census is taken every 10 years in the United States to determine (measure) the population. Money, calories, and the days and years of our lives are counted.

It was once thought that all things could be measured with exact certainty. But as smaller and smaller objects were measured, it became evident that the act of measuring distorted the measurement. This uncertainty in making measurements of the very small is discussed in more detail in Chapter 9.5. (Note that “Chapter 9.5” means “Chapter 9, Section 5.” This format will be used throughout this book to call your attention to further information in another part of the book.)

Measurement is crucial to understanding our physical environment, but first let's discuss the physical sciences and the methods of scientific investigation.

Chapter Outline

- 1.1 The Physical Sciences 2
- 1.2 Scientific Investigation 3
- 1.3 The Senses 4
 - 1.1 Highlight The “Face” on Mars 5
- 1.4 Standard Units and Systems of Units 6
 - 1.1 Conceptual Q&A Time and Time Again 10
- 1.5 More on the Metric System 12
- 1.6 Derived Units and Conversion Factors 14
 - 1.2 Highlight Is Unit Conversion Important? It Sure Is. 19
- 1.7 Significant Figures 20

PHYSICS FACTS

- Tradition holds that in the twelfth century, King Henry I of England decreed that 1 yard should be the distance from his royal nose to the thumb of his outstretched arm. (Had King Henry's arm been 3.37 inches longer, the yard and the meter would have been equal in length.)
- The abbreviation for the pound, lb, comes from the Latin word *libra*, which was a Roman unit of weight approximately equal to 1 pound. The word *pound* comes from the Latin *pondero*, meaning "to weigh." *Libra* is also a sign of the zodiac, symbolized by a set of scales (used for weight measurement).
- Is the old saying "A pint's a pound the world around" true? It depends on what you are talking about. The saying is a good approximation for water and similar liquids. Water weighs 8.3 pounds per gallon, so one-eighth of that, or 1 pint, weighs 1.04 lb.
- Thomas Jefferson suggested that the length of a pendulum with a period of 1 second be used as a length standard.
- The United States officially adopted the metric system in 1893.

1.1 The Physical Sciences

Preview Questions*

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

Think about the following:

- **Hung up.** A basketball player leaping up to make a shot seems to "hang" in the air before he slam-dunks a basketball.
- **Spot you one.** Driving in the summer, you may see what looks like water or a "wet spot" on the road ahead, but you never get to it.
- **All stuck up.** The professor rubs a balloon on his sweater and touches it to the ceiling, and the balloon stays there.
- **Mighty small.** There are pictures of individual atoms.
- **It doesn't add up.** Exactly 100 cc of ethanol alcohol is mixed with exactly 100 cc of water, and the resulting mixture is less than 200 cc.
- **Get in line.** There won't be a total solar eclipse visible from the United States until 2017, but there will be six or more visible elsewhere before then.
- **Dark Moon.** The dark side of the Moon isn't dark all the time.
- **A bolt from the blue.** You don't have to be in a thunderstorm for lightning to strike.
- **No blow.** One continent has no hurricanes, and a particular latitude has none either.
- **All shook up.** An earthquake with a magnitude of 8.0 on the Richter scale is not twice as energetic as one with a magnitude of 4.0 (but about a million times more).
- **Keep an eye on the sky.** There is evidence that a meteorite caused dinosaurs to become extinct.

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

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

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

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

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

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

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

Geology is the science of the planet Earth: its composition, structure, processes, and history.

