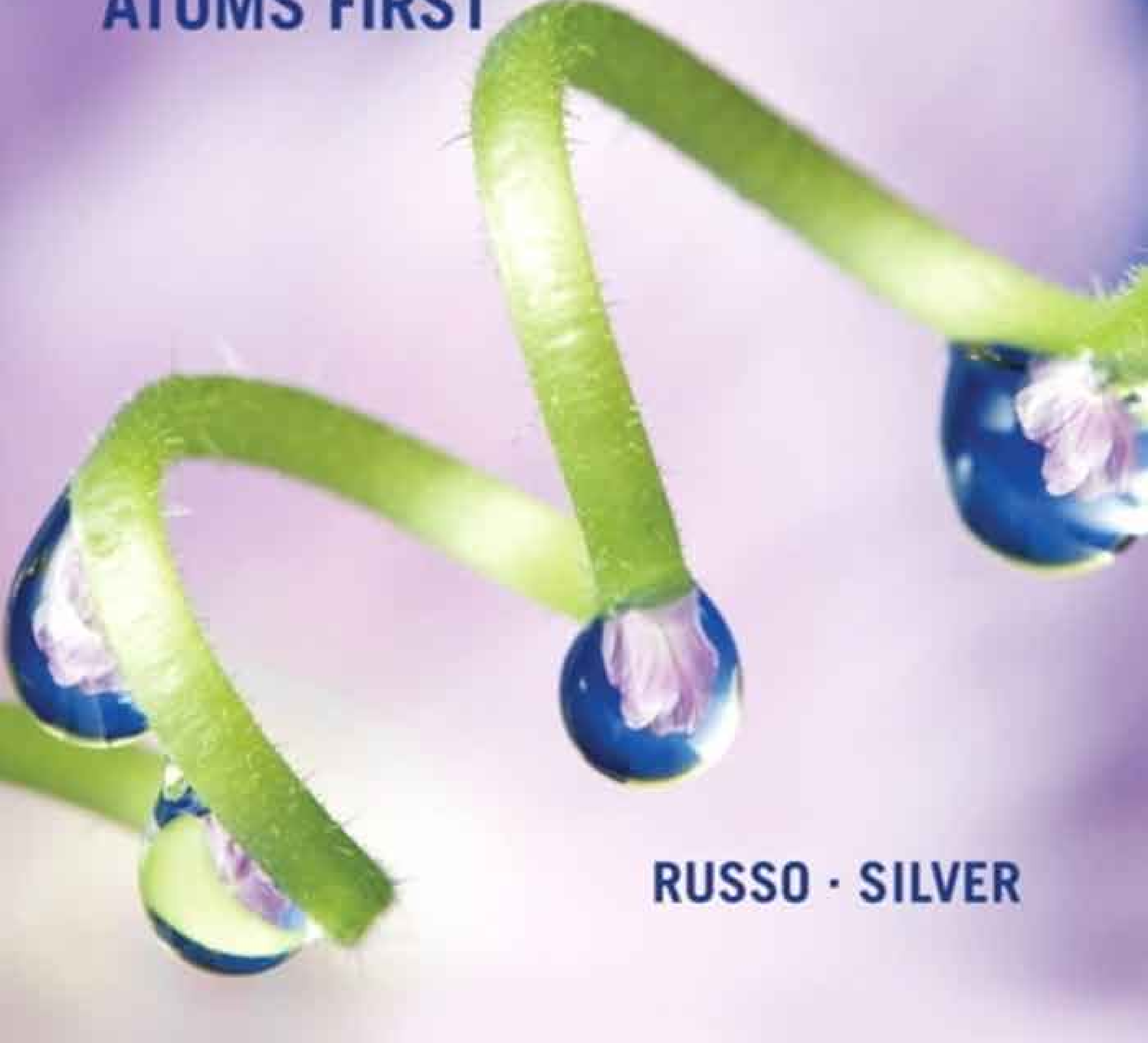
Fifth Edition

INTRODUCTORY CHEMISTRY

ATOMS FIRST



RUSSO · SILVER

Fifth Edition

INTRODUCTORY CHEMISTRY ATOMS FIRST

Steve Russo

Ithaca College

Mike Silver

Hope College

PEARSON

Boston Columbus Indianapolis New York San Francisco Upper Saddle River
Amsterdam Cape Town Dubai London Madrid Milan Paris Montréal Toronto
Delhi Mexico City São Paulo Sydney Hong Kong Seoul Singapore Taipei Tokyo

Editor in Chief: Adam Jaworski
Acquisitions Editor: Chris Hess
Executive Marketing Manager: Jonathan Cottrell
Project Editor: Jessica Moro
Assistant Editor: Lisa R. Pierce
Editorial Assistant: Fran Falk
Senior Marketing Assistant: Nicola Houston
Associate Content Producer: Jackie Jakob
Supervising Project Manager, Instructor Media: Shannon Kong
Managing Editor, Chemistry: Gina M. Cheselka
Project Manager: Wendy A. Perez
Full Service/Composition: PreMediaGlobal
Project Manager, Full Service: Jenna Gray, PreMediaGlobal
Illustrations: Imagineering
Design Manager: Mark Ong
Interior and Cover Design: Wanda España
Photo Manager: Maya Melenchuk
Photo Researcher: Kerri Wilson/Divya Narayanan, PreMediaGlobal
Manager, Rights and Permissions: Timothy Nicholls
Associate Project Manager, Rights and Permissions: Michael V. Farmer
Text Permissions Research: GEX, Inc.
Operations Specialist: Christy Hall
Cover Photo Credit: Vera Kuttelvaserova/Fotolia

Credits and acknowledgments borrowed from other sources and reproduced, with permission, in this textbook appear either within the text, near the source of the material, or in the Credits appendix.

Copyright © 2015, 2011, 2007, 2002 Pearson Education, Inc. All rights reserved. Manufactured in the United States of America. This publication is protected by Copyright, and permission should be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means: electronic, mechanical, photocopying, recording, or likewise. To obtain permission(s) to use material from this work, please submit a written request to Pearson Education, Inc., Permissions Department, 1 Lake Street, Department 1G, Upper Saddle River, NJ 07458.

Many of the designations used by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and the publisher was aware of a trademark claim, the designations have been printed in initial caps or all caps.

Library of Congress Cataloging-in-Publication Data

Russo, Steve, 1951 July 18—
Introductory chemistry : atoms first / Steve Russo, Ithaca College, Mike Silver, Hope College. — Fifth edition.
pages cm
Includes index.
ISBN-13: 978-0-321-92711-8 (alk. paper)
ISBN-10: 0-321-92711-7 (alk. paper)
1. Chemistry—Textbooks. I. Silver, Mike, 1953– II. Title.
QD33.2.R87 2015
540—dc23

2013028072

1 2 3 4 5 6 7 8 9 10—CRK—17 16 15 14 13

PEARSON

www.pearsonhighered.com

ISBN-10: 0-321-92711-7
ISBN-13: 978-0-321-92711-8

About the Authors

Steve Russo (right) has taken an early retirement as a Senior Lecturer in the Department of Chemistry at Cornell University and is now teaching chemistry part time at Ithaca College. Prior to that, he was an Assistant Professor at Indiana University. While there, he designed and implemented a state-of-the-art computer resource center for the undergraduate chemistry curriculum. He received his B.S. in chemistry from St. Francis College in New York City and his Ph.D. in physical organic chemistry from Cornell University. He is a member of the American Chemical Society and has been a recipient of the Dupont Teaching Award, Clark Teaching Awards while at Cornell University, and an Amoco Distinguished Teaching Award from Indiana University.

Mike Silver (left) is a Professor Emeritus of Chemistry at Hope College. He received his B.S. in chemistry from Farleigh Dickinson University in New Jersey and his Ph.D. in inorganic chemistry from Cornell University. He is also a member of the American Chemical Society (ACS) and past president of the ACS West Michigan Section, as well as a member of the Society of Cosmetic Chemists. He has received the Camille and Henry Dreyfus Teacher-Scholar Award for Excellence in Teaching and Research and the Provost's Award for Teaching Excellence. Currently, he teaches a course a semester at Hope College or Grand Rapids Community College, and he also serves as a consultant to the chemical and manufacturing industries in projects ranging from cancer drug design and synthesis to electrochromic automobile mirrors to adhesives for use in oral applications. Dr. Silver has designed and synthesized a variety of novel molecules, including an immune system stimulator to combat skin cancer and eczema, and an emulsifier that allows oil and water to coexist in what is called a multiple or triple emulsion. Both have been submitted for patent protection.

