FOUNDATIONS OF

COLLEGE CHEMISTRY

15E

Morris Hein • Susan Arena • Cary Willard

WILEY

This page intentionally left blank

Periodic Table of the Elements

	Main groups												Main groups					
	1[a] 1A[b]	2 2A	Transition metals										13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 **H** Hydrogen 1.00794																	2 **He** Helium 4.002602
2	3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012182											5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.00674	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.998403	10 **Ne** Neon 20.1797
3	11 **Na** Sodium 22.989770	12 **Mg** Magnesium 24.3050	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 **Al** Aluminum 26.981538	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.973762	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.4527	18 **Ar** Argon 39.948
4	19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.95591	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938049	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933200	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92160	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
5	37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.90585	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.90638	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium [98]	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.90550	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90447	54 **Xe** Xenon 131.29
6	55 **Cs** Cesium 132.90545	56 **Ba** Barium 137.327	57 ***La** Lanthanum 138.9055	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.078	79 **Au** Gold 196.96655	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98038	84 **Po** Polonium [209]	85 **At** Astatine [210]	86 **Rn** Radon [222]
7	87 **Fr** Francium [223]	88 **Ra** Radium 226.025	89 **†Ac** Actinium 227.028	104 **Rf** Rutherfordium [261]	105 **Db** Dubnium [262]	106 **Sg** Seaborgium [266]	107 **Bh** Bohrium [267]	108 **Hs** Hassium [269]	109 **Mt** Meitnerium [268]	110 **Ds** Darmstadtium [281]	111 **Rg** Roentgenium [272]	112 **Cn** Copernicium	113 **Uut**	114 **Fl** Flerovium	115 **Uup**	116 **Lv** Livermorium	117 **Uus**	118 **Uuo**

*Lanthanide series	58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.90765	60 **Nd** Neodymium 144.24	61 **Pm** Promethium [145]	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.92534	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93032	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93421	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
†Actinide series	90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.03588	92 **U** Uranium 238.0289	93 **Np** Neptunium 237.048	94 **Pu** Plutonium [244]	95 **Am** Americium [243]	96 **Cm** Curium [247]	97 **Bk** Berkelium [247]	98 **Cf** Californium [251]	99 **Es** Einsteinium [252]	100 **Fm** Fermium [257]	101 **Md** Mendelevium [258]	102 **No** Nobelium [259]	103 **Lr** Lawrencium [262]

Atomic masses in brackets are the masses of the longest-lived or most important isotope of certain radioactive elements.

[a] The labels on top (1, 2, 3 ... 18) are the group numbers recommended by the International Union of Pure and Applied Chemistry.

[b] The labels on the bottom (1A, 2A, ... 8A) are the group numbers commonly used in the United States and the ones we use in this text.

[c] The names and symbols of elements 113 and above have not been assigned.

[d] Discovered in 2010, element 117 is under review by IUPAC.

Further information is available at the Web site of WebElements™.