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

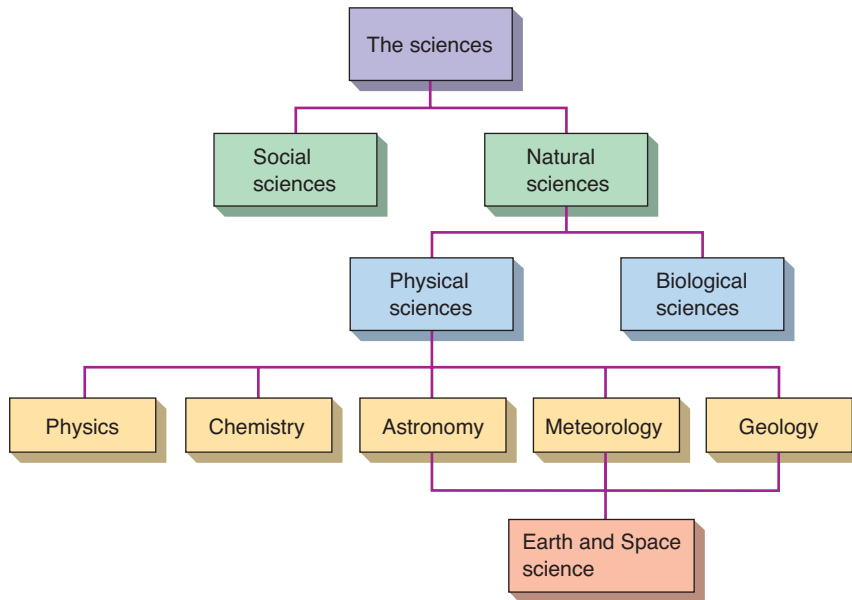


Figure 1.1 The Major Physical Sciences A diagram showing the five major physical sciences and how they fit into the various divisions of the sciences. (See text for discussion.)

(The last three physical sciences are sometimes combined as *Earth and Space Science*.)

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

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

Although the earliest humans had no sophisticated means to make measurements, they did have curiosity about the world around them. The desire to understand the movement of the stars, the passing of the seasons, and the hope of predicting the weather by using the clues of the wind and the clouds grew out of such curiosity and all were addressed by observations of the Earth and sky.

Indeed, observation forms the basis of all scientific knowledge, even in the modern world. Scientific knowledge is cumulative, and if our predecessors had not asked questions and made observations, our own knowledge of the physical sciences would be far less extensive. Each new discovery yields the possibility for more.

Did You Learn? *

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

1.2 Scientific Investigation

Preview Questions

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

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

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

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

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

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

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

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

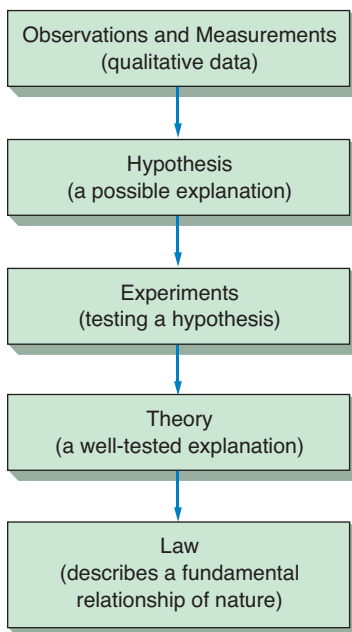


Figure 1.2 The Scientific Method
A flowchart showing the elements of the scientific method. If experiments show that a hypothesis is not consistent with the facts, more observations and measurements may be needed.

Did You Learn?

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

1.3 The Senses

Preview Questions

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

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

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

All the senses have limitations. For example, the unaided eye cannot see the vast majority of stars and galaxies. We cannot immediately distinguish the visible stars of our

1.1 Highlight The “Face” on Mars

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

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

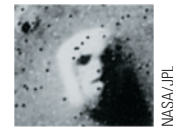
The “face” on Mars became a sensation, appearing in newspapers (particularly tabloids), in books, and on TV talk shows. Some people thought that it was evidence of life on Mars, either at present or in the past, or perhaps that it was the result of a visit to the planet by aliens. As for NASA's contention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

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

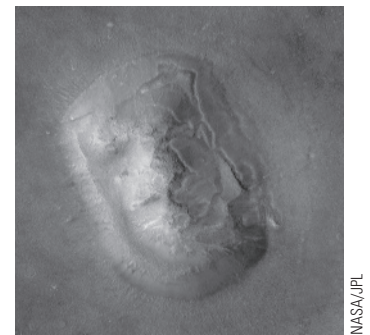
Not until 2001 did the MGS camera again pass over the object. This time there were no clouds, and the high-resolution picture was clearly that of a mesa similar to those common in the Cydonia region and the American West (Fig. 1b).

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

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



(a)



(b)

Figure 1 The Face on Mars

(a) In 1976, at the low resolution of the *Viking 1* camera, the appearance of a sculpted face can be seen.

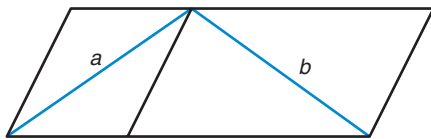
(b) In 2001, at the high resolution of the *Mars Global Surveyor* camera, the object is seen to be a common mesa.

galaxy from the planets of our solar system, which all appear as points of light (although with time the planets move). The limitations of the senses can be reduced by using measuring instruments such as microscopes and telescopes. Other examples of limitations are our temperature sense of touch being limited to a range of hotness and coldness before injury and our hearing being limited to a certain frequency range (Chapter 6.4).

