TIMBERLAKE & TIMBERLAKE

# BASIC CHEMISTRY

FOURTH EDITION

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Fourth Edition

KAREN C. TIMBERLAKE
WILLIAM TIMBERLAKE

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**Library of Congress Cataloging-in-Publication Data**

Timberlake, Karen C.
Basic chemistry.—Fourth edition/Karen Timberlake, Los Angeles Valley College, William Timberlake, Los Angeles Harbor College.
pages cm.
ISBN-13: 978-0-321-80928-5
ISBN-10: 0-321-80928-9
1. Chemistry—Textbooks. I. Timberlake, William E. II. Title.
QD31.3.T54 2014
540—dc23

2012031269

1 2 3 4 5 6 7 8 9 10—**CRK**—16 15 14 13 12 11

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**www.pearsonhighered.com**

ISBN-10: 0-321-80928-9
ISBN-13: 978-0-321-80928-5

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# Preface

Welcome to the fourth edition of *Basic Chemistry*. This text was written and designed to help you prepare for science-related professions, such as engineering, nursing, medicine, environmental or agricultural science, or for careers such as laboratory technology. This text assumes no prior knowledge of chemistry. The main objective in writing this text is to make the study of chemistry an engaging and positive experience for you by relating the structure and behavior of matter to real life. This new edition introduces more problem-solving strategies, including math remediation, new concept checks, more problem-solving guides, new Analyze the Problem features, conceptual and challenge problems, and new sets of combined problems.

It is our goal to help you become a critical thinker by understanding scientific concepts that will form a basis for making important decisions about issues concerning health and the environment. Thus, we have utilized materials that

- help you to learn and enjoy chemistry
- develop problem-solving skills that lead to success in your chemistry course
- promote learning and success in your chosen career

## New to This Fourth Edition

New and updated features have been added throughout this fourth edition, including the following:

- **Chapter Openers** provide timely examples and engaging, topical issues of the chemistry that is part of contemporary professions.
- **Integrated math remediation** includes new Key Math Skills that review basic math relevant to chemistry throughout the text concluding with a Key Math Skills review at the end of each chapter with examples.
- **Core Chemistry Skills** icons identify the key chemical principles in each chapter that are required for successfully learning chemistry. A Core Chemistry Skills review at the end of each chapter summarizes and gives examples.
- **Chapter Readiness** at the beginning of each chapter lists the Key Math Skills and Core Chemistry Skills from the previous chapters that provide the foundation for new chemistry principles in the current chapter.
- **Analyze the Problem features** that are now included in the solutions of the Sample Problems to strengthen critical-thinking skills illustrate the breakdown of a word problem into the components required to solve it.
- **UPDATED! Combining Ideas** features offer sets of integrated problems that test students' understanding by integrating topics from two or more previous chapters.
- **UPDATED! End-of-Chapter Problems** based on reviewer feedback and MasteringChemistry® metadata ensure a range of difficulty levels, while added section references make homework and review more efficient for students.
- **UPDATED! Chemistry Link to Health boxes**, "Brachytherapy," "Polycyclic Aromatic Hydrocarbons (PAHs)," and "Breathing Mixtures for Scuba," have been added.
- **UPDATED! Chemistry Link to the Environment boxes**, "Energy-Saving Fluorescent Bulbs," "Vanilla," and "Pheromones in Insect Communication," have been added.
- **UPDATED! Guides to Problem Solving** have been added.
- **UPDATED! Chapter Reviews** now include bulleted lists and thumbnail art samples related to the content of each section.

## Chapter-by-Chapter Organization and Changes to the Fourth Edition

In each textbook we write, we consider it essential to relate every chemical concept to real-life issues of health and environment. Because a chemistry course may be taught in different time frames, it may be difficult to cover all the chapters in this text. However, each chapter is a complete package, which allows some chapters to be skipped or the order of presentation to be changed. In this edition, we have incorporated many topics of organic chemistry from Chapter 17 and some of biochemistry from Chapter 18 into the early chapters of the text to integrate general chemistry with organic chemistry.

**Chapter 1, Chemistry in Our Lives,** introduces the concepts of chemicals and chemistry, discusses the scientific method in everyday terms, and guides students in developing a study plan for learning chemistry.

- New Chapter Opener features the work and career of a forensic scientist.
- A new section, "Learning Chemistry: Key Math Skills," reviews basic math required in chemistry, such as place values, positive and negative numbers, percentages, solving equations, and interpreting a line graph.

**Chapter 2, Measurements,** looks at measurement and emphasizes the need to understand numerical relationships of the

metric system. An explanation of scientific notation and working with a calculator is included in the chapter.

- New Chapter Opener features the work and career of a registered nurse.
- New Guide to Writing a Number in Scientific Notation was added.
- New material was added that illustrates how to count significant figures in equalities and in conversion factors used in a problem setup.
- New photos that were added include the standard kilogram, mass of a nickel, and a virus.
- The number of parts in multiple-part questions in *MasteringChemistry* was reduced when time needed for students to complete them exceeded 15 minutes.

**Chapter 3, Matter and Energy,** classifies matter and states of matter, describes temperature measurement, and discusses energy and its measurement. Physical and chemical changes and physical and chemical properties are now discussed in more depth. The section on forms of energy has been deleted. The feature Combining Ideas utilizing concepts from Chapters 1, 2, and 3 follows as an interchapter problem set.

- New Chapter Opener features the work and career of a dietitian.
- New Guide to Calculating Temperature was added.
- New problems were added to complete matched sets of problems.
- The effect of the high specific heat of water on coastal cities compared to inland cities was added.
- New Guide to Calculating Specific Heat was added.
- New Guide to Calculating Energy from a Food was added.
- Problems with high difficulty in *MasteringChemistry* were rewritten to identify data and needed answers.

**Chapter 4, Atoms and Elements,** looks at elements, atoms, subatomic particles, atomic numbers, and mass numbers. Using the naturally occurring isotopes and abundances, atomic mass is calculated.

- New Chapter Opener now features the chemistry utilized by a farmer and farming as a career.
- Number of elements now given as 118.
- Table 4.1 was expanded to include the symbols of the elements listed.
- Symbols of the elements Copernicium, Cn (112), Flerovium, Fl (114), and Livermorium, Lv (116) were added to the periodic table of elements.
- "Chemistry Link to Industry: Many Forms of Carbon" was moved into Section 4.1, "Elements and Symbols."
- Photo upgrades through Chapter 4 improve the visual representations of concepts.
- Updated art for the nuclei of the three naturally occurring magnesium isotopes now shows them as three different shades of blue.
- New analogy for the weighted average of bowling balls now introduces concepts of weighted average for atomic mass of an element.
- Table 4.8 now includes the "most prevalent isotopes."
- Isotopes and percent abundances of thallium and rubidium are now included in atomic mass calculations.
- Questions and Problems in *MasteringChemistry* that had high difficulty for students were rewritten.

**Chapter 5, Electronic Structure and Periodic Trends,** uses the electromagnetic spectrum to explain atomic spectra and develop the concept of energy levels and sublevels. Electrons in sublevels and orbitals are represented using orbital diagrams and electron configurations. Periodic properties of elements, including atomic radius and ionization energy, are related to their valence electrons. Section 5.4 is now titled "Orbital Diagrams and Electron Configurations." Section 5.6 is now titled "Trends in Periodic Properties." Small periodic tables have been added to Section 5.6 to illustrate the trends of periodic properties.

- New Chapter Opener features engineers working in the field of materials science.
- Peaks and dips of a wave are now described as crests and troughs.
- The wave equation is now solved for wavelength or for frequency.
- New Guide to Using the Wave Equation was added.
- New Guide to Drawing Orbital Diagrams was added.
- The discussion on electron energy levels was rewritten, and an updated illustration of energy levels was added.
- New diagrams of the *d* orbitals have been added to the representations of *s* and *p* orbitals.
- A discussion of metallic character has been added to Section 5.6, "Trends in Periodic Properties."
- A new summary of the properties for valence electrons, atomic size, ionization energy, and metallic character from top to bottom of a group and going from left to right across a period was added to Section 5.6, "Trends in Periodic Properties."

**Chapter 6, Ionic and Molecular Compounds,** describes how atoms form ionic and covalent bonds. Chemical formulas are written, and ionic compounds—including those with polyatomic ions—and molecular compounds are named. An introduction to the three-dimensional shape of carbon molecules provides a basis for the shape of organic and biochemical compounds. Organic chemistry is introduced with the properties of inorganic and organic compounds and condensed structural formulas of alkanes. Section 6.1 is now titled "Ions: Transfer of Electrons," 6.2 is titled "Writing Formulas for Ionic Compounds," 6.3 is

titled "Naming Ionic Compounds," and 6.5 is titled "Molecular Compounds: Sharing Electrons."

- New Chapter Opener features the work and career of a pharmacist.
- "Ions: Transfer of Electrons" has been rewritten to emphasize the stability of the electron configuration of a noble gas.
- New art comparing the particles and bonding of ionic compounds and molecular compounds has been added.
- New flowchart for Naming Chemical Compounds in Section 6.5 shows naming patterns for ionic and molecular compounds and includes naming alkanes.
- New Guide to Writing Formulas with Polyatomic Ions was added.
- New Concept Check, "Electron-Dot Formulas," was added.
- New Concept Checks include the names and formulas of ionic and covalent compounds.
- "Organic Compounds" and "Names and Formulas of Alkanes" are labeled as Extended Topics.
- Representations of methane and ethane have been updated to emphasize the tetrahedral shape.
- The skeletal formulas of alkanes have been added to the types of formulas for drawing alkanes.

**Chapter 7, Chemical Quantities,** discusses Avogadro's number, the mole, and molar masses of compounds, which are used in calculations to determine the mass or number of particles in a quantity of a substance. The mass percent composition of a compound is calculated and used to determine its empirical and molecular formula. Combining Ideas from Chapters 4, 5, 6, and 7 follows as an interchapter problem set.

- New Chapter Opener describes the work and career of a veterinarian.
- The periodic table in Section 7.2 now includes symbols of Fl (114) and Lv (116).
- New Concept Check 7.4, "Calculating Mass Percent from Experimental Data," was added.
- New Guide to Calculating Moles was added.
- New Guide to Calculating Mass Percent Composition was added.