Atomic Masses of the Elements

Based on the 2005 IUPAC Table of Atomic Masses

Name	Symbol	Atomic Number	Atomic Mass
Actinium*	**Ac**	89	227
Aluminum	**Al**	13	26.981538
Americium*	**Am**	95	243
Antimony	**Sb**	51	121.760
Argon	**Ar**	18	39.948
Arsenic	**As**	33	74.92160
Astatine*	**At**	85	210
Barium	**Ba**	56	137.327
Berkelium*	**Bk**	97	247
Beryllium	**Be**	4	9.012182
Bismuth	**Bi**	83	208.98038
Bohrium*	**Bh**	107	264
Boron	**B**	5	10.811
Bromine	**Br**	35	79.904
Cadmium	**Cd**	48	112.411
Calcium	**Ca**	20	40.078
Californium*	**Cf**	98	251
Carbon	**C**	6	12.0107
Cerium	**Ce**	58	140.116
Cesium	**Cs**	55	132.90545
Chlorine	**Cl**	17	35.4527
Chromium	**Cr**	24	51.9961
Cobalt	**Co**	27	58.933200
Copernicium	Cn	112	
Copper	**Cu**	29	63.546
Curium*	**Cm**	96	247
Darmstadtium*	**Ds**	110	271
Dubnium*	**Db**	105	262
Dysprosium	**Dy**	66	162.500
Einsteinium*	**Es**	99	252
Erbium	**Er**	68	167.26
Europium	**Eu**	63	151.964
Fermium*	**Fm**	100	257
Flerovium	Fl	114	
Fluorine	**F**	9	18.9984032
Francium*	**Fr**	87	233
Gadolinium	**Gd**	64	157.25
Gallium	**Ga**	31	69.723
Germanium	**Ge**	32	72.61
Gold	**Au**	79	196.96655
Hafnium	**Hf**	72	178.49
Hassium*	**Hs**	108	277
Helium	**He**	2	4.002602
Holmium	**Ho**	67	164.93032
Hydrogen	**H**	1	1.00794
Indium	**In**	49	114.818
Iodine	**I**	53	126.90447
Iridium	**Ir**	77	192.217
Iron	**Fe**	26	55.845
Krypton	**Kr**	36	83.80
Lanthanum	**La**	57	138.9055
Lawrencium*	**Lr**	103	262
Lead	**Pb**	82	207.2
Lithium	**Li**	3	6.941
Livermoriuum	Lv	116	
Lutetium	**Lu**	71	174.967
Magnesium	**Mg**	12	24.3050
Manganese	**Mn**	25	54.938049
Meitnerium*	**Mt**	109	268
Mendelevium*	**Md**	101	258
Mercury	**Hg**	80	200.59
Molybdenum	**Mo**	42	95.94
Neodymium	**Nd**	60	144.24
Neon	**Ne**	10	20.1797
Neptunium*	**Np**	93	237
Nickel	**Ni**	28	58.6934
Niobium	**Nb**	41	92.90638
Nitrogen	**N**	7	14.00674
Nobelium*	**No**	102	259
Osmium	**Os**	76	190.23
Oxygen	**O**	8	15.9994
Palladium	**Pd**	46	106.42
Phosphorus	**P**	15	30.973762
Platinum	**Pt**	78	195.078
Plutonium*	**Pu**	94	244
Polonium*	**Po**	84	209
Potassium	**K**	19	39.0983
Praseodymium	**Pr**	59	140.90765
Promethium*	**Pm**	61	145
Protactinium	**Pa**	91	231.03588
Radium*	**Ra**	88	226
Radon*	**Rn**	86	222
Rhenium	**Re**	75	186.207
Rhodium	**Rh**	45	102.90550
Roentgenium*	**Rg**	111	272
Rubidium	**Rb**	37	85.4678
Ruthenium	**Ru**	44	101.07
Rutherfordium*	**Rf**	104	261
Samarium	**Sm**	62	150.36
Scandium	**Sc**	21	44.955910
Seaborgium*	**Sg**	106	266
Selenium	**Se**	34	78.96
Silicon	**Si**	14	28.0855
Silver	**Ag**	47	107.8682
Sodium	**Na**	11	22.989770
Strontium	**Sr**	38	87.62
Sulfur	**S**	16	32.066
Tantalum	**Ta**	73	180.9479
Technetium*	**Tc**	43	98
Tellurium	**Te**	52	127.60
Terbium	**Tb**	65	158.92534
Thallium	**Tl**	81	204.3833
Thorium	**Th**	90	232.0381
Thulium	**Tm**	69	168.93421
Tin	**Sn**	50	118.710
Titanium	**Ti**	22	47.867
Tungsten	**W**	74	183.94
Uranium	**U**	92	238.0289
Vanadium	**V**	23	50.9415
Xenon	**Xe**	54	131.29
Ytterbium	**Yb**	70	173.04
Yttrium	**Y**	39	88.90585
Zinc	**Zn**	30	65.39
Zirconium	**Zr**	40	91.224

*This element has no stable isotopes. The atomic mass given is that of the isotope with the longest known half-life.