This page intentionally left blank

Brief Contents

CHAPTER 1 **What Is Chemistry?** 3

CHAPTER 2 **The Numerical Side of Chemistry** 29

CHAPTER 3 **The Evolution of Atomic Theory** 79

CHAPTER 4 **The Modern Model of the Atom** 121

CHAPTER 5 **Chemical Bonding and Nomenclature** 167

CHAPTER 6 **The Shape of Molecules** 217

CHAPTER 7 **Intermolecular Forces and the Phases of Matter** 253

CHAPTER 8 **Chemical Reactions** 283

CHAPTER 9 **Stoichiometry and the Mole** 315

CHAPTER 10 **Electron Transfer in Chemical Reactions** 363

CHAPTER 11 **What If There Were No Intermolecular Forces? The Ideal Gas** 413

CHAPTER 12 **Solutions** 449

CHAPTER 13 **When Reactants Turn into Products** 513

CHAPTER 14 **Chemical Equilibrium** 559

CHAPTER 15 **Electrolytes, Acids, and Bases** 603

CHAPTER 16 **Nuclear Chemistry** 655

CHAPTER 17 **The Chemistry of Carbon** 691

CHAPTER 18 **Synthetic and Biological Polymers** 737

Contents

About the Authors iii
Preface x

CHAPTER 1 **What Is Chemistry?** 3

1.1 Science and Technology 3
1.2 Matter 5
1.3 Matter and Its Physical Transformations 10
1.4 Matter and Its Chemical Transformations 13
1.5 How Science Is Done—The Scientific Method 15
1.6 Learning Chemistry With This Book 19
One More Thing 20

CHAPTER 2 **The Numerical Side of Chemistry** 29

2.1 Numbers in Chemistry—Precision and Accuracy 29
2.2 Numbers in Chemistry—Uncertainty and Significant Figures 32
2.3 Zeros and Significant Figures 34
2.4 Scientific Notation 37
2.5 How to Handle Significant Figures and Scientific Notation When Doing Math 41
2.6 Numbers With a Name—Units of Measure 45
2.7 Density: A Useful Physical Property of Matter 50
2.8 Doing Calculations in Chemistry—Unit Analysis 52
2.9 Rearranging Equations—Algebraic Manipulations With Density 58
2.10 One More Thing Quantifying Energy 60

CHAPTER 3 **The Evolution of Atomic Theory** 79

3.1 Dalton's Atomic Theory 79
3.2 Development of a Model for Atomic Structure 83
3.3 The Nucleus 84
3.4 The Structure of the Atom 88
3.5 The Law of Mendeleev—Chemical Periodicity 93
3.6 The Modern Periodic Table 97
3.7 An Introduction to Ions and the First Ionization Energy 103
3.8 One More Thing Isotopes, Mass Spectrometers, and Extraterrestrial Origins 108

CHAPTER 4 **The Modern Model of the Atom** 121

4.1 Seeing the Light—A New Model of the Atom 121
4.2 A New Kind of Physics—Energy Is Quantized 124
4.3 The Bohr Theory of Atomic Structure 125
4.4 Periodicity and Line Spectra Explained 128
4.5 Subshells and Electron Configuration 135
4.6 Regular Variations in the Properties of Elements 142

4.7 Compound Formation and the Octet Rule 146
4.8 One More Thing The Modern Quantum Mechanical Model of the Atom 150

CHAPTER 5 **Chemical Bonding and Nomenclature** 167

5.1 Ionic Bonding 167
5.2 Molecules—What Are They? Why Are They? 170
5.3 Holding Molecules Together—The Covalent Bond 171
5.4 Molecules, Dot Structures, and the Octet Rule 177
5.5 Multiple Bonds 182
5.6 Equal versus Unequal Sharing of Electrons—Electronegativity and the Polar Covalent Bond 187
5.7 Nomenclature—Naming Chemical Compounds 192
5.8 One More Thing Exceptions to the Octet Rule 201

CHAPTER 6 **The Shape of Molecules** 217

6.1 The Importance of Molecular Shape 217
6.2 Valence Shell Electron Pair Repulsion (VSEPR) Theory 219
6.3 Polarity of Molecules, or When Does 2 + 2 Not Equal 4? 228
6.4 Intermolecular Forces—Dipolar Interactions 236
6.5 One More Thing VSEPR Theory for Molecules Possessing Expanded Octet Atoms 238

CHAPTER 7 **Intermolecular Forces and the Phases of Matter** 253

7.1 Why Does Matter Exist in Different Phases? 253
7.2 Intermolecular Forces 259
7.3 A Closer Look at Dipole Forces—Hydrogen-Bonding 262
7.4 Nonmolecular Substances 266
7.5 One More Thing Vancomycin—The Antibiotic of Last Resort and Its Five Life-Saving Hydrogen Bonds! 270

CHAPTER 8 **Chemical Reactions** 283

8.1 What Is a Chemical Reaction? 283
8.2 How Are Reactants Transformed into Products? 284
8.3 Balancing Chemical Equations 287
8.4 Types of Reactions 290
8.5 Solubility and Precipitation Reactions 293
8.6 Introduction to Acid–Base Reactions 299
8.7 One More Thing Chemical Synthesis 301

CHAPTER 9 **Stoichiometry and the Mole** 315

9.1 Stoichiometry—What Is It? 316
9.2 The Mole 319
9.3 Reaction Stoichiometry 326
9.4 Dealing With a Limiting Reactant 333
9.5 Combustion Analysis 338
9.6 Going from Molecular Formula to Percent Composition 344
9.7 One More Thing Nonstoichiometric Compounds 346

CHAPTER 10 **Electron Transfer in Chemical Reactions** 363

10.1 What Is Electricity? 363
10.2 Electron Bookkeeping—Oxidation States 364
10.3 Recognizing Electron-Transfer Reactions 376
10.4 Electricity from Redox Reactions 380
10.5 Which Way Do Electrons Flow?—The EMF Series 388
10.6 Another Look at Oxidation: The Corrosion of Metals 393
10.7 One More Thing Less Common Oxidation States and Chemical Reactivity 397

CHAPTER 11 **What If There Were No Intermolecular Forces? The Ideal Gas** 413

11.1 Describing the Gas Phase—*P*, *V*, *n*, and *T* 413
11.2 Describing a Gas Mathematically—The Ideal Gas Law 419
11.3 Getting the Most from the Ideal Gas Law 425
11.4 One More Thing Deviations from Ideality 435

CHAPTER 12 **Solutions** 449

12.1 What Is a Solution? 449
12.2 Energy and the Formation of Solutions 452
12.3 Entropy and the Formation of Solutions 459
12.4 Solubility, Temperature, and Pressure 462
12.5 Molarity 464
12.6 Percent Composition 473
12.7 Reactions in Solution 476
12.8 Colligative Properties of Solutions 483
12.9 One More Thing Getting Unlikes to Dissolve—Soaps and Detergents 494

CHAPTER 13 **When Reactants Turn into Products** 513

13.1 Chemical Kinetics 514
13.2 Energy Changes and Chemical Reactions 516
13.3 Reaction Rates and Activation Energy—Getting over the Hill 523
13.4 How Concentration Affects Reaction Rate 531
13.5 Reaction Order 536
13.6 One More Thing Why Reaction Orders Have the Values They Do—Mechanisms 540

CHAPTER 14 **Chemical Equilibrium** 559

14.1 Dynamic Equilibrium—My Reaction Seems To Have Stopped! 559
14.2 Why Do Chemical Reactions Reach Equilibrium? 565
14.3 The Position of Equilibrium—The Equilibrium Constant, K_{eq} 568
14.4 Disturbing a Reaction Already at Equilibrium—Le Chatelier's Principle 575
14.5 How Equilibrium Responds to Temperature Changes 578
14.6 Equilibria for Heterogeneous Reactions 581
14.7 One More Thing Solubility and Equilibrium Calculations 584

CHAPTER 15 **Electrolytes, Acids, and Bases** 603

15.1 Electrolytes and Nonelectrolytes 603
15.2 Electrolytes Weak and Strong 609
15.3 Acids Weak and Strong 611
15.4 Bases—The Anti-Acids 615
15.5 Help! I Need Another Definition of Acid and Base 618
15.6 Weak Bases 621
15.7 Is This Solution Acidic or Basic? Understanding Water, Autodissociation, and K_w 623
15.8 The pH Scale 628
15.9 One More Thing Resisting pH Changes—Buffers 633

CHAPTER 16 **Nuclear Chemistry** 655

16.1 The Case of the Missing Mass—Mass Defect and the Stability of the Nucleus 655
16.2 Half-Life and the Band of Stability 660
16.3 Spontaneous Nuclear Changes— Radioactivity 662
16.4 Using Radioactive Isotopes to Date Objects 672
16.5 Nuclear Energy—Fission and Fusion 675
16.6 One More Thing Biological Effects and Medical Applications of Radioactivity 679

CHAPTER 17 **The Chemistry of Carbon** 691

17.1 Carbon—A Unique Element 692
17.2 Naturally Occurring Compounds of Carbon and Hydrogen—Hydrocarbons 696
17.3 Naming Hydrocarbons 702
17.4 Properties of Hydrocarbons 713
17.5 Functionalized Hydrocarbons—Bring On the Heteroatoms 714
17.6 One More Thing Functional Groups and Organic Synthesis 726

CHAPTER 18 **Synthetic and Biological Polymers** 737

18.1 Building Polymers 737
18.2 Polyethylene and Its Relatives 738
18.3 Nylon—A Polymer You Can Wear 742
18.4 Polysaccharides and Carbohydrates 744
18.5 Proteins 747
18.6 One More Thing DNA—The Master Biopolymer 751

Glossary G-1
Selected Answers A-1
Credits C-1
Index I-1

Preface

Many instructors have told us that our text is the most readable introductory chemistry textbook their students have ever used. They also told us that their students can use as much help as possible when learning how to solve problems. With each edition we have included more worked examples and more end-of-chapter problems, including one-step-beyond problems, visually oriented and concept-based problems, and in-class group exercises, and stronger tools to help students learn the skills they need. To make the material more memorable, we have chapter-opening "teasers." These are stories and anecdotes utilizing materials from history to the present day that pertain to the material in the chapter and are fun and interesting to read. Also, every edition of our text, starting from the first, has employed an **"atoms first approach."** Why atoms first? The simple answer is that this is the way we have always taught this material since we began teaching decades ago. Both of us were influenced by the late Professor Michell J. Sienko of Cornell University, a textbook author himself and a fabulously talented lecturer who could hold the attention of 500 students at a time. His textbook and lectures always built up the material from the "bottom up," from atoms to molecules to properties of molecules to stoichiometry and reactions and beyond. It instantly made sense for us to teach this way. Following an atoms first approach, we never had to say things like "I'm teaching you this now because it's covered in lab this week," or "This will make more sense when we cover polarity later." When building a house, one doesn't usually pour half of the foundation, start work on the second floor, and return later to complete the foundation. In the same way, the atoms first approach lays a proper foundation and then continually builds atop it; while it gives some choice as to the order of topics, the path it builds is consistently straightforward and does not have leaps of faith or distracting U-turns.