**Chapter 8, Chemical Reactions,** looks at the interaction of atoms and molecules in chemical reactions. Chemical equations are balanced and organized into combination, decomposition, single replacement, double replacement, and combustion reactions. Section 8.4, "Functional Groups and Reactions of Organic Compounds," and Section 8.5, "Biochemical Compounds," are now Extended Topics, which classify compounds according to their structures to predict their properties and reactions. The Chemistry Link to Health features, "Amines in Health and Medicine" and "Omega-3 Fatty Acids in Fish Oils," and the Chemistry Link to Industry feature, "Hydrogenation of Unsaturated Fats," are included in Chapter 8.

- New Chapter Opener describes the work and career of an exercise physiologist.
- Section 8.3, "Types of Reactions," now includes combustion reactions and balancing equations for combustion reactions.
- Chemistry Links to Health were added, including "Hand Sanitizers and Ethanol," "Polycyclic Aromatic Hydrocarbons (PAHs)" (moved from Chapter 17), and "Salicylic Acid from the Willow Tree" (moved from Chapter 14), and a new Chemistry Link to the Environment, "Pheromones in Insect Communication," was also added.
- Section 8.5 is now titled "Biochemical Compounds: Extended Topic," which discusses functional groups in carbohydrates, lipids, and proteins.

**Chapter 9, Chemical Quantities in Reactions,** describes the mole and mass relationships among the reactants and products and provides calculations of limiting reactants and percent yields. A section on "Energy in Chemical Reactions" completes the chapter.

- New Chapter Opener describes the work and career of an environmental scientist.
- Mole and mass relationships among the reactants and products are examined along with calculations of percent yield and limiting reactants.
- A new diagram illustrates the process of changing grams of one substance to the grams of another substance.
- New diagrams illustrate the change in energy level of reactants and products for exothermic reactions and for endothermic reactions.

**Chapter 10, Properties of Solids and Liquids,** introduces electron-dot formulas for molecules and ions with single and multiple bonds as well as resonance structures. Electronegativity leads to a discussion of the polarity of bonds and molecules. Electron-dot formulas and VSEPR theory illustrate covalent bonding and the three-dimensional shapes of molecules and ions. The attractive forces between particles and their impact on states of matter and changes of state are described. Combining Ideas from Chapters 8, 9, and 10 follows as an interchapter problem set.

- New Chapter Opener describes the work and career of a histologist.
- New illustrations of molecular models provide visual representations of three-dimensional structures.
- New wedge–dash notation for tetrahedral structures and trigonal pyramidal structures was added.
- The heating curve, Figure 10.6, for water has been updated.

- Ethanol, acetic acid, and acetone have been added to heat calculations.
- Heat equation for combining energy calculations is reviewed.
- A new Guide to Determination of Polarity of a Molecule has been added.
- The Guides to Calculations Using Heat of Fusion and Heat of Vaporization were rewritten.
- Table 10.6, Comparison of Bonding and Attractive Forces, has been updated.
- A new diagram of unsymmetrical distribution of electrons in nonpolar molecules to give weak dispersion force attractions was added.
- Sublimation was moved to the end of the chapter.

**Chapter 11, Gases,** describes the properties of a gas and calculates changes in gases using the gas laws and the ideal gas law. The amounts of gases required or produced in chemical reactions are calculated.

- New Chapter Opener describes the work and career of a respiratory therapist.
- A table of initial and final gas conditions now includes the factors that remain constant.
- A new Guide to Calculating the Molar Mass of a Gas has been added.
- Several GPS Steps have been rewritten.

**Chapter 12, Solutions,** describes solutions, saturation and solubility, concentrations, and colligative properties. The volumes and molarities of solutions are used in calculations of reactants and products in chemical reactions, as well as dilutions and titrations. Section 12.4 is now titled "Concentration of Solutions" and Section 12.5 is now titled "Dilution and Chemical Reactions in Solution." Section 12.6, "Properties of Solutions," discusses the properties of solutions and the impact of particle concentration on the boiling point, freezing point, and osmotic pressure.

- New Chapter Opener describes the work and career of a dialysis nurse.
- Sections on "Formation of Solutions" and "Electrolytes" have been rewritten for improved clarity.
- New photos added include rock candy made from a saturated sugar solution, vanilla extract and lemon extract, and the Alaska Upis beetle, which produces its own biological antifreeze.
- A new Table 12.7 summarizes percent concentration and molarity and their units.
- A new Guide to Calculating Molality was added.
- A new Guide to Using Molality was added.
- New material on using molality to calculate freezing point depression and boiling point elevation was added.
- New problems were added to provide matched sets of problems.

**Chapter 13, Reaction Rates and Chemical Equilibrium,** looks at the rates of reactions and the equilibrium condition when forward and reverse rates for a reaction become equal. Equilibrium expressions for reactions are written, and equilibrium constants are calculated. Using equilibrium constants, reactions are evaluated to determine whether stress causes the equilibrium to shift in the direction of the reactants or the products. Le Châtelier's principle is used to evaluate the impact on concentrations when a stress is placed on the equilibrium system. The equilibrium of dissolving and crystallizing in saturated solutions is evaluated using solubility product constants.

- New Chapter Opener describes the work and career of a chemical oceanographer.
- Enzymes in laundry detergents are discussed as examples of catalysts in everyday products.
- Art in Figures 13.8 and 13.9 has been updated.
- A new diagram of analogy of water in tanks reaching equilibrium has been added.
- A new Figure 13.11 has been added, illustrating the effect of concentration changes on equilibrium.
- Updated diagrams illustrate the decrease of reactants and increase of products to reach equilibrium.
- Guides to Writing the Equilibrium Constant Expression, Calculating the $K_c$ Value, Using the Equilibrium Constant, Calculating $K_{sp}$, and Calculating Molar Solubility from $K_{sp}$ have been updated and rewritten.
- Art on the effect of adding a common ion of $Mg^{2+}$ or $CO_3^{2-}$ to a solution of $MgCO_3$ has been updated.
- New photos of slightly soluble salts, including calcium oxalate, calcium carbonate, and cadmium sulfide, have been added.

**Chapter 14, Acids and Bases,** discusses acids and bases and their strengths, conjugate acid–base pairs, the dissociation of weak acids and bases and water, pH and pOH, and buffers. Acid–base titration uses the neutralization reactions between acids and bases to calculate quantities of acid in a sample. Section 14.9, "Acid–Base Properties of Salt Solutions," has been deleted. Combining Ideas from Chapters 11, 12, 13, and 14 follows as an interchapter problem set.

- New Chapter Opener describes the work and career of a clinical laboratory technician.
- Three-dimensional models of sulfuric acid, bicarbonate, carbonic acid, formate, and formic acid were added.
- Table 14.4, Relative Strengths of Acids and Bases, was moved to Section 14.3, "Strengths of Acids and Bases."
- A new Guide to Writing Conjugate Acid–Base Pairs has been added.
- New material on diprotic acids has been added.
- New art on weak acid hydrofluoric acid was added.

- New material and art on gastric cells and the production of HCl has been added to Chemistry Link to Health, "Stomach Acid, HCl."
- New photos of calcium hydroxide and information about its use in the food industry, dentistry, and preparation of corn kernels for hominy were added.
- Guides to Calculating $[H_3O^+]$ and $[OH^-]$ in Aqueous Solutions and Calculating pH of an Aqueous Solution have been rewritten.
- A new Guide Calculating $[H_3O^+]$ from pH was added.
- A new photo of sodium bicarbonate reacting with acetic acid has been added to chemical reactions of acids and bases.

**Chapter 15, Oxidation and Reduction,** looks at the characteristics of oxidation and reduction reactions. Oxidation numbers are assigned to the atoms in elements, molecules, and ions to determine the components that lose electrons during oxidation and gain electrons during reduction. The half-reaction method is utilized to balance oxidation–reduction reactions. The production of electrical energy in voltaic cells and the requirement of electrical energy in electrolytic cells are diagrammed using half-cells. The activity series is used to determine the spontaneous direction of an oxidation–reduction reaction.

- New Chapter Opener describes the work and career of a dentist.
- A new Guide to Using Oxidation Numbers has been added.
- Oxidation–reduction equations are now balanced using half-reactions in acidic or basic solutions.
- The Guide to Balancing Redox Equations Using Half-Reactions was rewritten.
- Section 15.4, which is titled "Electrical Energy from Oxidation–Reduction Reactions," now begins with the Activity Series followed by Voltaic Cells.
- The section "Oxidation of Alcohols" is now an Extended Topic at the end of the chapter and includes the oxidation of alcohol in the body.

**Chapter 16, Nuclear Chemistry,** looks at the type of radioactive particles that are emitted from the nuclei of radioactive atoms. Equations are written and balanced for both naturally occurring radioactivity and artificially produced radioactivity. The half-lives of radioisotopes are discussed, and the amount of time for a sample to decay is calculated. Radioisotopes important in the field of nuclear medicine are described. Combining Ideas from Chapters 15 and 16 follows as an interchapter problem set.

- New Chapter Opener describes the work and career of a radiologist.
- A new Sample Problem, Dating Using Half-Lives, now calculates time elapsed for a bone sample.
- New photos added include a smoke detector and bone in a skeleton used in carbon dating.

**Chapter 17, Organic Chemistry,** discusses each family of organic compounds, thus forming a basis for understanding the biomolecules of living systems. In this fourth edition, topics such as functional groups, reactions of organic compounds, and naming organic acids are now included in earlier chapters on naming molecular compounds and chemical reactions. This organic chapter is now streamlined with an emphasis on naming and drawing formulas of organic compounds from alkanes with substituents to amines and amides.

- New Chapter Opener describes the work and career of a firefighter.
- The skeletal formula for carbon chains has been added.
- Drawing a skeletal formula has been added to Sample Problem 17.2 along with drawing condensed structural formulas.
- A new Guide to Naming Aromatic Compounds has been added.
- Skeletal structures are now included as compounds in Questions and Problems.
- A table of the IUPAC and common names of selected carboxylic acids was added.
- New illustrations for naming esters were added.