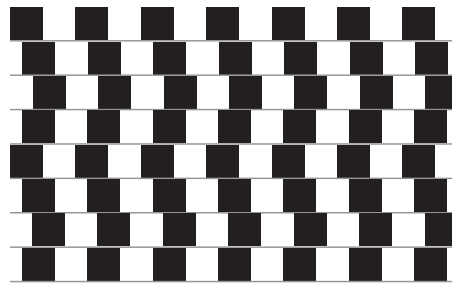
Not only do the senses have limitations, but they also can be deceived, thus providing false information about our environment. For example, perceived sight information may not always be a true representation of the facts because the brain can be fooled. There are many well-known optical illusions, such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

Did You Learn?

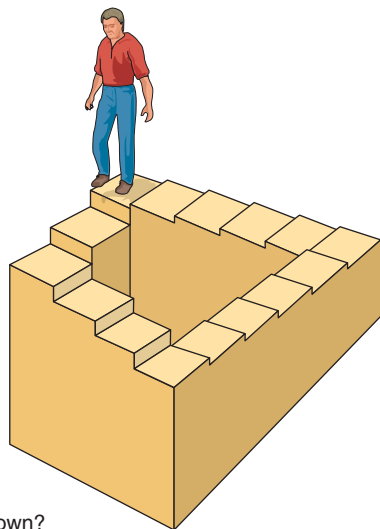
- Sight and hearing give us the greatest amount of information about our environment.
- The limitations of the senses can be reduced by using instruments such as microscopes and telescopes.



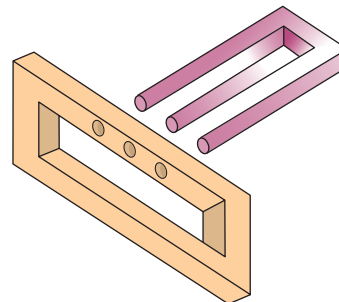
(a) Is the diagonal line b longer than the diagonal line a ?



(b) Are the horizontal lines parallel or do they slope?



(c) Going down?



(d) Is something dimensionally wrong here?

Figure 1.3 Some Optical Illusions

We can be deceived by what we see.

Answer the questions under the drawings.

1.4 Standard Units and Systems of Units

Preview Questions

- What is a standard unit?
- What are the standard units of length, mass, and time in the SI?

To describe nature, we make measurements and express these measurements in terms of the magnitudes of units. Units enable us to describe things in a concrete way, that is, numerically. Suppose that you are given the following directions to find the way to campus when you first arrive in town: “Keep going on this street for a few blocks, turn left at a traffic light, go a little ways, and you’re there.” Certainly some units or numbers would be helpful.

Many objects and phenomena can be described in terms of the *fundamental* physical quantities of length, mass, and time (*fundamental* because they are the most basic quantities or properties we can imagine). In fact, the topics of *mechanics*—the study of motion and force—covered in the first few chapters of this book require *only* these physical quantities. Another fundamental quantity, electric charge, will be discussed in Chapter 8. For now, let’s focus on the units of length, mass, and time.

To measure these fundamental quantities, we compare them with a reference, or standard, that is taken to be a standard unit. That is, a **standard unit** is a *fixed and reproducible value for the purpose of taking accurate measurements*. Traditionally, a government or international body establishes a standard unit.

A *group of standard units and their combinations* is called a **system of units**. Two major systems of units in use today are the **metric system** and the **British system**. The latter is used primarily in the United States, but the metric system is used throughout most of the world (● Fig. 1.4). The United States is the only major country that has not gone completely metric.



Figure 1.4 A Mostly Metric World

This Canadian sign warns drivers that the metric system is in use. Notice the differences in the magnitudes of the speed limit.