Our goal with this text has always been to help students make sense of chemistry. As chemists, we know that chemistry is intrinsically interesting, that its principles do form a reasonably coherent whole, and that its problem-solving skills can be mastered by anyone. But, too often, students see the subject as incomprehensible and the course as a frightening labyrinth. All too frequently, they fall back on rote learning—memorizing algorithms, plugging numbers into formulas, and forgetting much of what they learned starting as soon as the pencil is dropped at the end of the final exam. As chemistry instructors, we hate to see that. Therefore, we designed this book to promote comprehension and problem solving as complementary skills. A student who understands the principles of chemistry does not have to rely strictly on memorization and is more likely to enjoy and retain the material. This understanding and sufficient practice at solving problems will help students master the principles. We hope that our book will help students come out of the course with a body of knowledge and skills that will serve them and that they will want to retain.

New to This Edition

What can authors possibly add to a fifth edition of a textbook? The answer turns out to be "Plenty!"

1. **Learning Outcomes:** Each end-of-chapter review section now begins with a table of learning outcomes for each section of the chapter, correlated to the end-of-chapter problems. The learning outcomes consist of goals and skills the student should learn and practice before moving on to the next chapter.
2. **One More Thing:** We have always been proud of the conceptual depth that this book plumbs, but some instructors have told us that they skip sections that go to great conceptual depth. Still, we wanted to add even more of this depth for this fifth edition that other reviewers and users have asked for. How to satisfy both? Our solution was to create a final section for every chapter titled "One More Thing." Being so titled, it gives the instructor an option to skip it and be guilt-free when time requirements are tight. We have made sure that it can be skipped without doing damage to the flow of the material that follows. In some cases, this section contains material that was previously incorporated in the main body of the chapter in the previous edition. In other cases it contains totally new material that we thought would be great to add for its conceptual and interest value. Now the instructor, and each individual student, has the option to jump into the deepest end of the conceptual pool if he or she wants.
3. **WorkPatches Hints Available in MasteringChemistry:** Judging from instructor and student feedback over the years, WorkPatches have always been a favorite feature of this book. They were always meant to be a way to break the reader out of the passive reading mode and make students more interactive by encouraging them to think about what was just read before going on. They accomplish this by posing a conceptual question, followed by a continuation of the main text that assumes the question was successfully answered without ever revealing the actual answer. Skipping a WorkPatch therefore is like joining in the middle of a conversation, something a reader would not want to do. We realize we are forcing the reader to do something here, and the answers are provided at the end of the chapter, but we don't want readers looking up these answers without first trying to come up with an answer on their own. So, in this edition, for the first time, we offer some help and something in step with the times. Today many, if not most, students have a smartphone. Included in the fifth edition is a QR code that will link the reader's phone to a site where he or she can get a hint to any WorkPatch. Given the love affair that students have with this technology, our hope is that this will be an incentive for them to interact more with the text. For readers who do not have a smartphone or a tablet, the hints can still be accessed by visiting MasteringChemistry for the fifth edition.
4. **Concept Questions:** In this edition we wanted to give readers more than just lists of topics that we call "Have You Learned This?" and summaries that we call "Skills to Know," which we have always included at the end of each chapter. Now, for the first time, each chapter ends with ten multiple-choice questions called "Concept Questions." These are meant to be done quickly and will give readers an opportunity to see if they have grasped the fundamental concepts presented in the chapter. Instructors know that if we throw a little technobabble at students, we can often shake students' confidence in what they know. The concept questions often use this approach, but if students have a true understanding, then smoke won't get in the way of their finding the correct response. The concept questions give them this opportunity.

5. **New End-of-Chapter Problems:** As always, we endeavor to refine and improve our end-of-chapter problems. We have gone through each chapter and, based on our own ideas and with input from users, replaced or improved more than 20% of the existing end-of-chapter questions. We receive many compliments on the number, variety, and quality of our end-of-chapter problems. Every instructor knows the value of time students spend working on such problems. As Professor Sienko would tell every one of his classes on the first day, "If you are not in some degree of pain during this course, you are not learning." Our book provides an enjoyable read due to its conversational style, atoms first approach, conceptual depth, and clean layout. The pain comes from struggling with well-thought-out end-of-chapter problems. Of course, the payback is good performance on exams and a lifelong retention of the major concepts of chemistry.

The conversational tone and the atoms first approach have always been and remain the principle hallmarks of our text. We are big believers in their power to help students learn. With each new edition, and with generous help from our users, we have hunted down errors and hopefully corrected them all. If you find any, please email us at silver@hope.edu (Mike Silver) and srusso@ithaca.edu (Steve Russo). Please send along any other comments you might have as well, good or bad. We love hearing from our users, and we accept constructive criticism reasonably well (although we prefer high praise).

Promoting Active Learning

How can we, as textbook authors, promote active learning? First, quite simply, we provide a book that makes sense to students. A student who understands the material is less likely to fall back on passive memorization. As one instructor told us, "This book allows me to spend class time doing hands-on learning versus spending time explaining the book."

Second, we incorporate devices to encourage active reading. A flip through the book will show many sets of practice problems. These practice problems are located so that students can immediately apply the skill the text has just presented. They are presented in sets of three or four; the first problem is solved step-by-step in the text, and the answers to the others are given at the back of the book. Each chapter contains an average of 25 practice problems.

However, we are not naïve. We know that many students routinely skip over these in-chapter practice problems. Therefore, we have included conceptual practice problems called WorkPatches. A WorkPatch is a "stealth" problem. It follows smoothly from the preceding text and is not boxed off. What is more, a student who tries to read through a WorkPatch without solving it will find that the subsequent text refers to, and often depends on, the answer—but does not say what it is. (The solutions to all WorkPatches are given at the end of the chapter.) In some cases, a WorkPatch serves as the springboard into the next topic, and all WorkPatches are now connected to hints, which can be accessed by scanning the QR code in the next few pages or back of the textbook. WorkPatches are denoted by a yellow stop sign/red light icon.

Helping Students Master Problem-Solving Skills

An instructor flipping through our text might be inclined to ask, "Where are all the worked examples?" In fact, this text has an abundance of worked examples and other problem-solving aids, but we have handled them in a way that preserves the text's coherence. As in the previous editions, many worked examples are presented in the text itself. We feel strongly that problem-solving techniques should be explained with the same care and continuity we use for concepts.

When students are working on problems, however, they also need access to compact summaries and examples. We have augmented these resources in the following ways:

- Important problem-solving methods are summarized in charts in the text.
- The same charts, accompanied by worked examples and additional material, appear in a special Skills to Know section at the end of the chapter immediately preceding the end-of-chapter problems. This section is intended as a "help center" to which students can refer while working problems. (A few of the more purely conceptual chapters do not have a Skills to Know section.)
- An abundance of additional step-by-step methods, worked examples, and practice problems are provided in the *Student Workbook and Selected Solutions* that accompanies the text, authored by our colleagues Saundra Yancy McGuire and Elzbieta Cook at Louisiana State University. For a weak or struggling student, nothing is more important than abundant, guided, confidence-building practice. This workbook enables us to offer a truly realistic amount of help while maintaining a clean, readable textbook. The *Workbook* also contains a generous mathematics review. We came to know Dr. McGuire when she directed the Center for Learning and Teaching at Cornell; she currently directs the Center for Academic Success at Louisiana State University. We are extremely glad that she chose to join her expertise with ours and are thankful to Elzbieta Cook for agreeing to revise the supplements for the fifth edition.
- As noted earlier, each chapter contains internal practice problems and WorkPatches in addition to end-of-chapter problems.

Room to Practice: Extensive Problem Sets

- Each problem set at the end of the chapter includes a section of additional problems that are not categorized by chapter section.
- There are now even more visually oriented problems.
- Each problem set contains a sufficient abundance of each of the types of problems an instructor might require.
- As in the previous editions, answers to selected problems are provided at the end of the book. (The full solutions for these selected problems, as well as for all the practice problems, are available in the *Student Workbook and Selected Solutions* manual.)