**Chapter 18, Biochemistry,** looks at the chemical structures and reactions of chemicals that occur in living systems. We focus on four types of biomolecules—carbohydrates, lipids, proteins, and nucleic acids—as well as their biochemical reactions. The shape of proteins is related to the activity and regulation of enzyme activity. A discussion of the genetic code and protein synthesis completes the chapter. Combining Ideas from Chapters 17 and 18 follows as an interchapter problem set.

- New Chapter Opener describes the work and career of a forensic toxicologist.
- An updated graph of blood glucose levels with time has replaced the previous graph.
- New monosaccharide open-chain structures have been added to Questions and Problems for Carbohydrates.
- The term Haworth Structures is now used for the term cyclic structures for monosaccharides, disaccharides, and polysaccharides.
- The Guide to Drawing Haworth Structures has been rewritten.
- Art added to the introduction of lipids distinguishes between the structures of fatty acids, waxes, triacylglycerols, and steroids.

- Table 18.2 has been expanded and includes more examples of common fatty acids as well as their skeletal formulas.
- New art and ball-and-stick models of *cis*-2-butene and *trans*-2-butene have been added.
- New material on some typical waxes and their condensed structural formulas has been added.
- New art illustrating triacylglycerols has been added.
- New art for the olestra molecule has been added.
- New art for a steroid and cholesterol has been added.
- New art for amino acids and ionized amino acids has been added.
- New single letter abbreviations for amino acids have been added.
- New art for the ribbon models of proteins has been added.
- New art for the induced-fit model of enzyme action has been added.

# Instructional Package

*Basic Chemistry*, Fourth Edition, provides an integrated teaching and learning package of support material for both students and professors.

## For Students

The **Study Guide for *Basic Chemistry*, Fourth Edition,** by Karen Timberlake is keyed to the learning goals in the text and designed to promote active learning through a variety of exercises with answers as well as practice tests. The **Study Guide** also contains complete solutions to odd-numbered problems. (ISBN 0321834437)

**MasteringChemistry®** The most advanced, most widely used online chemistry tutorial and homework program is available for the fourth edition of *Basic Chemistry*. MasteringChemistry® utilizes the Socratic method to coach students through problem-solving techniques, offering hints and simpler questions on request to help students *learn*, not just practice. A powerful grade book with diagnostics that gives instructors unprecedented insight into their students' learning is also available. For the fourth edition, 12 new tutorials have been created to guide students through the most challenging Basic Chemistry topics and help them make connections between chemical concepts.

**Pearson eText** offers students the power to create notes, highlight text in different colors, create bookmarks, zoom, and view single or multiple pages. Access to the Pearson eText for *Basic Chemistry*, Fourth Edition, is available for purchase either as a stand-alone item (ISBN 0321834291) or within Mastering Chemistry®. (ISBN 032183433X)

**Laboratory Manual by Karen Timberlake** This best-selling lab manual coordinates 35 experiments with the topics in *Basic Chemistry*, Fourth Edition, and uses new terms during the lab and explores chemical concepts. Laboratory investigations develop skills of manipulating equipment, reporting data, solving problems, making calculations, and drawing conclusions. These labs are also available within Pearson Custom Library, which gives instructors the power to create a custom text by selecting content from our course-specific collections. (ISBN 0321811852)

## For Instructors

**MasteringChemistry®** MasteringChemistry® is the first adaptive-learning online homework and tutorial system. Instructors can create online assignments for their students by choosing from a wide range of items, including end-of-chapter problems and research-enhanced tutorials. Assignments are automatically graded with up-to-date diagnostic information, helping instructors pinpoint where students struggle either individually or as a class as a whole. For the fourth edition, new tutorials have been created to guide students through the most challenging *Basic Chemistry* topics and help them make connections between chemical concepts.

**Instructor Solutions Manual** Prepared by Mark Quirie, this manual highlights chapter topics. It contains complete solution setups and answers to all the problems in the text. (ISBN 0321834445)

**Instructor's Resource Materials for *Basic Chemistry*, Fourth Edition** This resource includes all the art, photos, and tables from the book in JPG format for use in classroom projection or when creating study materials and tests. In addition, the instructors can access the PowerPoint™ lecture outlines, featuring over 2000 slides. Also available are downloadable files of the *Instructor Solutions Manual* and a set of "clicker questions" designed for use with classroom-response systems. (ISBN 0321809483)

**TestGen Test Bank** Prepared by William Timberlake, this resource includes more than 1600 questions in multiple-choice, matching, true/false, and short-answer format. (ISBN 032183447X)

**Online Instructor Manual for Laboratory Manual** This manual contains answers to report pages for the *Laboratory Manual.* (ISBN 0321812859)

Also visit the Pearson Education catalog page for Timberlake's *Basic Chemistry*, Fourth Edition, at **www.pearsonhighered.com** to download available instructor supplements.

## Acknowledgments

The preparation of a new text is a continuous effort of many people. As in our work on other textbooks, we are thankful for the support, encouragement, and dedication of many people who put in hours of tireless effort to produce a high-quality book that provides an outstanding learning package. The editorial team at Pearson Publishing has done an exceptional job. We want to thank, Adam Jaworski, editor in chief, who supported our vision of this fourth edition and the development of new math remediation strategies with Chapter Readiness, Key Math Skills, and Core Chemistry Skills, which appear throughout the chapter along with their reviews at the end of each chapter and with the new Analyze the Problem feature that clarifies the components of a word problem for problem solving. We also appreciate the addition of new Concept Checks, more Guides to Problem Solving, new Chemistry Links to Health, Chemistry Link to History, Chemistry Link to Industry, and Chemistry Link to the Environment boxes, and new problems in Understanding the Concepts and Combining Ideas.

We much appreciate all the wonderful work of Jessica Moro, project editor, who was like an angel encouraging us at each step, while skillfully coordinating reviews, art, web site materials, and all the things it takes to make a book come together. We appreciate the work of Beth Sweeten, project manager, and Andrea Stefanowicz of PreMediaGlobal, who brilliantly coordinated all phases of the manuscript to the final pages of a beautiful book. Thanks to Mark Quirie, manuscript and accuracy reviewer, and Betty Pessagno, copy editor, who precisely analyzed and edited the initial and final manuscripts and pages to make sure the words and problems were correct to help students learn chemistry. Their keen eyes and thoughtful comments were extremely helpful in the development of this text.

We are especially proud of the art program in this text, which lends beauty and understanding to chemistry. We would like to thank Connie Long and Derek Bacchus, art director and book designer, whose creative ideas provided the outstanding design for the cover and pages of the book. Eric Schrader, photo researcher, was invaluable in researching and selecting vivid photos for the text so that students can see the beauty of chemistry. Thanks also to *Bio-Rad Laboratories* for their courtesy and use of *KnowItAll ChemWindows*, drawing software that helped us produce chemical structures for the manuscript. The macro-to-micro illustrations designed by Production Solutions and Precision Graphics give students visual impressions of the atomic and molecular organization of everyday things and are a fantastic learning tool. We want to thank Martha Ghent for the hours spent proofreading all the pages. We also appreciate all the hard work put in by the marketing team in the field and Jonathan Cottrell, marketing manager.

We are extremely grateful to an incredible group of peers for their careful assessment of all the new ideas for the text; for their suggested additions, corrections, changes, and deletions; and for providing an incredible amount of feedback about improvements for the book. In addition, we appreciate the time scientists took to let us take photos and discuss their work with them. We admire and appreciate every one of you.

If you would like to share your experience with chemistry, or have questions and comments about this text, we would appreciate hearing from you.

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**KAREN TIMBERLAKE** is Professor Emerita of Chemistry at Los Angeles Valley College, where she taught chemistry for allied health and preparatory chemistry for 36 years. She received her bachelor's degree in chemistry from the University of Washington and her master's degree in biochemistry from the University of California at Los Angeles.

Professor Timberlake has been writing chemistry textbooks for 40 years. During that time, her name has become associated with the strategic use of pedagogical tools that promote student success in chemistry and the application of chemistry to real-life situations. More than one million students have learned chemistry using texts, laboratory manuals, and study guides written by Karen Timberlake. In addition to ***Basic Chemistry,*** **Fourth Edition,** she is also the author of ***Chemistry: An Introduction to General, Organic, and Biological Chemistry,*** **Eleventh Edition,** and ***General, Organic, and Biological Chemistry: Structures of Life,*** **Fourth Edition.**

Professor Timberlake belongs to numerous scientific and educational organizations including the American Chemical Society (ACS) and the National Science Teachers Association (NSTA). She was the Western Regional Winner of Excellence in College Chemistry Teaching Award given by the Chemical Manufacturers Association. She received the McGuffey Award in Physical Sciences from the Textbook Authors Association for her textbook ***Chemistry: An Introduction to General, Organic, and Biological Chemistry,*** **Eighth Edition.** She received the "Texty" Textbook Excellence Award from the Textbook Authors Association for the first edition of ***Basic Chemistry.*** She has participated in education grants for science teaching including the Los Angeles Collaborative for Teaching Excellence (LACTE) and a Title III grant at her college. She speaks at conferences and educational meetings on the use of student-centered teaching methods in chemistry to promote the learning success of students.

Her husband, William Timberlake, who is the coauthor of this text, is Professor Emeritus of Chemistry at Los Angeles Harbor College, where he taught preparatory and organic chemistry for 36 years. He received his bachelor's degree in chemistry from Carnegie Mellon University and his master's degree in organic chemistry from the University of California at Los Angeles. When the Professors Timberlake are not writing textbooks, they relax by hiking, traveling, trying new restaurants, cooking, playing tennis, and taking care of their grandchildren, Daniel and Emily.