Length

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

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

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

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

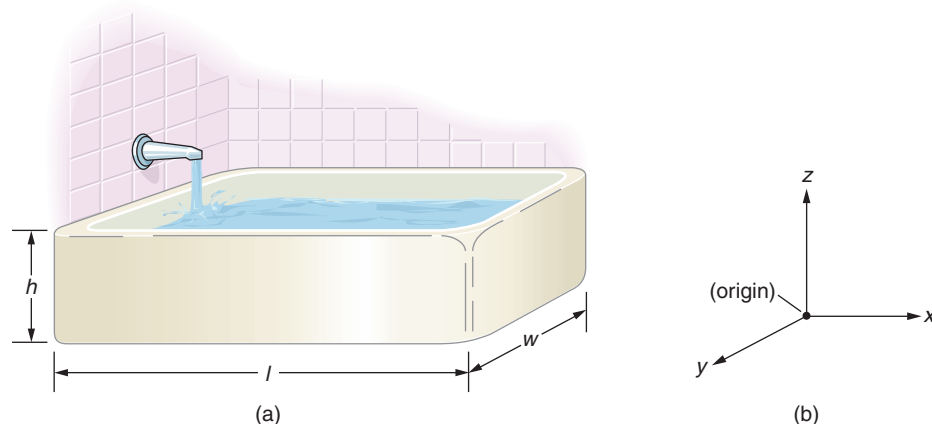


Figure 1.5 Space Has Three Dimensions

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

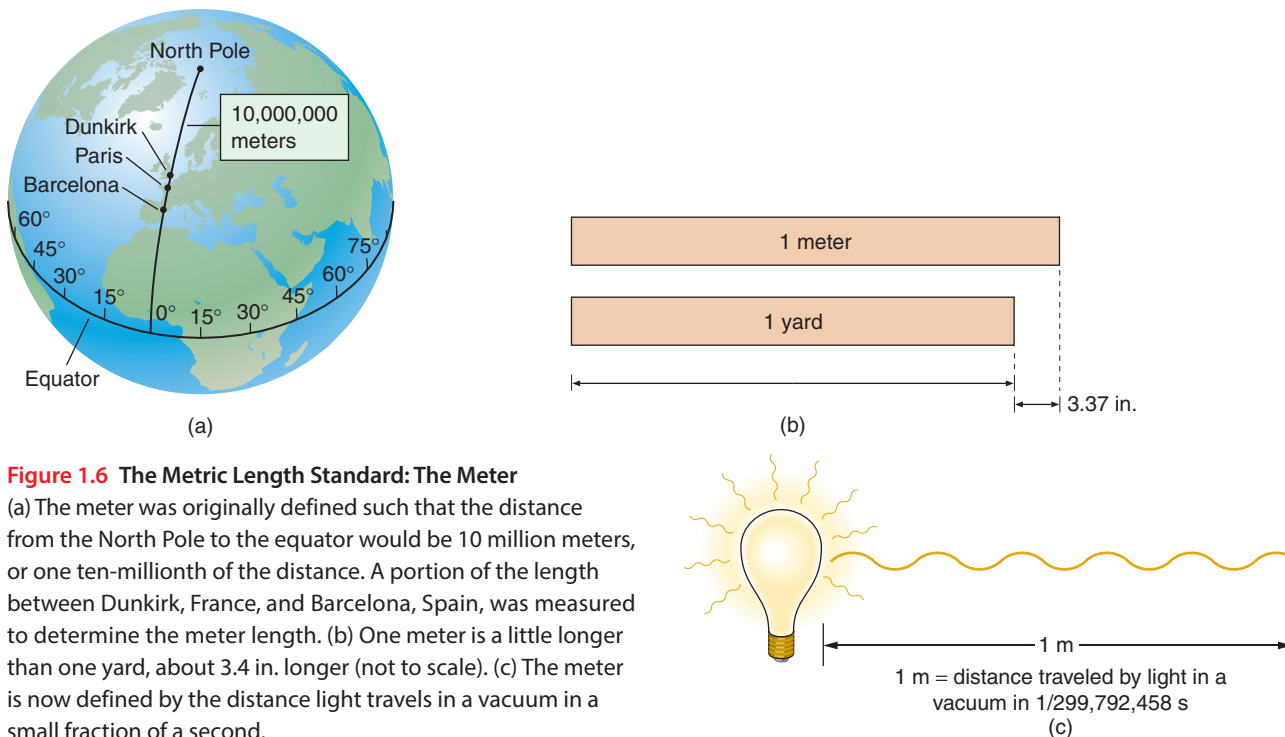


Figure 1.6 The Metric Length Standard: The Meter

(a) The meter was originally defined such that the distance from the North Pole to the equator would be 10 million meters, or one ten-millionth of the distance. A portion of the length between Dunkirk, France, and Barcelona, Spain, was measured to determine the meter length. (b) One meter is a little longer than one yard, about 3.4 in. longer (not to scale). (c) The meter is now defined by the distance light travels in a vacuum in a small fraction of a second.

The standard unit of length in the British system is the *foot*, which historically was referenced to the human foot. As noted in the Physics Facts at the beginning of this chapter, King Henry I used his arm to define the yard. Other early units commonly were referenced to parts of the body. For example, the *hand* is a unit that even today is used in measuring the heights of horses (1 hand is 4 in.).

Mass

Mass is the amount of matter an object contains. The more massive an object, the more matter it contains. (More precise definitions of mass in terms of force and acceleration, and in terms of gravity, will be discussed in Chapter 3.)