Making Chemistry Memorable

Instructors have told us that a surprising number of their students actually read our book rather than using it mainly as a resource while solving problems. We explain chemistry using everyday, conversational language, and we tie the concepts and calculations to stories and examples that help bring them to life. We use humor in places. We also ensure that the students know which points are fundamental and which represent additional detail. You will notice that most of the illustrations lack legends. That is because the text and the illustrations work hand-in-hand, and each illustration is placed exactly where it belongs.

We Want to Hear from You

One of the pleasures of revising a book is hearing from instructors who use it—learning what works and doesn't work, and gathering ideas. If you have any comments or suggestions, please feel free to contact us at the following email addresses: srusso@ithaca.edu (Steve Russo); silver@hope.edu (Mike Silver).

Acknowledgments

We very much wish to acknowledge the people who were instrumental in helping us with this fifth edition. We are indebted to our editors, Terry Haugen and Chris Hess, for believing enthusiastically in this book and championing a fifth edition. We very much want to thank Lisa Pierce, Jenna Gray, Wendy Perez, and Gina Cheselka, our project managers. These are the people who are the conductors of the orchestra. They overlook all the details, crack the whip when necessary, and make sure the final product is beautiful music rather than a cacophony of noise. Fran Falk, our editorial coordinator, was responsible for acquiring the prescriptive reviews, which greatly helped shape the direction of this edition. Divya Narayanan and Kerri Wilson did a wonderful job in photo research and finding new images that were needed. We are very grateful to Wynne Au Yeung and Mark Ong, who were in charge of the art and design program and are responsible for maintaining and improving what we believe to be one of the key features of our book, its clean, nonchoppy, and organized look that helps to make it so readable. Our genuine thanks also go to Wanda España who was in charge of the cover and interior design. We have had a tradition of some great and beautiful covers for the book, and that tradition has been maintained. We certainly also must acknowledge Jonathan Cottrell, our marketing manager, whose job is to get the message out about what makes this book so unique, and Jackie Jakob, our associate content producer, who has led the effort to tie our book to MasteringChemistry, the extremely useful online tutorial and assessment program.

We wish to extend our genuine thanks to the reviewers whose patient and thoughtful comments helped us shape this fifth edition. Their ability to provide excellent suggestions and find errors that we could not see no matter how hard we looked was incredible.

Jeff Allison, *Austin Community College*
Chris Bahn, *Montana State University*
Michael Hauser, *St. Louis Community College at Meramec*
Theresa Hill, *Rochester Community & Technical College*
Amy Johnson, *Eastern Michigan University*
Jesudoss Kingston, *Iowa State University*
Laurie LeBlanc, *Cuyamaca College*
Luigi Marzilli, *Louisiana State University*
Manish Mehta, *Oberlin College*
Mary Sohn, *Florida Institute of Technology*
Susan Thomas, *University of Texas at San Antonio*

We also want to thank Elzbieta Cook at Louisiana State University for her efforts in updating the *Student Workbook and Selected Solutions Manual* as well as the *Instructors Guide and Complete Solutions Manual*.

With regard to the previous editions that helped to shape the nature of this book, we want to thank all the people who have been involved over the years. In addition, for as long as new editions of this book are written, we will always want to thank the people who were on board and who believed in the vision and helped to create the earliest editions: Emiko Koike, Blakely Kim,

Irene Nunes, Jonathan Peck, Lisa Leung, Tony Asaro, and Saundra McGuire. And last, but certainly not least, Maureen Kennedy, Joan Marsh, Margot Otway, and Ben Roberts—the original four chambers who helped to inspire and create the heart of this book. We will always be in your debt.

Supplements

Name of Supplement	Available in Print	Available Online	Instructor or Student Supplement	Description
Student Workbook and Selected Solutions for Introductory Chemistry: Atoms First, 5th edition (0-321-95693-1)	✓		Supplement for Students	By Saundra Yancy McGuire of Louisiana State University and Elzbieta Cook of, Louisiana State University. Features examples from each chapter, learning objectives, review of key concepts from the text, and additional problems for student practice. Also provides comprehensive answers and explanations to selected end-of-chapter problems from the text. Provides over 200 worked examples and more than 550 practice problems and quiz questions to help students develop and practice their problem-solving skills.
Laboratory Manual for Introductory Chemistry (0-321-73025-9)		✓	Supplement for Students	By Wendy Gloffke and coauthored by Doris Kimbrough of the University of Colorado at Denver with contributions from Chris Bahn of Montana State University. Helps students develop data acquisition, organization, and analysis skills while teaching basic techniques. Written to accompany the text, this manual offers 25 experiments. This lab manual is available via Catalyst: The Pearson Custom Laboratory Program for Chemistry. This program allows you to custom build a chemistry lab manual that matches your content needs and course organization. You can either write your own labs using the Lab Authoring Kit tool or select from the hundreds of labs available at http://www.pearsonlearningsolutions.com/custom-library/catalyst. This program also allows you to add your own course notes, syllabi, or other materials.
MasteringChemistry® with Pearson eText for Introductory Chemistry: Atoms First, 5th edition (0-321-92456-8) www.masteringchemistry.com		✓	Supplement for Students and Instructors and Students	MasteringChemistry is the leading online homework and tutorial system for the sciences. 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 whole class.
Instructor's Guide with Complete Solutions for Introductory Chemistry: Atoms First, 5th edition (0-321-95692-3)	✓		Supplement for Instructors	By Saundra Yancy McGuire of Louisiana State University and Elzbieta Cook of Louisiana State University Includes chapter summaries, complete descriptions of appropriate chemical demonstrations for lecture, suggestions for addressing common student misconceptions, and examples of everyday applications of selected topics for lecture use, as well as the solutions for all the problems in the text.

Test Bank (Download Only) for Introductory Chemistry: Atoms First, 5th edition (0-321-95691-5)	✓	Supplement for Instructors	By Christine Hermann of Radford University This printed test bank includes over 1700 questions that correspond to the major topics in the text.
Instructor Manual for the Laboratory Manual (0-321-73026-7)	✓	Supplement for Instructors	By Wendy Gloffke and coauthored by Doris Kimbrough of the University of Colorado at Denver with contributions from Chris Bahn of Montana State University. This manual includes lists of equipment and chemicals needed to perform each lab.
Instructor's Resource Materials (Download Only) for Introductory Chemistry: Atoms First, 5th edition (0-321-95734-2)	✓	Supplement for Instructors	The online instructor resources include all the art, photos, and tables from the book in high-resolution format for use in classroom projection or for creating study materials and tests. In addition, the Instructor can access modifiable PowerPoint® lecture outlines to highlight key points in his or her lecture. Also available are downloadable files of the *Instructor Teaching Guide*, the Test Bank with more than 1000 questions, and a set of "clicker questions" suitable for use with classroom-response systems.

The atoms first approach—
Making chemistry accessible

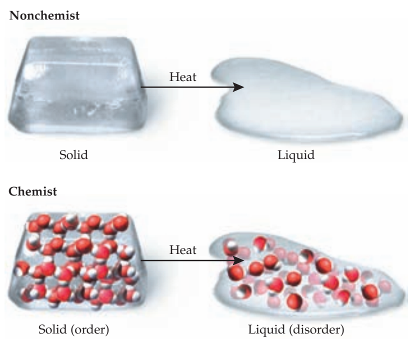
Students in this course tend to be vastly diverse in terms of chemical and mathematical background. Written from an **atoms first approach**, the authors focus on the concepts behind chemical equations to help students become more proficient problem-solvers. Combined with a conversational tone, this text encourages mastery of conceptual understanding and quantitative skills students need to gain a deeper understanding of chemistry, rather than just memorization.

1.6 Learning Chemistry with This Book **19**

the Bohr Model of the atom, developed in the early 1900s. More sophisticated models of the atom exist, but many working chemists still use this model to make predictions about their chemistry. Therefore, we will go ahead and use the Bohr Model, keeping in mind that it predicts some chemical properties pretty well so long as you don't push it beyond its capabilities.

1.6 Learning Chemistry with This Book

A common misconception is that chemistry is all math, calculations, and numerical problem-solving. In all honesty, chemistry does have that side to it. But when a chemist is presented with a question about matter, the first thing that comes to mind is *not* a complicated mathematical formula. Instead, chemists use a basic set of fundamental concepts, often best represented with images instead of mathematical equations. For example, a chemist and a non-chemist picture the concept of melting differently:



Advantages of an Atom's First Approach:

- starts at the very beginning, providing a solid foundation; building up material from the "bottom-up"
- first discusses atoms—history, their electronic structure, the modern model of atoms and then moves on to chemical bonding and molecules.