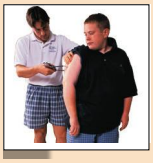
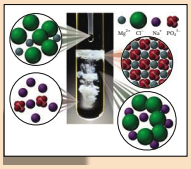
## DEDICATION

We dedicate this book to

- Our son, John, daughter-in-law, Cindy, grandson, Daniel, and granddaughter, Emily, for the precious things in life
- The wonderful students over many years whose hard work and commitment always motivated us and put purpose in our writing

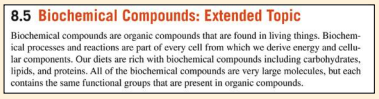
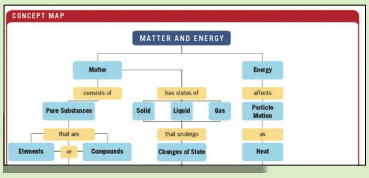
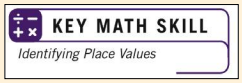
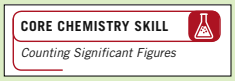
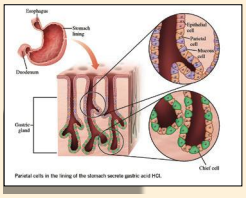
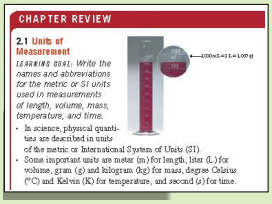
# Students learn chemistry using real-world examples

"Discovery consists of seeing what everybody has seen and thinking what nobody has thought."
—Albert Szent-Györgyi

| Feature | Description | Benefit | Page |
|---|---|---|---|
| NEW! Chapter Opener  | Chapters begin with **stories** involving careers in fields such as nursing, dentistry, agriculture, engineering, exercise physiology, and veterinary sciences. | Shows you how health professionals use chemistry every day | 69 |
| UPDATED! Chemistry Link to Health  | **Chemistry Links to Health** apply chemical concepts to relevant topics of health and medicine such as weight loss and weight gain, trans fats, anabolic steroids, alcohol abuse, blood buffers, kidney dialysis, and cancer. | Provides you with connections that illustrate the importance of understanding chemistry in real life health and medical situations | 259 |
| Chemistry Links to the Environment  | **Chemistry Links to the Environment** relate chemistry to environmental topics such as global warming, radon in our homes, acid rain, and pheromones. | Helps you extend your understanding of the impact of chemistry on the environment | 56 |
| Chemistry Links to Industry and Chemistry Link to History  | **Chemistry Links to Industry** describe industrial and commercial applications while **Chemistry Links to History** describe the historical development of chemical ideas. | Helps you understand the importance of chemistry in industry and history | 106, 4 |
| UPDATED! Macro-to-Micro Art  | **Macro-to-Micro Art** utilizes photographs and drawings to illustrate the atomic structure of chemical phenomena. | Helps you connect the world of atoms and molecules to the macroscopic world | 245 |

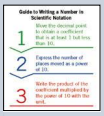
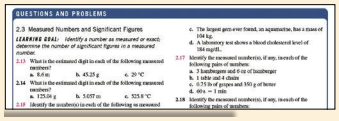
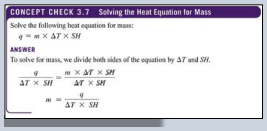
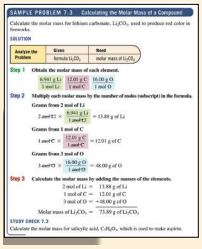
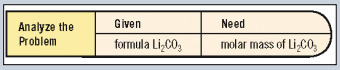
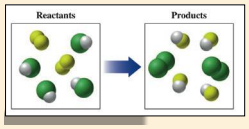
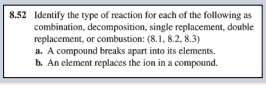
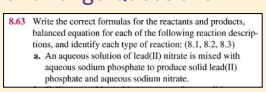
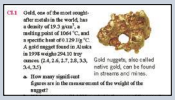
# Engage students in the world of chemistry

"I never teach my pupils; I only attempt to provide the conditions in which they can learn."
—Albert Einstein

| Feature | Description | Benefit | Page |
|---|---|---|---|
| **Learning Goals**<br>  | **Learning Goals** at the beginning and end of each section identify the key concepts for that section and provide a roadmap for your study. | Helps you focus your studying by emphasizing what is most important in each section | 169 |
| **Writing Style**<br>  | Timberlake's accessible **writing style** is based on careful development of chemical concepts suited to the skills and backgrounds of students in preparatory chemistry. | Helps you understand new terms and chemical concepts | 263 |
| **UPDATED! Concept Maps**<br>  | **Concept Maps** at the end of each chapter show how all the key concepts fit together. | Encourages learning by providing a **visual** guide to the interrelationship among all the concepts in each chapter | 96 |
| **NEW! Key Math Skills**<br>  | **Key Math Skills** provide practice problems related to basic math. | Helps you master the basic quantitative skills to succeed in preparatory chemistry | 12 |
| **NEW! Core Chemistry Skills**<br>  | **Core Chemistry Skills** provide content crucial to problem-solving strategies related to chemistry. | Helps you master the basic problem-solving skills needed to succeed in chemistry | 33 |
| **UPDATED! Art Program**<br>  | The **art program** is beautifully rendered, pedagogically effective, and includes questions with all the figures. | Helps you think critically using photos and illustrations | 498 |
| **UPDATED! Chapter Reviews**<br>  | The **Chapter Reviews** include Learning Goals and new visual thumbnails to summarize the key points in each section. | Helps you determine your mastery of the chapter concepts and study for your tests | 61 |

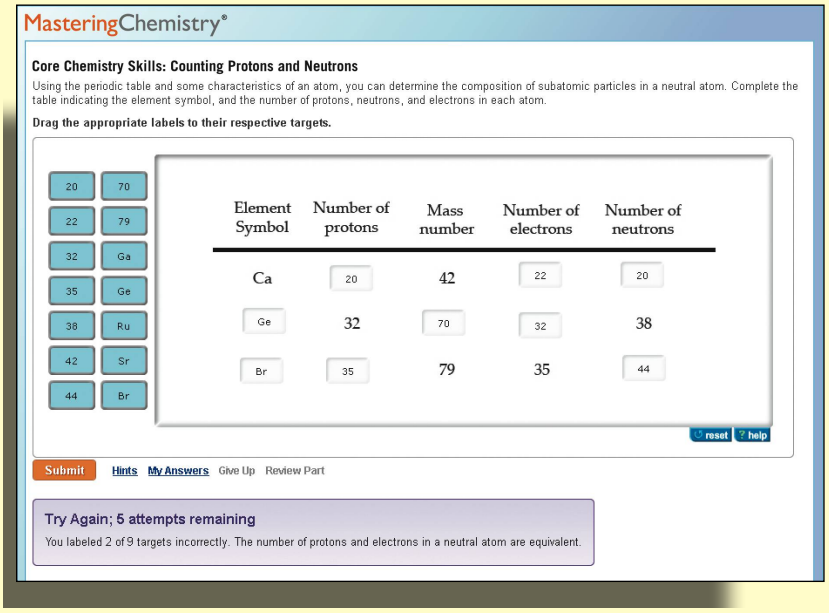
# Many tools show students how to solve problems

"The whole art of teaching is only the art of awakening the natural curiosity of young minds."
—Anatole France

| Feature | Description | Benefit | Page |
|---|---|---|---|
| UPDATED! Guides to Problem Solving (GPS)  | **Guides to Problem Solving (GPS)** illustrate the steps needed to solve problems. | Visually guides you step-by-step through each problem-solving strategy | 31 |
| End-of-Section Questions and Problems  | **Questions** and **Problems** are placed at the end of each section. Problems are paired and the Answers to the odd-numbered problems are given at the end of each chapter. | Encourages you to become involved immediately in the process of problem solving | 34 |
| UPDATED! Concept Checks  | **Concept Checks** that transition from conceptual ideas to problem-solving strategies are placed throughout each chapter. | Allows you to check your understanding of new chemical terms and ideas as they are introduced in the chapter | 88 |
| UPDATED! Sample Problems with Study Checks  | **Sample Problems** illustrate worked-out solutions with step-by-step explanations and required calculations. **Study Checks** associated with each Sample Problem allow you to check your problem-solving strategies. | Provides the intermediate steps to guide you successfully through each type of problem | 214 |
| NEW! Analyze the Problems   | **Analyze the Problems** feature now included in Sample Problem Solutions convert information in a word problem into components for problem solving. | Helps you identify and utilize the components within a word problem to set up a solution strategy | 214 |
| UPDATED! Understanding the Concepts   | **Understanding the Concepts** are questions with visual representations placed at the end of each chapter. | Builds an understanding of newly learned chemical concepts | 273 |
| UPDATED! Additional Questions and Problems  | **Additional Questions and Problems** at the end of chapter provide further study and application of the topics from the entire chapter. | Promotes critical thinking | 275 |
| Challenge Questions  | **Challenge Questions** at the end of each chapter provide complex questions. | Promotes critical thinking, group work, and cooperative learning environments | 276 |
| UPDATED! Combining Ideas  | **Combining Ideas** are sets of integrated problems that are placed after every 2–4 chapters. | Tests your understanding of the concepts from previous chapters by integrating topics | 102 |

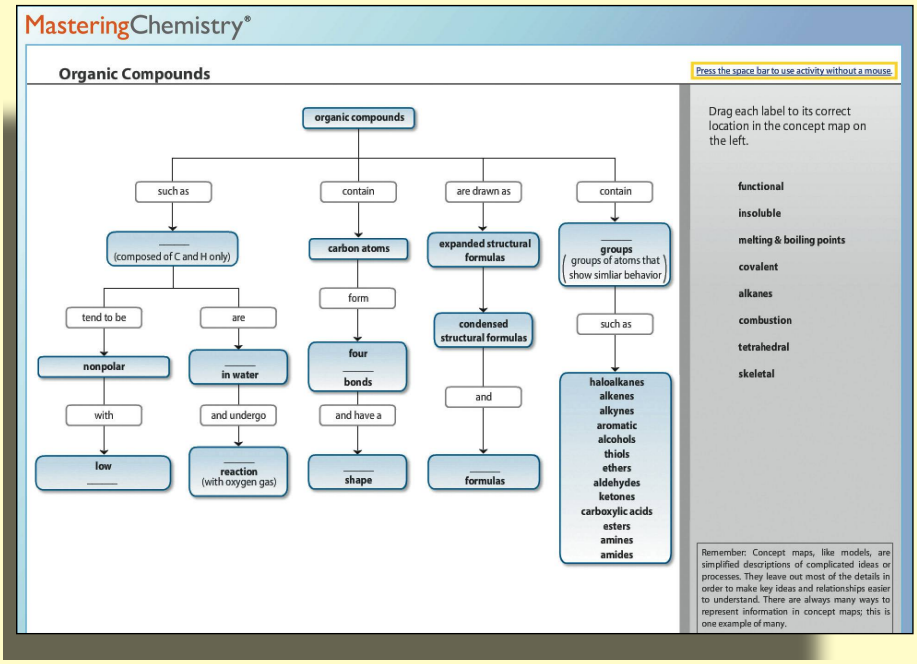
# MasteringChemistry® for Students

**The Mastering platform is the most effective and widely used online homework, tutorial, and assessment system for the sciences.** The Mastering system motivates students to learn outside of class and arrive prepared for lecture or lab.