FOUNDATIONS OF

COLLEGE CHEMISTRY

This page intentionally left blank

15E

FOUNDATIONS OF COLLEGE CHEMISTRY

Morris Hein

Mount San Antonio College

Susan Arena

University of Illinois, Urbana-Champaign

Cary Willard

Grossmont College

WILEY

VP & Director: Petra Recter
Senior Acquisition Editor: Nicholas Ferrari
Product Designer: Sean Hickey
Senior Product Designer: Geraldine Osnato
Senior Marketing Manager: Kristine Ruff
Associate Director, Product Delivery: Kevin Holm
Senior Production Editor: Elizabeth Swain
Design Director: Harry Nolan
Senior Designer: Maureen Eide
Senior Market Solutions Assistant: Mallory Fryc
Senior Photo Editor: Mary Ann Price
Production Management Services: codeMantra, CSR Sofia Buono and Gandhimathi Ganesan
Cover: Paul Nicklen / Getty Images

This book was typeset in 10/12 Times New Roman MT Std at codeMantra and printed and bound by Quad Graphics, Versailles. The cover was printed by Quad Graphics, Versailles.

The paper in this book was manufactured by a mill whose forest management programs include sustained yield—harvesting of its timberlands. Sustained yield harvesting principles ensure that the number of trees cut each year does not exceed the amount of new growth.

This book is printed on acid free paper. ∞

Library of Congress Cataloging-in-Publication Data
Names: Hein, Morris. | Arena, Susan. | Willard, Cary.
Title: Foundations of college chemistry.
Description: 15th edition / Morris Hein, Susan Arena, Cary Willard. |
Hoboken, NJ : John Wiley & Sons, Inc., [2016] | Includes bibliographical
references and index.
Identifiers: LCCN 2015041455 | ISBN 9781119083900 (looseleaf: alk. paper)
Subjects: LCSH: Chemistry—Textbooks.
Classification: LCC QD33.2 .H45 2016 | DDC 540—dc23 LC record available at
http://lccn.loc.gov/2015041455

Binder-ready version	ISBN 978-1-119-08390-0
Evaluation/desk copy	ISBN 978-1-119-24673-2
High School binding	ISBN 978-1-119-23455-5

The inside back cover will contain printing identification and country of origin if omitted from this page. In addition, if the ISBN on the back cover differs from the ISBN on this page, the one on the back cover is correct.

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

ABOUT THE AUTHOR

MORRIS HEIN earned his PhD at the University of Colorado, Boulder. He was Professor Emeritus of Chemistry at Mt. San Antonio College, where he regularly taught the preparatory chemistry course and organic chemistry. He was the original author of *Foundations of College Chemistry*, and his name has become synonymous with clarity, meticulous accuracy, and a step-by-step approach that students can follow. Morris passed away in late 2014 and was actively working on our texts till the very end. His sharp eyes and attention to detail will be sorely missed.

SUSAN ARENA earned a BS and MA in Chemistry at California State University-Fullerton. She has taught science and mathematics at all levels, including middle school, high school, community college, and university. At the University of Illinois she developed a program for increasing the retention of minorities and women in science and engineering. This program focused on using active learning and peer teaching to encourage students to excel in the sciences. She has coordinated and led workshops and programs for science teachers from elementary through college levels that encourage and support active learning and creative science teaching techniques. For several years she was director of an Institute for Chemical Education (ICE) field center in Southern California. In addition to *Foundations of College Chemistry,* 15th edition, she is co-author of *Introduction to General, Organic and Biochemistry*, 10th edition. Susan enjoys reading, knitting, traveling, classic cars, and gardening in her spare time when she is not playing with her grandchildren.