Learning Outcomes

2.1	Numbers in Chemistry—Precision and Accuracy	Explain what an exact number is and what a measured number is. [55, 56] Describe the difference between precision and accuracy. [57, 58, 59]
2.2	Numbers in Chemistry—Uncertainty and Significant Figures	Explain why measured numbers always have uncertainty associated with them. [61, 62, 63, 65]
2.3	Zeros and Significant Figures	Identify leading zeros and trailing zeros in a measured number. [64, 66, 67] Identify the amount of uncertainty in a written measured quantity. [63, 68, 69]
2.4	Scientific Notation	Convert a number from standard to scientific notation and vice versa. [71, 75, 173, 182] Identify the degree of uncertainty in a number written in scientific notation. [72, 74, 75fg]
2.5	How to Handle Significant Figures and Scientific Notation When Doing Math	Correctly add or subtract numbers according to the rules of significant figures. [77, 80acd, 161ad] Correctly multiply or divide numbers according to the rules of significant figures. [78, 80b, 161bc]
2.6	Number With a Name—Units of Measure	Identify the common SI units used by science. [81, 82, 83, 85, 88]
2.7	Density: A Useful Physical Property of Matter	Define density, and use it to do calculations. [95, 96, 97, 98]
2.8	Doing Calculations in Chemistry—Unit Analysis	Convert the units of a measured quantity to some other units using unit analysis. [102, 107, 110]

New! Learning Outcomes

Each chapter ends with a section of Learning Outcomes, correlated to the end-of-chapter problems. The Learning Outcomes consist of goals and skills the student should learn and practice before moving on to the next chapter.

Making chemistry manageable and relevant with practical study tools

Students often ask, "When will I use this?" and have difficulty relating chemistry to real topics or events in everyday life. Russo and Silver's text includes various real-world applications and learning tools, placed strategically to boost interest and help students develop essential study skills as they assess their own progress.

7.1 Why Does Matter Exist in Different Phases?

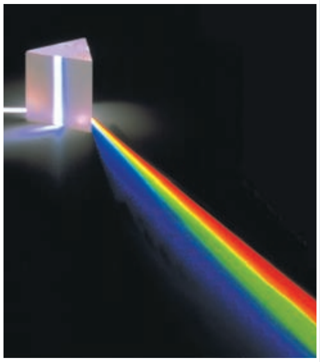
It's the middle of July, 34 °C, and you feel as if you're covered with a wet blanket. Sound familiar?

These are the sweltering, high-humidity days of summer when there is just too much water in the air. You can't see this water because it exists in the gas, or vapor, phase, but you can certainly feel it. It makes you feel miserable. Today's solution to this problem is, of course, the air-conditioner, which cools the air by drawing it in with a fan and passing it over cold refrigeration coils. If you were to look at the coils inside an air-conditioner, you would notice they are dripping wet. Cooling humid air causes the water vapor in the air to *condense* to a liquid on the cold coils, and in this way the air is dried as it is "conditioned." This is why air-conditioned air feels so good on a humid summer day—it's not just cooler, it's also drier. By setting an air-conditioner on its highest setting, you can sometimes cause the refrigeration coils to get so cold that the liquid water on them freezes. Thus, simply by cooling the air, an air-conditioner can drive atmospheric water through three phases—from the *gas phase* thr... and into the *solid phase*.

Section-Level Applications

Compelling applications and vignettes also appear as appropriate at the section level throughout the text.

r such a model
elieve it or not,
rom examining
any light, but
when atoms of
gas state were
large amounts
u are looking
very time you
n. Neon lights
es filled with
s that give off a
range-red light
with electrical
yellow light is
sodium-vapor
en a tube filled
en gas glows
hen electrified.
rious nature,



Real-World Applications

Applications are woven directly into the text's conversational narrative, evoking powerful images in students' minds and helping them grasp and retain concepts. Examples from areas such as nutrition and the atmosphere and including specific examples related to DNA modification and corrosion show that chemistry is a fascinating science.

Concept Questions

1. Which of the following statements is true regarding science and technology?
   (a) They are completely unrelated.
   (b) Technology precedes science.
   (c) Science precedes technology.
   (d) Science is the application of technology.
2. Matter can exist as which of the following?
   (a) As a homogeneous mixture of substances.
   (b) As a pure substance.
   (c) As a heterogeneous mixture of substances.
   (d) As all of the above.
3. To be a compound, a substance must
   (a) be made from more than one type of element.
   (b) not be a mixture.
   (c) be homogeneous.
   (d) be all of the above.
4. An elemental substance
   (a) can also be a compound.
   (b) can never be a compound.
   (c) cannot participate in a chemical reaction.
   (d) cannot change state since it is a pure element.
5. When a pure substance melts, it
   (a) undergoes a chemical change.
   (b) changes state.
   (c) changes from a liquid to a solid.
   (d) sublimes.
6. The melting point and the freezing point of a pure substance are
   (a) unrelated.
   (b) identical.
   (c) for the same change of state.
   (d) chemical properties of the substance.
7. A chemical property of hydrogen is that it
   (a) is a gas at room temperature.
   (b) is odorless.
   (c) combines with chlorine to make the compound hydrogen chloride (HCl).
   (d) combines with air to give a mixture of hydrogen and air.
8. In a chemical reaction
   (a) a physical change takes place.
   (b) products are converted into reactants.
   (c) one or more substances are converted into different substances.
   (d) elemental substances change into different elements.
9. A law is explained by
   (a) experimental data.
   (b) bias.
   (c) a theory.
   (d) an experiment.
10. The difference between a hypothesis and a theory is that
    (a) a hypothesis is a guess, whereas a theory is fact.
    (b) a theory is an untested hypothesis.
    (c) a theory is a well-tested hypothesis.
    (d) a theory is never wrong, whereas a hypothesis may be wrong.

Answers: 1c, 2d, 3a, 4b, 5b, 6b, 7c, 8c, 9c, 10c

New! Concept Questions

Asking students to think a bit further, these questions were written to gauge level of understanding and encourage students to review and apply the important concepts of a specific chapter.

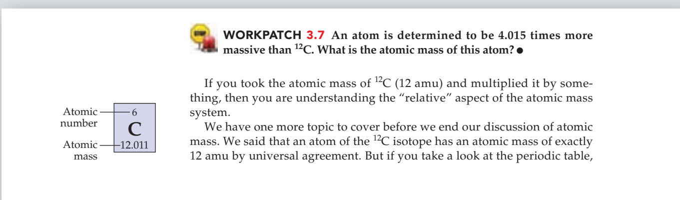
Motivating students and providing personalized coaching and feedback

MasteringChemistry®

MasteringChemistry is the most effective, widely used online tutorial, homework and assessment system for chemistry. It helps teachers maximize class time with customizable, easy-to-assign, and automatically graded assessment that motivate students to learn outside of class and arrive prepared for lecture. These assessments can easily be customized and personalized by teachers to suit their individual teaching style. To learn more, visit www.masteringchemistry.com.

Student Tutorials

Tutorials have been adapted and authored by an advisory board of expert chemists who teach with the atoms first approach. Immediate feedback helps students develop the problem-solving skills and motivation needed to succeed in this course.



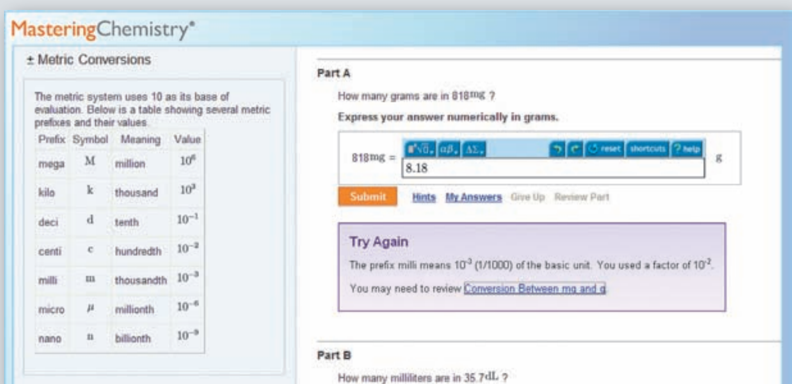
WORKPATCH 3.7 An atom is determined to be 4.015 times more massive than ^{12}C. What is the atomic mass of this atom? ●

If you took the atomic mass of ^{12}C (12 amu) and multiplied it by something, then you are understanding the "relative" aspect of the atomic mass system.

We have one more topic to cover before we end our discussion of atomic mass. We said that an atom of the ^{12}C isotope has an atomic mass of exactly 12 amu by universal agreement. But if you take a look at the periodic table,

New! WorkPatch Hints

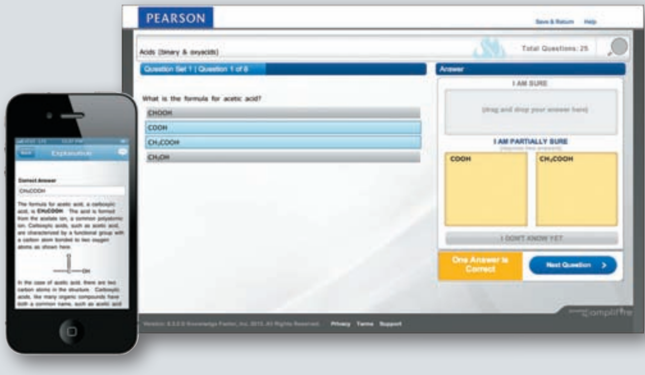
Conceptual practice problems called WorkPatches are now assignable in MasteringChemistry. Students who are having trouble completing a WorkPatch problem can scan the QR code on this page or visit the Study Area in MasteringChemistry for hints, and then go back and try the WorkPatch problem again.