## NEW! Key Math Skills and Core Chemistry Skills Tutorials

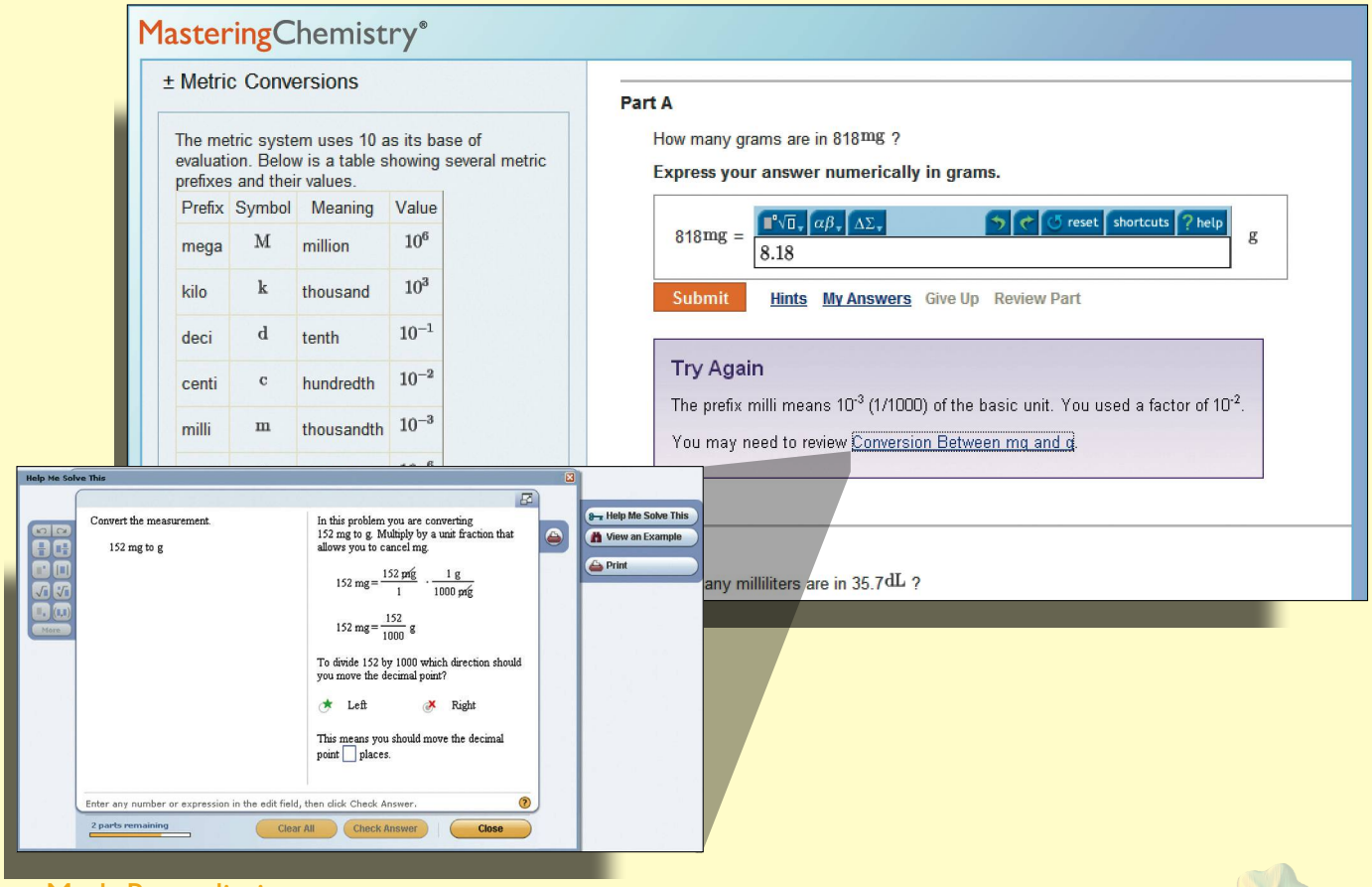
Key Math Skills and Core Chemistry Skills Tutorials provide assignable practice problems related to the in-text feature boxes, ensuring that students master the basic quantitative and science skills they need to succeed in the course.




## NEW! Concept Map Quizzes

Concept Map Quizzes use drag-and-drop applets and related multiple-choice assessment questions to help students make connections between important concepts within each chapter.

**MasteringChemistry promotes interactivity and active learning in Basic Chemistry.** Research shows that Mastering's immediate feedback and tutorial assistance help students understand and master concepts and skills in chemistry—allowing them to retain more knowledge and perform better in this course and beyond.




## Math Remediation

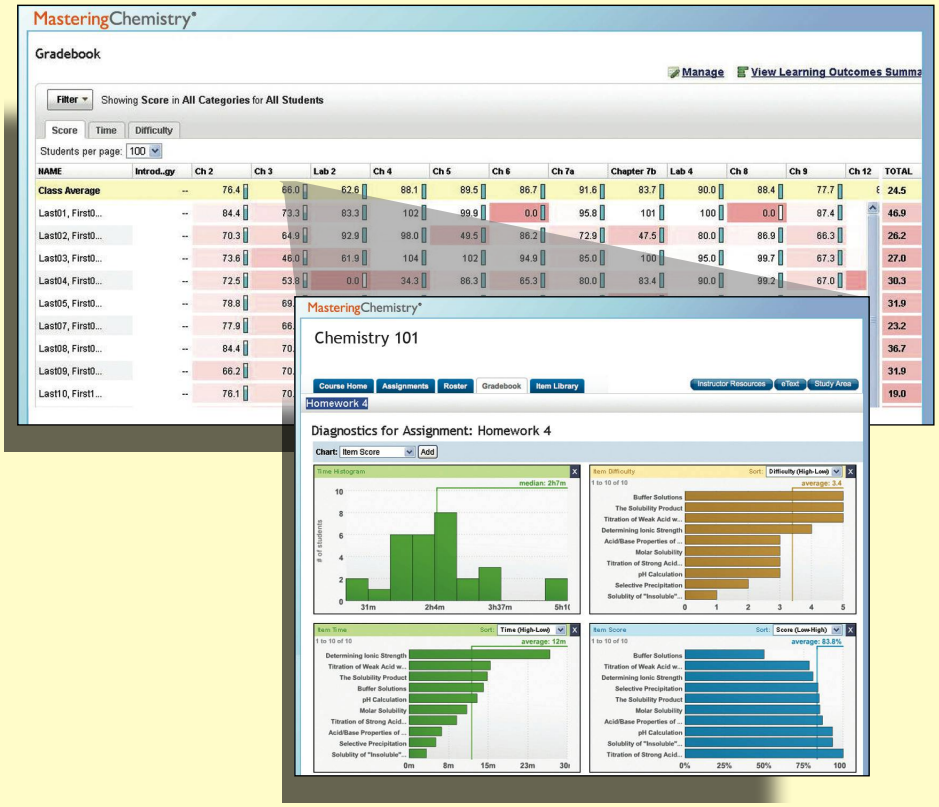
MasteringChemistry offers a variety of math remediation options for students to brush up on required quantitative skills. The Mathematics Review chapter contains practice tutorials covering key math topics in the course. A new Math Remediation Quiz provides a comprehensive set of review questions with links to additional algorithmically generated practice problems in MathXL. Select tutorials also contain Math Remediation Links to additional MathXL® questions.

## End-of-Chapter Questions and Problems

A high percentage of the text's end-of-chapter questions and problems are now easily assignable within MasteringChemistry. The overall number of algorithmic and randomized problems has also been increased for this edition.

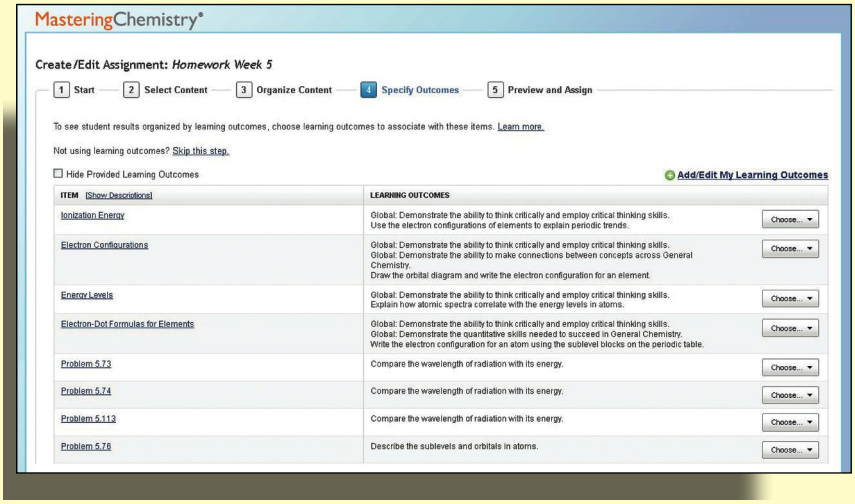
# MasteringChemistry® for Instructors

**With the Mastering gradebook and diagnostics,** you'll be better informed about your students' progress than ever before. Mastering captures the step-by-step work of every student—including wrong answers submitted, hints requested, and time taken at each step of an assigned problem.




## Gradebook and Diagnostics

The Gradebook gives you an at-a-glance overview of student performance on automatically graded assignments. Challenging assignments and struggling students are highlighted in red. Additional diagnostics summarize the most difficult problems, struggling students, grade distribution, and score improvement over the duration of the course.