The standard metric unit of mass is the **kilogram** (kg). Originally, this amount of matter was related to length and was defined as the amount of water in a cubic container 0.10 m, or 10 cm, on a side (● Fig. 1.7a). However, for convenience, the mass standard was referenced to a material standard (an artifact or a human-made object). Currently, the kilogram is defined to be the mass of a cylinder of platinum–iridium kept at the International Bureau of Weights and Measures in Paris. The U.S. prototype (copy) is kept at the National Institute of Standards and Technology (NIST) in Washington, D.C. (Fig. 1.7b).

This standard is based on an artifact rather than on a natural phenomenon. Even though the cylinder is kept under controlled conditions, its mass is subject to slight changes because of contamination and loss from surface cleaning. A property of nature, by definition, is always the same and in theory can be measured anywhere. Scientists have yet to agree on an appropriate fundamental constant, such as the speed of light for the meter, on which to base the kilogram.

The unit of mass in the British system is the *slug*, a rarely used unit. We will not use this unit in our study because a quantity of matter in the British system is expressed in terms of weight on the surface of the Earth and in units of *pounds*. (The British system is sometimes said to be a gravitational system.) Unfortunately, weight is not a *fundamental* quantity, and its use often gives rise to confusion. Of course, a fundamental quantity should be the same and not change. However, weight is the gravitational attraction on an object by a celestial body, and this attraction is different for different celestial bodies. (The gravitational attraction of a body depends on its mass.)

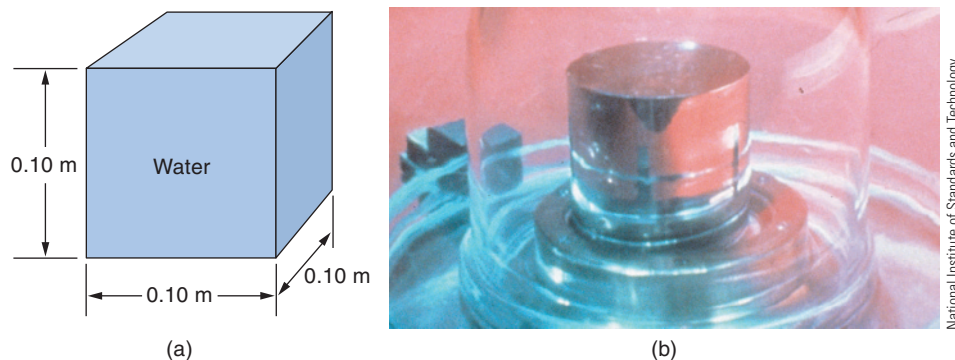


Figure 1.7 The Metric Mass Standard: The Kilogram (a) The kilogram was originally defined in terms of a specific volume of water, that of a cube 0.10 m on a side (at 4°C, the temperature at which water has its maximum density). As such, the mass standard was associated with the length standard. (b) Prototype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

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

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

Time

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

Some terms often used when referring to time are *duration*, *period*, and *interval*. A common descriptive definition is that **time** is *the continuous, forward flow of events*. Without events or happenings of some sort, there would be no perceived time

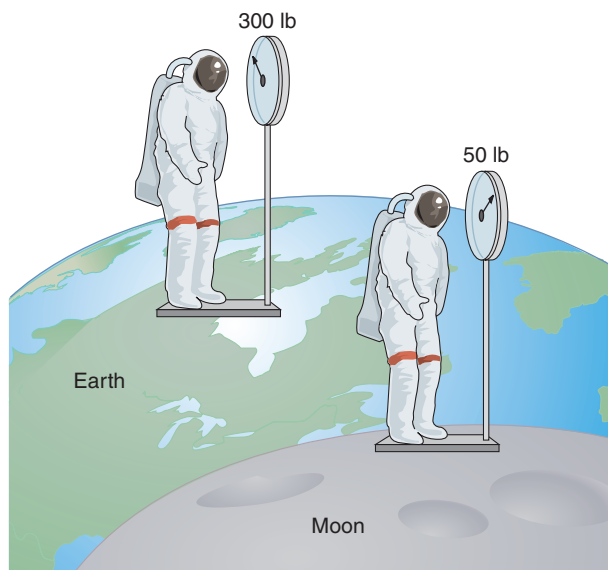


Figure 1.8 Mass Is the Fundamental Quantity The weight of an astronaut on the Moon is $\frac{1}{6}$ the astronaut's weight on the Earth, but the astronaut's mass is the same in any location.