Math Review

MasteringChemistry offers a variety of math remediation options for students to brush up on required quantitative skills including both Math Review Tutorials that can be assigned as prerequisites before moving onto more difficult material and Math Remediation Tutorials that offer just in time help to specific students based on their individual answer inputs. These exercises include guided solutions, sample problems, and feedback when students answer incorrectly.

www.masteringchemistry.com



NEW! Dynamic Study Modules

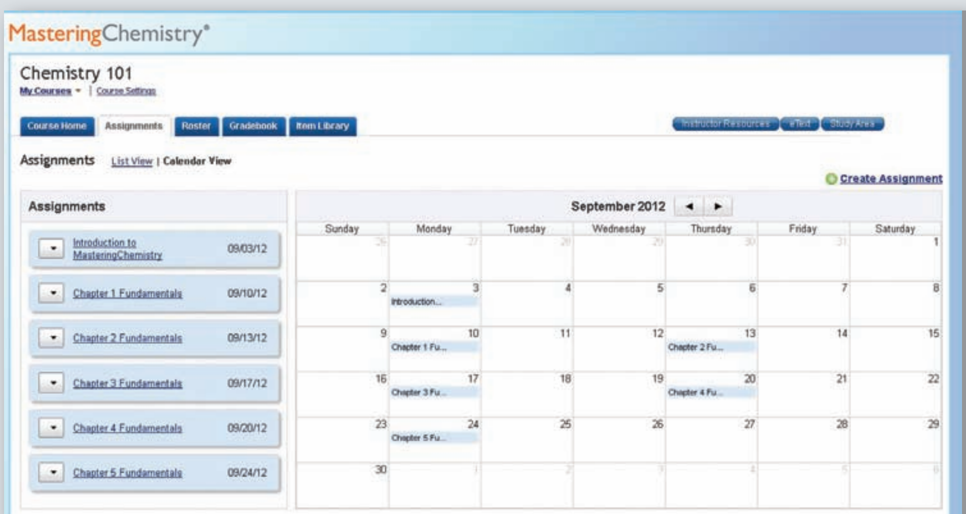
These are designed to enable students to study effectively on their own as well as help students quickly access and learn the nomenclature they need to be more successful in chemistry.

These modules can be accessed on smartphones, tablets, and computers and results can be tracked in the MasteringChemistry® Gradebook. How it works:

1. Students receive an initial set of questions and benefit from the metacognition involved with asking them to indicate how confident they are with their answer.
2. After answering each set of questions, students review their answers.
3. Each question has explanation material that reinforces the correct answer response and addresses the misconceptions found in the wrong answer choices.
4. Once students review the explanations, they are presented with a new set of questions. Students cycle through this dynamic process of test-learn-retest until they achieve mastery of the material.

Gradebook and Student Performance Snapshot

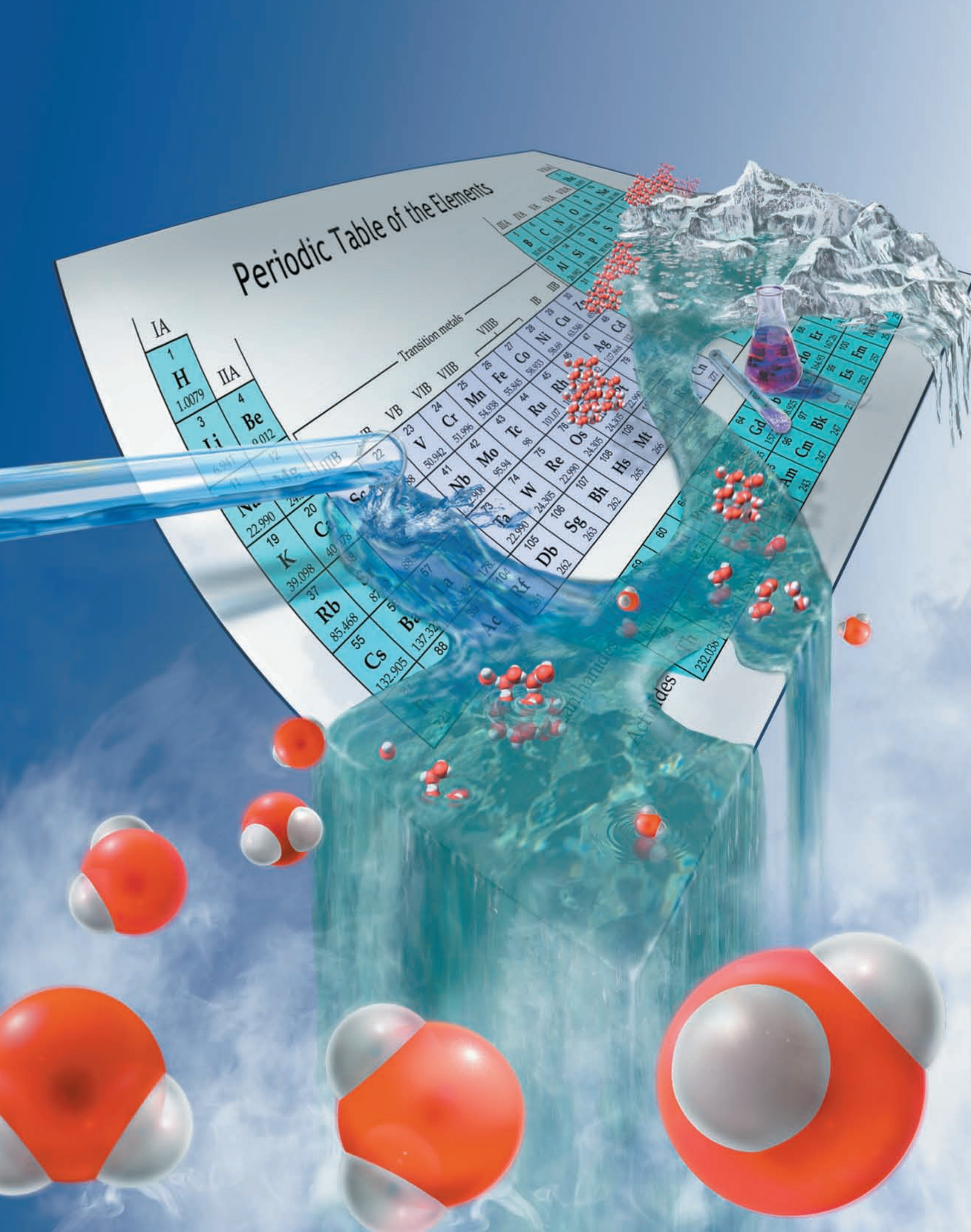
The Gradebook feature captures the step-by-step work of each student in class, including the time taken on every step. With a single click, charts summarize the most difficult problems, vulnerable students, grade distribution, and even score improvement over the course.



Calendar Features

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

- Instructors can schedule assignments by dragging and dropping the assignment onto a date in the calendar.
- The calendar view gives students a syllabus-style overview of due dates, making it easy to see all assignments due in a given month.


Periodic Table of the Elements
Transition metals

CHAPTER 1

What Is Chemistry?

Congratulations! You are taking a chemistry course. Chances are that you are taking it for one or more of the following reasons:

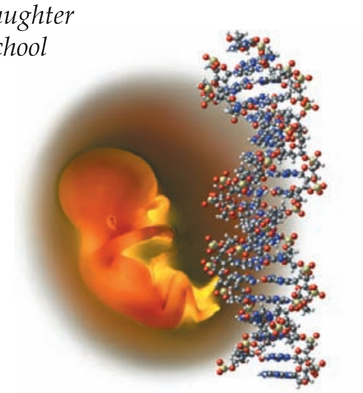
1. I have to take a science course, geology was closed, and physics is too hard.
2. All my friends are in the class.
3. It fits into my schedule.
4. It is required for my major.

There are much better reasons. Read on!

It is the early part of the twentieth century, 1914 to be exact. I am overcome with grief. My youngest child is burning with fever. The sickness has spread from her ear to her entire body. Her skin has a scarlet look, and she is in great pain. The doctor has applied some tincture of iodine, but he does not know how to cure her. He has told us to make arrangements. My beloved child will not see her fourth birthday.

It is the early part of the twenty-first century, 2014 to be exact. My daughter was ill yesterday with an earache. Our pediatrician diagnosed a streptococcus infection and administered the antibiotic amoxicillin. My daughter thought it tasted good, and she is back in preschool today, completely free of fever and pain.

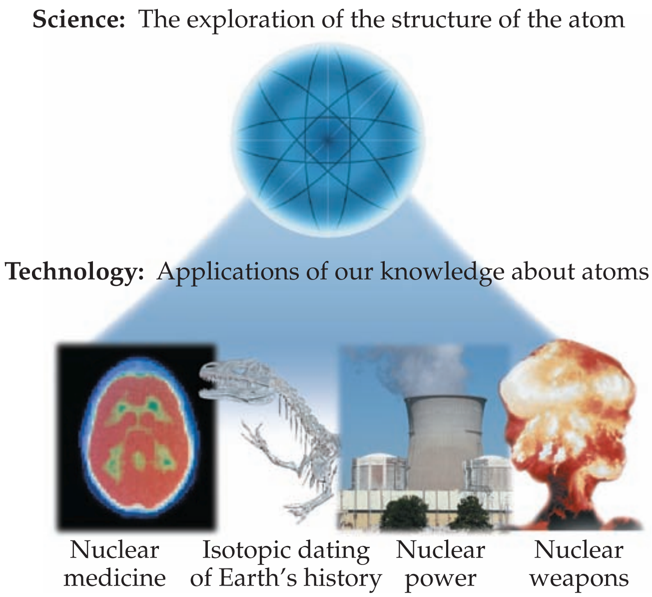
It is the year 2036. We have chosen to have a daughter. Unlike most of today's parents, we will not preselect her IQ. However, we do agree with our genetic counselor that her system should be genetically engineered so that she will be immune to all known bacterial and viral infections.