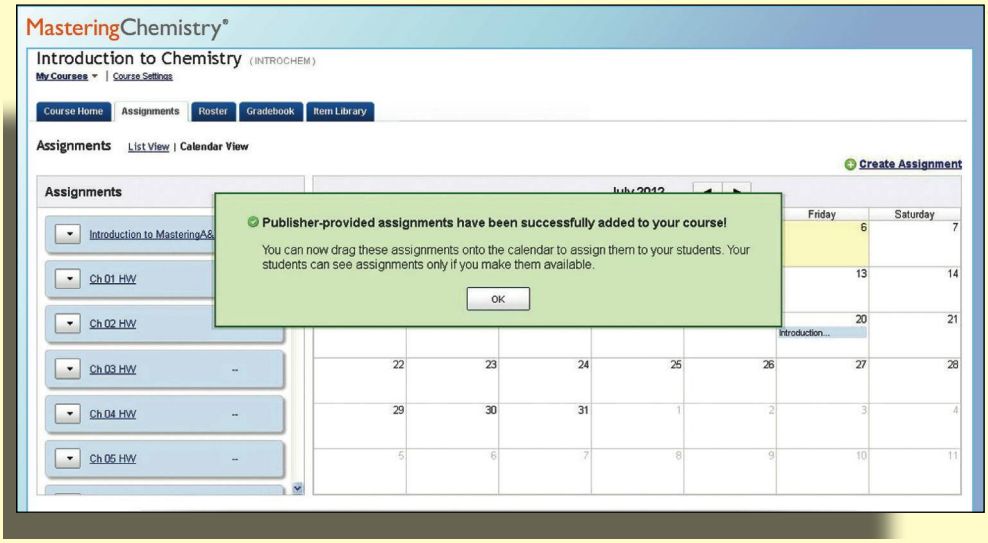



## NEW! Learning Outcomes

Let Mastering do the work in tracking student performance against your learning outcomes:

- Add your own or use the publisher-provided learning outcomes.
- View class performance against the specified learning outcomes.
- Export results to a spreadsheet that you can further customize and share with your chair, dean, administrator, or accreditation board.

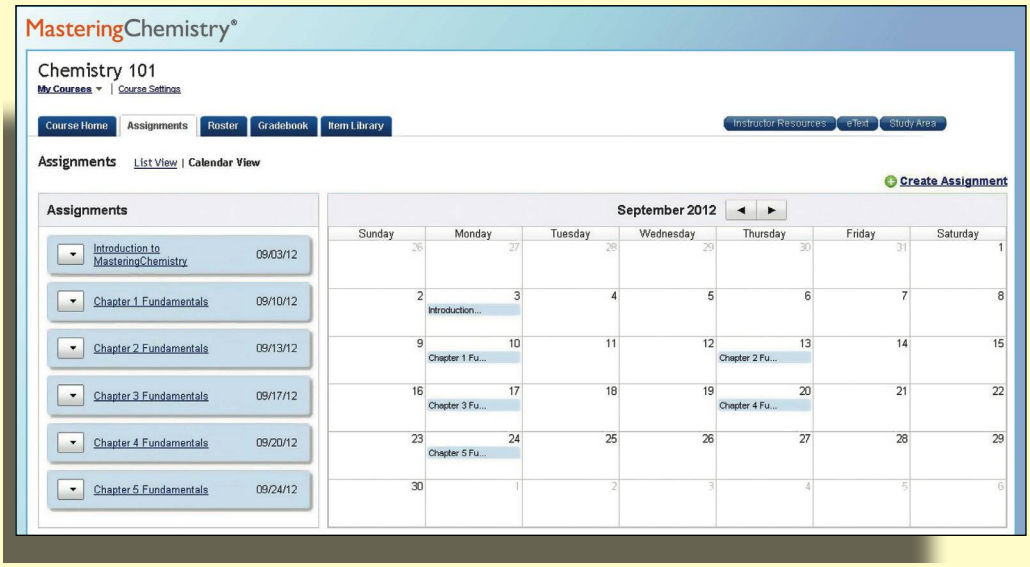
**Mastering provides a rich and flexible set of course materials** to get you started quickly, including homework, tutorial, and assessment tools that you can use as is or customize to fit your needs.




## NEW! Calendar Features

The Course Home default page now features a **Calendar View** displaying upcoming assignments and due dates.

- You can schedule assignments by dragging and dropping the assignment onto a date in the calendar. If the due date of an assignment needs to change, you can drag the assignment to the new due date and change the "available from and to dates" accordingly.
- The calendar view gives students a syllabus-style overview of due dates, making it easy to see all assignments due in a given month.




## NEW! Publisher Assignments

When creating a course, you now have the option of copying a complete set of pre-built assignments for each chapter pulled from the Mastering item library, containing end-of-chapter questions, tutorials, reading quiz questions, and media activities.

# Chemistry in Our Lives

## LOOKING AHEAD



Sarah works as a forensic scientist where she applies scientific procedures to evidence from law enforcement agencies. Such evidence may include blood, hair, or fiber from clothing found at a crime scene. At work, she analyzes blood for the presence of drugs, poisons, and alcohol. She prepares tissues for typing factors and for DNA analysis. Her lab partner Mark is working on matching characteristics of a bullet to a firearm found at a crime scene. He is also using fingerprinting techniques to identify the victim of a crime.

A female victim is found dead in her home. The police suspect that she was murdered, so samples of her blood and stomach contents are sent to Sarah. Using a variety of qualitative and quantitative tests, Sarah finds traces of ethylene glycol. The qualitative tests show that ethylene glycol is present, while the quantitative tests indicate the amount of ethylene glycol the victim has in her system. Sarah determines that the victim was poisoned when she ingested ethylene glycol placed in an alcoholic beverage. Since the initial symptoms of ethylene glycol poisoning are similar to being intoxicated, the victim was unaware of the poisoning.

The alcohol in beverages undergoes oxidation reactions to other compounds that are eliminated by the body. When ethylene glycol is oxidized, the products can cause renal failure and may be toxic to the body.

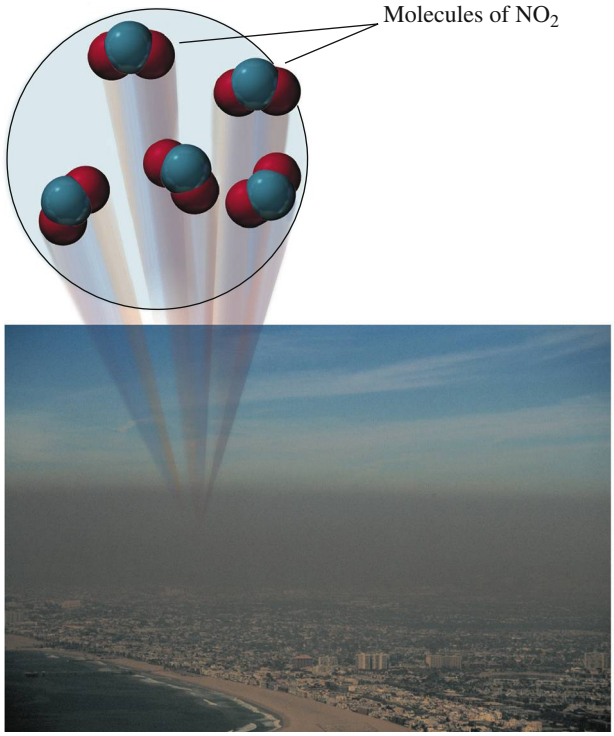
### Career: Forensic Scientist

Most forensic scientists work in crime laboratories that are part of city or county legal systems where they analyze bodily fluids and tissue samples collected by crime scene investigators. In analyzing these samples, a forensic scientist identifies the presence or absence of specific chemicals within the body to help solve the criminal case. Some of the chemicals they look for include alcohol, illegal or prescription drugs, poisons, arson debris, metals, and various gases such as carbon monoxide. In order to identify these substances, a variety of chemical instruments and highly specific methodologies are used. A forensic scientist also analyzes samples from criminal suspects, athletes, and potential employees. They also work on cases involving environmental contamination and animal samples for wildlife crimes. A forensic scientist usually has a bachelor's degree that includes courses in math, chemistry, and biology.

Now that you are in a chemistry class, you may be wondering what you will be learning. What questions in science have you been curious about? Perhaps you are interested in how smog is formed, what causes ozone depletion, how nails form rust, or how aspirin relieves a headache. Just like you, chemists are curious about the world we live in.

- How does car exhaust produce the smog that hangs over our cities? One component of car exhaust is nitrogen oxide (NO), which forms in car engines where high temperatures convert nitrogen gas ($N_2$) and oxygen gas ($O_2$) to NO. In chemistry, these reactions are written in the form of equations such as $N_2(g) + O_2(g) \longrightarrow 2NO(g)$.
- Why has the ozone layer been depleted in certain parts of the atmosphere? During the 1970s, scientists discovered that substances called chlorofluorocarbons (CFCs) were associated with the depletion of ozone. As CFCs are broken down by ultraviolet (UV) light, chlorine (Cl) is released that causes the breakdown of ozone ($O_3$) molecules and destroys the ozone layer.

$$Cl(g) + O_3(g) \longrightarrow ClO(g) + O_2(g)$$




The chemical reaction of NO with oxygen in the air forms $NO_2$, which produces the reddish brown color of smog.

- Why does aspirin relieve a headache? When a part of the body is injured, substances called prostaglandins are produced, which cause inflammation and pain. Aspirin acts to block the production of prostaglandins, thereby reducing inflammation, pain, and fever.

Chemists perform many different kinds of research. Some design new fuels and more efficient ways to use them. Researchers in the medical field develop new treatments for diabetes, genetic defects, cancer, AIDS, and other diseases. Researchers in the environmental field study the ways in which human development impacts the environment and develop processes that help reduce environmental degradation. For the researcher in the laboratory, the physician in the dialysis unit, the environmental chemist, or the agricultural scientist, chemistry plays a central role in understanding problems, assessing possible solutions, and making important decisions.

A geochemist collects newly erupted lava samples from Kilauea Volcano, Hawaii.

**CHAPTER READINESS**

**Key Math Skills**

- Identifying Place Values **(1.4A)**
- Using Positive and Negative Numbers in Calculations **(1.4B)**
- Calculating a Percentage **(1.4C)**
- Solving Equations **(1.4D)**
- Interpreting a Line Graph **(1.4E)**

## 1.1 Chemistry and Chemicals

**LEARNING GOAL**

*Define the term chemistry and identify substances as chemicals.*

**Chemistry** is the study of the composition, structure, properties, and reactions of matter. *Matter* is another word for all the substances that make up our world. Perhaps you imagine that chemistry takes place only in a laboratory where a chemist is working in a white coat and goggles. Actually, chemistry happens all around you every day and has an impact on everything you use and do. You are doing chemistry when you cook food, add bleach to your laundry, or start your car. A chemical reaction has taken place when silver tarnishes or an antacid tablet fizzes when dropped into water. Plants grow because chemical reactions convert carbon dioxide, water, and energy to carbohydrates. Chemical reactions take place when you digest food and break it down into substances that you need for energy and health.

Antacid tablets undergo a chemical reaction when dropped into water.

### Branches of Chemistry

The field of chemistry is divided into several branches. General chemistry is the study of the composition, properties, and reactions of matter. Organic chemistry is the study of substances that contain the element carbon. Biological chemistry is the study of the chemical reactions that take place in biological systems.

Today chemistry is often combined with other sciences, such as geology and physics, to form cross-disciplines such as geochemistry and physical chemistry. Geochemistry is the study of the chemical composition of ores, soils, and minerals of the surface of the Earth and other planets. Physical chemistry is the study of the physical nature of chemical systems, including energy changes.

# Chemistry Link to History

## EARLY CHEMISTS: THE ALCHEMISTS

For many centuries, chemists have studied changes in matter. From the time of the ancient Greeks to about the sixteenth century, early scientists, called alchemists, described matter in terms of four components of nature: earth, air, fire, and water. These components had the qualities of hot, cold, wet, or dry. By the eighth century, alchemists believed that they could rearrange these qualities to change metals such as copper and lead into gold and silver. They searched for an unknown substance called a *philosopher's stone*, which they thought would turn metals into gold as well as prolong youth and postpone death. Although these efforts failed, the alchemists did provide information on the processes and chemical reactions involved in the extraction of metals from ores. During the many centuries that alchemy flourished, alchemists made observations of matter and identified the properties of many substances. They also designed some of the first laboratory equipment and developed early laboratory procedures.

The alchemist Paracelsus (1493–1541) thought that alchemy should be about preparing new medicines, not about producing gold. Using observation and experimentation, he proposed that a healthy body was regulated by a series of chemical processes that could be unbalanced by certain chemical compounds and rebalanced by using minerals and medicines. For example, he determined that inhaled dust, not underground spirits, caused lung disease in miners. He also thought that goiter was a problem caused by contaminated water, and he treated syphilis with compounds of mercury. His opinion of medicines was that the right dose makes the difference between a poison and a cure. Today this idea is part of the risk–benefit assessment of medicine. Paracelsus changed alchemy in ways that helped to establish modern medicine and chemistry.

Alchemists in the Middle Ages developed laboratory procedures.


Swiss alchemist Paracelsus (1493–1541) believed that chemicals and minerals could be used as medicines.

## Chemicals


Toothpaste is a combination of many chemicals.

A **chemical** is a substance that always has the same composition and properties wherever it is found. All the things you see around you are composed of one or more chemicals. Chemical processes take place in chemistry laboratories, manufacturing plants, and pharmaceutical labs as well as every day in nature and in our bodies. Often the terms *chemical* and *substance* are used interchangeably to describe a specific type of matter.

Every day, you use products containing substances that were developed and prepared by chemists. Soaps and shampoos contain chemicals that remove oils on your skin and scalp. When you brush your teeth, the substances in toothpaste clean your teeth, prevent plaque formation, and stop tooth decay. Some of the chemicals used to make toothpaste are listed in Table 1.1.

**TABLE 1.1 Chemicals Commonly Used in Toothpaste**

| Chemical | Function |
|---|---|
| Calcium carbonate | Used as an abrasive to remove plaque |
| Sorbitol | Prevents loss of water and hardening of toothpaste |
| Sodium lauryl sulfate | Used to loosen plaque |
| Titanium dioxide | Makes toothpaste white and opaque |
| Triclosan | Inhibits bacteria that cause plaque and gum disease |
| Sodium fluorophosphate | Prevents formation of cavities by strengthening tooth enamel with fluoride |
| Methyl salicylate | Gives toothpaste a pleasant wintergreen flavor |

In cosmetics and lotions, chemicals are used to moisturize, prevent deterioration of the product, fight bacteria, and thicken the product. Your clothes may be made of natural materials such as cotton or synthetic substances such as nylon or polyester. Perhaps you wear a

ring or watch made of gold, silver, or platinum. Your breakfast cereal is probably fortified with iron, calcium, and phosphorus, while the milk you drink is enriched with vitamins A and D. Antioxidants are chemicals added to food to prevent it from spoiling. Some of the chemicals you may encounter when you cook in the kitchen are shown in Figure 1.1.

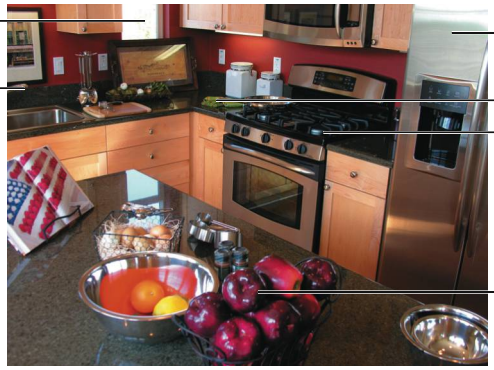



FIGURE 1.1 Many of the items found in a kitchen are chemicals or products of chemical reactions.
**Q** What are some other chemicals found in a kitchen?

## CONCEPT CHECK 1.1 Chemicals

Why is the copper in a copper wire an example of a chemical?

### ANSWER

Copper has the same composition and properties wherever it is found. Thus, copper is a chemical.

## SAMPLE PROBLEM 1.1 Everyday Chemicals

Identify the chemical in each of the following statements:

**a.** Soda cans are made from aluminum.
**b.** Salt (sodium chloride) is used to preserve meat and fish.
**c.** Sugar (sucrose) is used as a sweetener.

### SOLUTION

**a.** aluminum **b.** salt (sodium chloride) **c.** sugar (sucrose)

### STUDY CHECK 1.1

Which of the following are chemicals?

**a.** iron **b.** tin **c.** a low temperature **d.** water

The answers to all of the *Study Checks* can be found at the end of each chapter.

## QUESTIONS AND PROBLEMS

### 1.1 Chemistry and Chemicals

***LEARNING GOAL:*** *Define the term chemistry and identify substances as chemicals.*

In every chapter, odd-numbered exercises in the *Questions and Problems* are paired with even-numbered exercises. The answers for the magenta, odd-numbered *Questions and Problems* are given at the end of this chapter. The complete solutions to the odd-numbered *Questions and Problems* are in the *Student Solutions Manual*.

**1.1** Write a one-sentence definition for each of the following:
**a.** chemistry **b.** chemical

**1.2** Ask two of your friends (not in this class) to define the terms in Problem 1.1. Do their answers agree with the definitions you provided?

**1.3** Obtain a bottle of multivitamins and read the list of ingredients. What are four chemicals from the list?

**1.4** Obtain a box of breakfast cereal and read the list of ingredients. What are four chemicals from the list?

**1.5** Read the labels on some items found in your medicine cabinet. What are the names of some chemicals contained in those items?

**1.6** Read the labels on products used to wash and clean your car. What are the names of some chemicals contained in those products?

**1.7** Pesticides are chemicals. Give one advantage and one disadvantage of using pesticides.

**1.8** Sugar is a chemical. Give one advantage and one disadvantage of eating sugar.

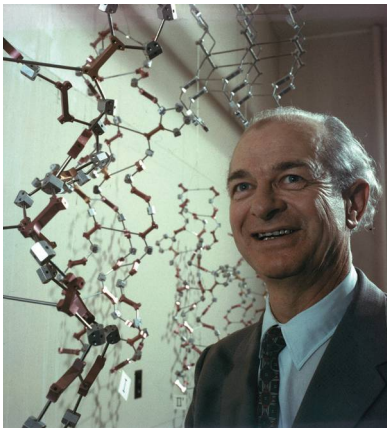
**LEARNING GOAL**

*Describe the activities that are part of the scientific method.*

# 1.2 Scientific Method: Thinking Like a Scientist

When you were very young, you explored the things around you by touching and tasting. As you grew, you asked questions about the world in which you live. What is lightning? Where does a rainbow come from? Why is water blue? As an adult, you may have wondered how antibiotics work or why vitamins are important to your health. Every day, you ask questions and seek answers to organize and make sense of the world around you.

When the late Nobel Laureate Linus Pauling described his student life in Oregon, he recalled that he read many books on chemistry, mineralogy, and physics. "I mulled over the properties of materials: why are some substances colored and others not, why are some minerals or inorganic compounds hard and others soft?" He said, "I was building up this tremendous background of empirical knowledge and at the same time asking a great number of questions." Linus Pauling won two Nobel Prizes: the first, in 1954, was in chemistry for his work on the nature of chemical bonds and the determination of the structures of complex substances; the second, in 1962, was the Peace Prize.



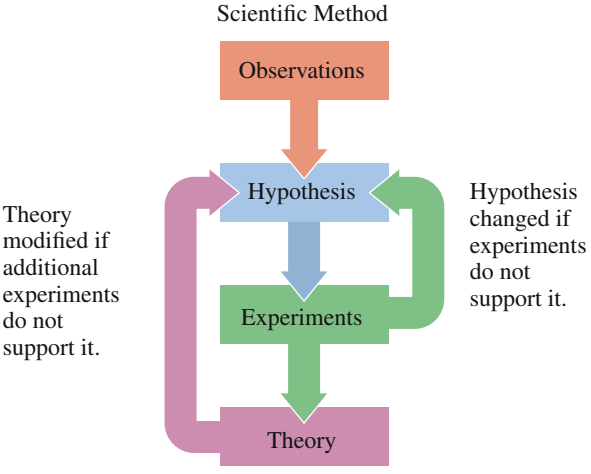
Linus Pauling won the Nobel Prize in chemistry in 1954.

Students make observations in the chemistry laboratory.

## Scientific Method

Although the process of trying to understand nature is unique to each scientist, a set of general principles, called the **scientific method**, helps to describe how a scientist thinks.