1.1 Science and Technology

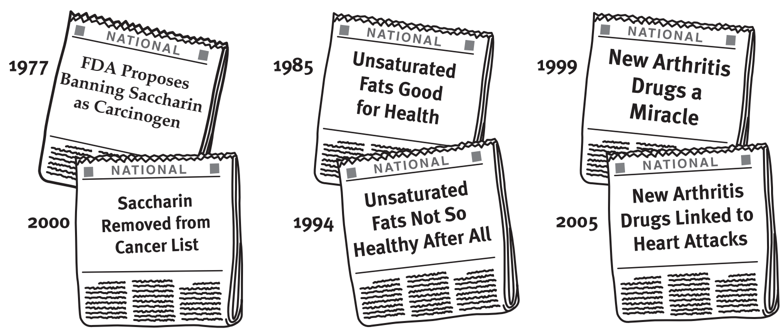
The span from 1914 to 2014 was 100 years. The year 2034 is only 20 years away. The pace at which things are changing is accelerating at an unbelievable rate. One hundred years from now will be as different from today as today is from 500 years ago. Within the past decade, a significant portion of the genetic code for the human genome has been unraveled. One hundred years ago we had never even heard of DNA; today we are cloning it. One hundred years ago we burned coal; in less than half that time from now we'll generate energy in fusion reactors powered by hydrogen taken from seawater, duplicating the process that occurs within the cores of stars.

Change this rapid is new for humanity. Until recently, each new generation could expect to live pretty much like the one before it. Not anymore. We scarcely have time to get used to one change before ten more are upon us. We've barely had time to think about the ethics of birth control, a development of the 1970s, and now stem cell research, life prolongation, and cloning are knocking at our door. Your personal computer and its software are almost outdated the day you buy them. What is feeding all this change? The answer is *science*.



The dictionary defines **science** as "the experimental investigation and explanation of natural phenomena" or "knowledge from experience." Science begins with a simple question, like "how?" or "why?" How are atoms put together? Why do bats fly at night? Science is the pursuit of knowledge for its own sake, because we are curious. But science itself can't cause change unless something is done with the knowledge it uncovers. For that we need **technology**, the *application* of scientific knowledge. So science is also the pipeline for technology—feeding it and supplying it with ideas. For example, scientists asked "How are atoms put together?" and their experiments led them to an answer. Today, technologists can use that knowledge to change our lives by developing nuclear medical technologies to treat cancer and by building nuclear bombs. As is so often the case with scientific knowledge, it can be used to achieve very different ends.

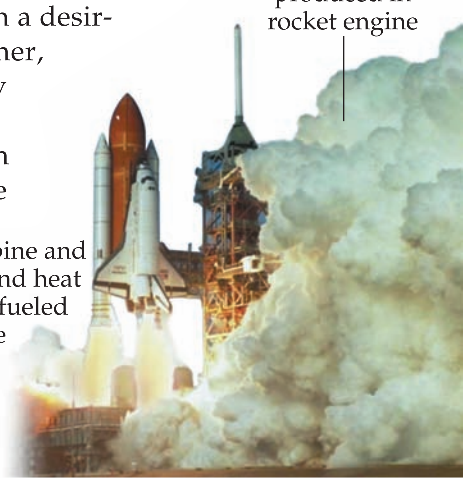
Because science feeds technology, it's not a bad idea to ask the question "Is science always right?" Just consider these headlines:



What is going on? Isn't science only about absolute, fundamental, provable truths? Unfortunately, no. Science, like literature, art, and music, is a human endeavor. And because it is a human endeavor, carried out by human scientists, you would not be wise to bet on science's infallibility. Ego, mistakes, and stubbornness can all get in the way of finding the truth. And what about technology? Is the technological application of scientific knowledge always good? Consider some of the forces that drive technology: the desire to benefit humankind, the desire to make a profit, the desire to be stronger than our enemies. Which motive do you think drives the cigarette industry in its application of knowledge concerning the effects of nicotine?

This brings us to some very important questions. Who should decide which areas of science are explored? Who should decide if a scientific result is real or a hoax? Who should decide what is done with scientific knowledge? In a free society, the answer is supposed to be the collective "you." After all, what scientists discover and technologists put into practice will dramatically affect how you live. In addition, much of the scientific research in this country is paid for by your tax dollars. Does this mean you have to earn a Ph.D. in chemistry, biology, or physics so that you can make informed decisions? For most people, that is not a practical or even a desirable solution. But total ignorance of science is not the answer either, because science and technology affect us directly in our everyday living.

This book is about the branch of science known as *chemistry*, often considered the "central science" since it forms a bridge between the principles of physics and the practice of biology. **Chemistry** is the study of matter and the transformations it undergoes (matter is being transformed within the space shuttle's rocket engines illustrated here). To understand this definition, we need to focus on two key concepts: *matter* and *transformation*.

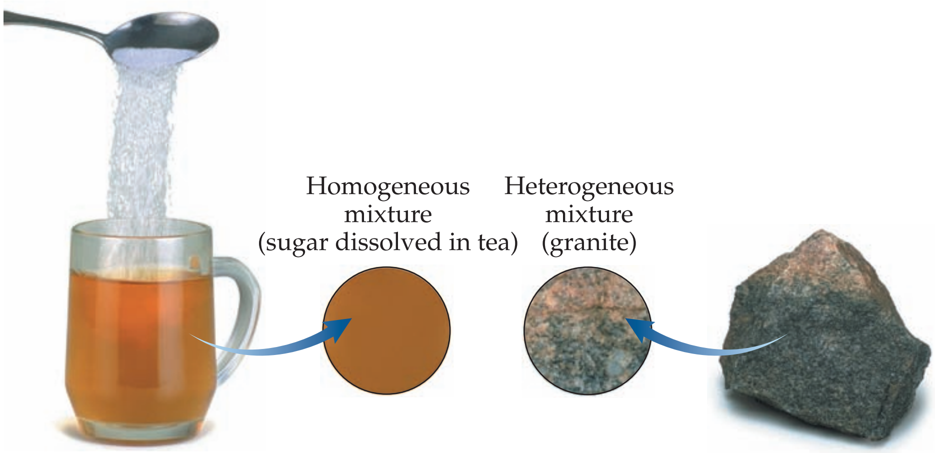


Hydrogen and oxygen combine and *transform* into water vapor and heat in the space shuttle's liquid-fueled engine, helping to propel the shuttle into space.

1.2 Matter

Matter can be simply defined as "stuff"—anything that has mass and occupies space. Some matter you can feel and see, like this book. Other matter, like the air that surrounds you, is difficult to detect, but it still exists. It occupies space (the volume of the room), and it has mass (a tank filled with helium gas weighs more than the empty tank). Defining matter as "stuff" is adequate for most everyday situations. Since scientists often ask very specific questions, however, it almost always requires much more precise and detailed definitions. Chemists define matter by dividing it into two broad types, *pure substances* and *mixtures*. In **pure substances**, only a single type of matter is present. **Mixtures** occur when two or more pure substances are intermingled with each other. For example, table salt (chemical name, sodium chloride) is a pure substance. So is water. And so is table sugar (chemical name, sucrose). If you put salt and sugar in a jar together and shake, however, you have a mixture. Dissolve sugar in water, and you have another mixture. Some things that you might not think of as mixtures actually do fit the definition—a rock, for example. In most rocks, you'll see a mixture of different minerals, each a different pure substance.

Chemists further subdivide mixtures into two types, *homogeneous* and *heterogeneous*. **Homogeneous mixtures** (*homo-*, meaning "the same") are ones in which the composition of the mixture is identical throughout. A cup of tea with some sugar dissolved in it is a homogeneous mixture. Once well stirred, such a mixture is exactly the same no matter where you sample it.



Another name for a homogeneous mixture is a **solution**. Our well-stirred cup of tea with sugar is a solution. The air you are breathing, consisting of a mixture made mostly of nitrogen gas and a smaller amount of oxygen gas, is also a homogeneous mixture, or a solution. Under normal conditions, no matter where you sample the air in the room, its composition (percent nitrogen and percent oxygen) is the same.

The rock pictured above is an example of a **heterogeneous mixture** (*hetero-*, meaning "different") because its composition is not the same throughout. Sometimes, heterogeneous mixtures can appear to be homogeneous even when they aren't. A mixture of table salt and table sugar is a heterogeneous mixture even when the two substances are ground together into a fine powder. This is true because a tiny sample taken at one place in the mixture might contain a different ratio of salt to sugar than a tiny sample taken at some other place. If the amount taken is small enough, it would even be possible to get a sample from this mixture that was pure sugar or pure salt, no matter how well you mechanically ground the two together. Only when such a tiny sample has the same composition wherever you sample it (as in the tea with sugar) can you call the mixture homogeneous.

A precise dividing line between a heterogeneous mixture and a homogeneous one is difficult to specify. Just how uniform does a mixture have to be in order to be considered homogeneous? Obviously, if the sample analyzed is of atomic size and includes only one atom, then no mixture can be considered homogeneous. In a larger sample containing billions and billions of atoms, the limiting factor is the analysis procedure used and how small a difference in composition is detectable by the experiment. In this text, we shall consider only obvious examples for discussion and classification and leave the more ambiguous determinations to the philosophers in the audience.

WORKPATCH 1.1 Classify the following examples of matter as pure substances, heterogeneous mixtures, or homogeneous mixtures (solutions).

(a) piece of wood
(b) iron nail
(c) rusty iron nail
(d) well-stirred mixture of food dye in water
(e) beeswax and candle wax mixed together by hand
(f) beeswax and candle wax melted together, stirred well, then allowed to solidify ●

Check your answers to WorkPatch 1.1 against the answers given at the end of the chapter. Did you get the right answers for the last two items? These items should make you think. Only one of the mixtures of beeswax and candle wax represents a solution because only one of the mixing processes (melting) can produce a homogeneous mixture.

Practice Problems

1.1 Which of the following are solutions?

(a) our atmosphere
(b) gold powder and silver powder ground together
(c) piece of 18-karat jewelry made from melting gold and silver metals together
(d) detergent dissolved in water
(e) oil droplets suspended in water

Answer: (a), (c), and (d)

1.2 Examination of "homogenized" milk under a microscope reveals suspended globules of fat. Is milk a heterogeneous mixture or a homogeneous mixture? Explain.

1.3 Fog is a suspension of tiny droplets of water in air. Is fog a heterogeneous mixture or a homogeneous mixture? Explain.

Before leaving the definition of matter, we want to say something about what matter is made of. All the matter that exists on our planet—from the air, to the dust in the air, to the ground we walk on, to the water that covers most of the planet, to the lifeforms that live on it—is made from **elements**, which are the basic building blocks of matter. At the time of writing, there are 118 known elements, 90 that occur naturally and 28 that can be synthetically prepared. All the known elements have been organized in a tabular form known as the *periodic table*.

The periodic table is so important to chemistry that we shall devote most of Chapter 3 to it. (A more complete periodic table and a list of the full names of all the elements appear inside the front cover of this book.)

Fe *(ferrum)*
Iron

Au *(aurum)*
Gold

Al
Aluminum

C
Carbon

S
Sulfur

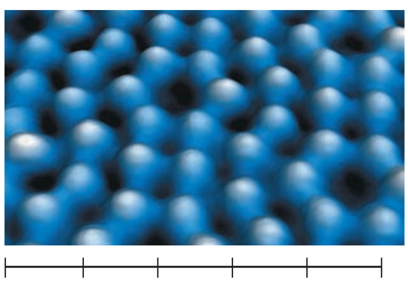
Periodic Table of the Elements

	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 H 1.0079																	2 He 4.003
2	3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
3	11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.066	17 Cl 35.453	18 Ar 39.948
4	19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.8
5	37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc 98	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.441	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.905	54 Xe 131.29
6	55 Cs 132.905	56 Ba 137.327	57 La 138.906	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po 209	85 At 210	86 Rn 222
7	87 Fr 223	88 Ra 226.025	89 Ac 227.028	104 Rf 261	105 Db 262	106 Sg 263	107 Bh 262	108 Hs 265	109 Mt 266	110 Ds 269	111 Rg 272	112 Cn 277		114 Fl		116 Lv		

58 Ce 140.115	59 Pr 140.908	60 Nd 144.24	61 Pm 145	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.925	66 Dy 162.5	67 Ho 164.93	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967
90 Th 232.038	91 Pa 231.036	92 U 238.029	93 Np 237.048	94 Pu 244	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 251	99 Es 252	100 Fm 257	101 Md 258	102 No 259	89 Lr 262

Many elements have names that you are probably quite familiar with—carbon, silver, gold, iron, aluminum, uranium, hydrogen, helium, oxygen, and nitrogen are a few. Chemists represent the elements with one-, two-, or three-letter symbols (as shown in the periodic table), some taken from the English names (like C for carbon, H for hydrogen, and Al for aluminum) and others taken from the Latin names (like Fe for iron from the Latin word *ferrum*; Au for gold from the Latin word *aurum*) or other languages.

When we say that elements are the basic building blocks of matter, how basic is basic? For example, suppose you had a piece of pure elemental gold. What would happen if you cut the piece of gold in half, and then in half again, and then again, and then again? How many times could you divide the piece and still have elemental gold? People have been trying to answer this question for centuries. Around 400 B.C., the Greek philosopher Democritus suggested an atomic theory of the universe. Simply put, this theory said that all things are made up of minute, indivisible, indestructible particles called *atoms*. That this might be true was by no means self-evident. A piece of gold does not appear to be made of individual particles. Nevertheless, Democritus would have said that you can keep dividing your piece of gold only until you get down to a single atom of gold. In fact, Democritus was right, but his theory was not an easy sell. Aristotle, another Greek philosopher living around the same time, placed more trust in his senses and said that matter was continuous and not made up of discrete individual atoms. According to Aristotle, you could keep dividing your gold into smaller and smaller pieces forever; at no point would you reach an indivisible particle. Because Aristotle's proposition seemed more obviously correct, his theory carried the day for more than 2000 years.



An image of silicon taken with a scanning tunneling microscope. Each purple sphere is a silicon atom.

As you will see in Chapter 3, scientists did eventually return to the atomic theory. We now know that all the elements exist as atoms, and an **atom** is the smallest possible piece of an element. Atoms are so tiny that, until recently, scientists thought we would never be able to see them. They spoke too soon. Though no one has seen an atom through an ordinary microscope, in the early 1980s, a device called a scanning tunneling microscope produced the first images of individual atoms—like the silicon atoms that appear as purple spheres on the surface of the silicon crystal shown in the photograph at left.

With the knowledge that matter is made up of atoms of the elements, we can now divide pure substances into two types, *elemental substances* and *compounds*. An **elemental substance** is one that is made from atoms of just one element. For example, our piece of pure gold is made from just gold atoms and nothing else. The same is true of a piece of pure iron (or any other pure metal), the oxygen you breathe, and the helium gas in a balloon.

Compounds, on the other hand, are pure substances made from atoms of two or more different elements. Water, for example, is a compound made from atoms of hydrogen and oxygen. A **chemical formula** for a compound indicates the number of atoms of each element that make up the smallest possible piece of that compound. The chemical formula for water, H_2O, tells us that the smallest possible piece of water is made from two hydrogen atoms and one oxygen atom. Because water is made from two different elements, it is classified as a compound. So is table sugar, whose formula is $C_{12}H_{22}O_{11}$. The oxygen in the air you breathe is a different case. The formula for oxygen, O_2, tells us that the smallest piece of life-sustaining oxygen gas has two oxygen atoms in it. However, though oxygen is made from two atoms, both are atoms of the same element, and so oxygen is not considered to be a compound; oxygen is an elemental substance. To summarize:

Matter

Pure substance

Mixture

Elemental substance: consists of a single element

Compound: consists of more than one element

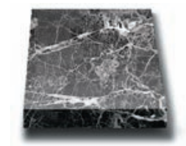
Homogeneous mixture (solution): composition is uniform throughout

Heterogeneous mixture: composition is not uniform throughout


Gold

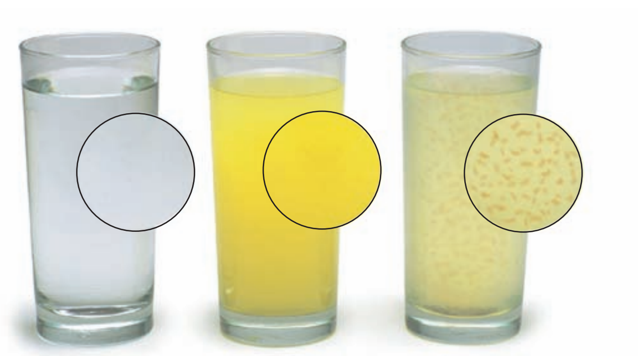

Water


Sugared tea


Marble

Classifying matter according to this scheme sometimes requires careful examination. Consider, for example, a glass of water, a glass of lemonade made from a powdered mix, and a glass of lemonade made from freshly squeezed lemons.

The water is a pure substance and a compound. The lemonade made from the mix is a homogeneous mixture (a solution). The lemonade made from lemons is a heterogeneous mixture because of the lemon pulp bits floating in it.


Pure water | Lemonade from powdered mix | Lemonade from freshly squeezed lemons

Practice Problems

1.4 Which of the following are compounds?

(a) iron oxide (Fe_2O_3)
(b) ozone (O_3)
(c) iron (Fe)
(d) carbon monoxide (CO)
(e) propane (C_3H_8)

Answer: (a), (d), and (e) because each is made from more than one kind of element; (b) and (c) are elemental substances, not compounds, because each is made of only one element.

1.5 Which of the following are compounds?

(a) sulfur (S_8)
(b) mixture of iron powder and aluminum powder
(c) mixture of O_2 gas and N_2 gas
(d) sulfur dioxide (SO_2)
(e) ammonia (NH_3)

1.6 True or false? A compound is a pure substance, but a pure substance need not be a compound. Give examples to prove your answer.