1. **Observations.** The first step in the scientific method is to observe, describe, and measure an event in nature. Observations based on measurements are called *data.*
2. **Hypothesis.** After sufficient data are collected, a *hypothesis* is proposed, which states a possible interpretation of the observations. The hypothesis must be stated in a way that it can be tested by experiments.
3. **Experiments.** Experiments are tests that determine the validity of the hypothesis. Often, many experiments are performed to test the hypothesis, and a large amount of information is collected. Many experiments are needed to support the original hypothesis. However, if just one experiment produces a different result than predicted by the hypothesis, a modified hypothesis must be proposed. Then new experiments are conducted to test the new hypothesis.
4. **Theory.** When experiments are repeated by many scientists with consistent results, the hypothesis may be confirmed. Consequently, that hypothesis may become a *theory.* Even then, a theory continues to be tested and, based on new experimental results, may need to be modified or replaced. Then the cycle of the scientific method begins again with the proposal of a new hypothesis.




The scientific method develops a theory using observations, hypotheses, and experiments.

## Using the Scientific Method in Everyday Life

You may be surprised to realize that you use the scientific method in your everyday life. Suppose you visit a friend in her home. Soon after you arrive, your eyes start to itch and you begin to sneeze. Then you observe that your friend has a new cat. Perhaps you ask yourself why you are sneezing and you form the hypothesis that you are allergic to cats. To test your hypothesis, you leave your friend's home. If the sneezing stops, perhaps your hypothesis is correct. You test your hypothesis further by visiting another friend who also has a cat. If you start to sneeze again, your experimental results support your hypothesis that you are allergic to cats. However, if you continue sneezing after you leave your friend's home, your hypothesis is not supported. Now you need to form a new hypothesis, which could be that you have a cold.

Through observation you may determine that you are allergic to cat hair and dander.

## CONCEPT CHECK 1.2 Scientific Method

Identify each of the following as an observation (O), a hypothesis (H), or an experiment (E):

**a.** Drinking coffee at night keeps me awake.
**b.** If I stop drinking coffee in the afternoon, I will be able to sleep at night.
**c.** I will try drinking coffee only in the morning.

### ANSWER

**a.** Describing what happens when I drink coffee is an observation (O).
**b.** Describing what may happen if I stop drinking coffee in the afternoon is a hypothesis (H).
**c.** Changing the time for drinking coffee is an experiment (E).

## SAMPLE PROBLEM 1.2 Scientific Method

Identify each of the following statements as an observation (O) or a hypothesis (H):

**a.** A silver tray turns a dull gray color when left uncovered.
**b.** North of the equator, it is warmer in summer than in winter.
**c.** Ice cubes float in water because they are less dense.

### SOLUTION

**a.** observation (O)
**b.** observation (O)
**c.** hypothesis (H)

### STUDY CHECK 1.2

The following statements are found in a student's notebook. Identify each of the following as an observation (O), a hypothesis (H), or an experiment (E):

**a.** "Today I placed two tomato seedlings in the garden, and two more in a closet. I will give all the plants the same amount of water and fertilizer."
**b.** "After 50 days, the tomato plants in the garden are 3 ft high with green leaves. The plants in the closet are 8 in. tall and yellow."
**c.** "Tomato plants need sunlight to grow."

A silver tray tarnishes when exposed to the air.

Tomato plants grow faster when placed in the sun.

# Chemistry Link to the Environment

## DDT—GOOD PESTICIDE, BAD PESTICIDE

DDT (**D**ichloro**d**iphenyl**t**richloroethane) was once one of the most commonly used pesticides. DDT is an example of organic compounds, which typically are composed of the elements of carbon (C) and hydrogen (H). In a molecule of DDT, there are 14 carbon atoms and 9 hydrogen atoms, as well as 5 chlorine atoms. The hydrocarbon portion makes DDT insoluble in water, and the Cl atoms make DDT difficult to break down.

Although DDT was first synthesized in 1874, it was not used as an insecticide until 1939. Before DDT was widely used, insect-borne diseases such as malaria and typhus were rampant in many parts of the world. Paul Müller, who discovered that DDT was an effective pesticide, was recognized for saving many lives and received the Nobel Prize in Physiology or Medicine in 1948. DDT was considered the ideal pesticide because it was toxic to many insects, had a low toxicity to humans and animals, and was inexpensive to prepare.

In the United States, DDT was used extensively in homes as well as on crops, such as cotton and soybeans. Because of its stable chemical structure, DDT did not break down quickly in the environment, which meant that it did not have to be applied as often. At first, everyone was pleased with DDT as crop yields increased and diseases such as malaria and typhus were controlled.


A 1947 advertisement recommends the household use of DDT.

However, by the early 1950s, problems attributed to DDT began to surface. Insects were becoming more resistant to the pesticide. At the same time, the public was increasingly concerned about the long-term impact of a substance that could remain in the environment for many years. The metabolic systems of humans and animals cannot break down DDT, which is soluble in fats but not in water and is stored in the fatty tissues of the body. Although the concentration of DDT applied to crops was very low, runoff containing DDT reached the oceans, where the DDT was absorbed by fish.

When birds such as the Brown Pelicans in Florida and California consumed fish contaminated with DDT, the amount of calcium in their eggshells was significantly reduced. As a result, incubating eggs cracked open early, causing offspring to die. Due to this difficulty with reproduction, the populations of birds such as the Brown Pelican dropped significantly and they became endangered.

The Brown Pelican was once an endangered species due to the use of DDT.

By 1972, DDT was banned in the United States. Since then, the population of Brown Pelicans has increased, and they are no longer considered endangered. Today new types of pesticides, which are more water-soluble and break down faster in the environment, have replaced the long-lasting pesticides such as DDT. However, these new pesticides are much more toxic to humans.

A field is sprayed with pesticide.

## QUESTIONS AND PROBLEMS

### 1.2 Scientific Method: Thinking Like a Scientist

***LEARNING GOAL:*** *Describe the activities that are part of the scientific method.*

**1.9** Define each of the following terms of the scientific method:

**a.** hypothesis **b.** experiment
**c.** theory **d.** observation

**1.10** Identify each of the following activities in the scientific method as an observation (O), a hypothesis (H), an experiment (E), or a theory (T):

**a.** Formulate a possible explanation for your experimental results.
**b.** Collect data.

**c.** Design an experimental plan that will give new information about a problem.
**d.** State a generalized summary of your experimental results.

**1.11** Identify each activity, **a**–**f**, as an observation (O), a hypothesis (H), an experiment (E), or a theory (T).
At a popular restaurant, where Chang is the head chef, the following occurred:
**a.** Chang determined that sales of the house salad had dropped.
**b.** Chang decided that the house salad needed a new dressing.
**c.** In a taste test, Chang prepared four bowls of lettuce, each with a new dressing: sesame seed, olive oil and balsamic vinegar, creamy Italian, and blue cheese.

Customers rated the sesame seed dressing as the best.

**d.** The tasters rated the sesame seed salad dressing as the favorite.
**e.** After two weeks, Chang noted that the orders for the house salad with the new sesame seed dressing had doubled.
**f.** Chang decided that the sesame seed dressing improved the sales of the house salad because the sesame seed dressing enhanced the taste.

**1.12** Identify each activity, **a**–**f**, as an observation (O), a hypothesis (H), an experiment (E), or a theory (T).
Lucia wants to develop a process for dyeing shirts so that the color will not fade when the shirt is washed. She proceeds with the following activities:
**a.** Lucia notices that the dye in a design fades when the shirt is washed.
**b.** Lucia decides that the dye needs something to help it combine with the fabric.
**c.** She places a spot of dye on each of four shirts and then places each one separately in water, salt water, vinegar, and baking soda and water.
**d.** After one hour, all the shirts are removed and washed with a detergent.
**e.** Lucia notices that the dye has faded on the shirts in water, salt water, and baking soda, while the dye did not fade on the shirt soaked in vinegar.
**f.** Lucia thinks that the vinegar binds with the dye so it does not fade when the shirt is washed.

## 1.3 Learning Chemistry: A Study Plan

**LEARNING GOAL**

*Develop a study plan for learning chemistry.*

Here you are taking chemistry, perhaps for the first time. Whatever your reasons for choosing to study chemistry, you can look forward to learning many new and exciting ideas.

### Features in This Text Help You Study Chemistry

This text has been designed with study features to complement your individual learning style. On the inside of the front cover is a periodic table of the elements. On the inside of the back cover are tables that summarize useful information needed throughout your study of chemistry. Each chapter begins with *Looking Ahead*, which outlines the topics in the chapter. At the end of the text, there is a comprehensive *Glossary and Index*, which lists and defines key terms used in the text. *Key Math Skills* that will be helpful to your understanding of chemical calculations are reviewed. *Core Chemistry Skills* that are critical to learning chemistry are indicated by icons in the margin, and summarized at the end of each chapter. In the *Chapter Readiness* list at the beginning of every chapter, the *Key Math Skills* and *Core Chemistry Skills* from previous chapters related to the current chapter concepts are highlighted for your review.

**KEY MATH SKILL**

**CORE CHEMISTRY SKILL**

Before you begin reading, obtain an overview of a chapter by reviewing the topics in *Looking Ahead*. As you prepare to read a section of the chapter, look at the section title and turn it into a question. For example, for Section 1.1, "Chemistry and Chemicals," you could ask "What is chemistry?" or "What are chemicals?". Throughout each chapter, you will find *Concept Checks* that will help you understand key ideas. When you come to a *Sample Problem*, take the time to work it through and compare your solution to the one provided. Then try the associated *Study Check*. Many *Sample Problems* are accompanied by a *Guide to Problem Solving* (*GPS*), which gives the steps needed to work the problem. In some *Sample Problems*, an *Analyze the Problem* feature shows how to organize the data in the word problem to obtain a solution. At the end of each chapter section, you will find a set of *Questions and Problems* that allows you to apply problem solving immediately to the new concepts.

| Analyze the Problem | Given | Need |
|---|---|---|
| | 165 lb | kilograms |

Throughout each chapter, boxes titled "Chemistry Link to Health," "Chemistry Link to History," "Chemistry Link to Industry," and "Chemistry Link to the Environment" help you connect the chemical concepts you are learning to real-life situations. Many of the figures and diagrams use macro-to-micro illustrations to depict the atomic level of