CARY WILLARD received her BS in chemistry from California State Polytechnic Institute, Pomona, and her PhD from the University of California, Davis. She has been teaching chemistry at Grossmont College in El Cajon, California for over 20 years. She teaches the chemistry courses for both science and nonscience majors. Her biggest successes are the students who come into chemistry afraid of the subject and leave having discovered that chemistry really is fun. Her interest in sharing the excitement of science to the community resulted in Grossmont College hosting a Science Festival, multiple Science Decathlons, model airplane flying, and robotics competitions. Cary is also a member of the BE WiSE (Better Education for Women in Science and Engineering) steering committee and works with the group to share the excitement of scientific research with a new generation of young women. In her spare time, Cary enjoys exploring the San Diego region both on foot and in her kayak.

This page intentionally left blank

This page intentionally left blank

BRIEF CONTENTS

This page intentionally left blank

CONTENTS

PREFACE

This new Fifteenth Edition of *Foundations of College Chemistry* presents chemistry as a modern, vital subject and is designed to make introductory chemistry accessible to all beginning students. The central focus is the same as it has been from the first edition: to make chemistry interesting and understandable to students and teach them the problem-solving skills they will need. In preparing this new edition, we considered the comments and suggestions of students and instructors to design a revision that builds on the strengths of previous editions including clear explanations and step-by-step problem solving. We have especially tried to relate chemistry to the real lives of our students as we develop the principles that form the foundation for the further study of chemistry, and to provide them with problem-solving skills and practice needed in their future studies. We have focused on using electronic materials to enhance the student experience. To that end we have authored and added new interactive features ourselves and enhanced our existing electronic materials to draw the students into direct involvement in an active learning experience.

Foundations of College Chemistry, 15th Edition, is intended for students who have never taken a chemistry course or those who have had a significant interruption in their studies but plan to continue with the general chemistry sequence. Since its inception, this book has helped define the preparatory chemistry course and has developed a much wider audience. In addition to preparatory chemistry, our text is used extensively in one-semester general-purpose courses (such as those for applied health fields) and in courses for nonscience majors.

Development of Problem-Solving Skills

We all want our students to develop real skills in solving problems. We believe that a key to the success of this text is the fact that our problem-solving approach works for students. It is a step-by-step process that teaches the use of units and shows the change from one unit to the next. We have used this problem-solving approach in our examples throughout the text to encourage students to think their way through each problem. In this edition we continue to use examples to incorporate fundamental mathematical skills, scientific notation, and significant figures. We have added Problem-Solving Strategy boxes in the text to highlight the steps needed to solve chemistry problems. Painstaking care has been taken to show each step in the problem-solving process and to use these steps in solving example problems. We continue to use four significant figures for atomic and molar masses for consistency and for rounding off answers appropriately. We have been meticulous in providing answers, correctly rounded, for students who have difficulty with mathematics.

FOSTERING STUDENT SKILLS *Attitude* plays a critical role in problem solving. We encourage students to learn that a systematic approach to solving problems is better than simple memorization. Throughout the book we emphasize the use of our approach to problem solving to encourage students to think through each problem. Once we have laid the foundations of concepts, we highlight the steps so students can locate them easily. Important rules and equations are highlighted for emphasis and ready reference.

STUDENT PRACTICE Practice problems follow the examples in the text, with answers provided at the end of the chapter. The end of each chapter begins with a *Chapter Review* and *Review Questions* section, which help students review key terms and concepts, as well as material presented in tables and figures. This is followed by *Paired Exercises*, covering concepts and numerical exercises, where two similar exercises are presented side by side. The section titled *Additional Exercises* includes further practice problems presented in a more random order. The final section of exercises is titled Challenge Exercises and contains problems designed to stretch the student's understanding of concepts and to integrate

PREFACE

This new Fifteenth Edition of *Foundations of College Chemistry* presents chemistry as a modern, vital subject and is designed to make introductory chemistry accessible to all beginning students. The central focus is the same as it has been from the first edition: to make chemistry interesting and understandable to students and teach them the problem-solving skills they will need. In preparing this new edition, we considered the comments and suggestions of students and instructors to design a revision that builds on the strengths of previous editions including clear explanations and step-by-step problem solving. We have especially tried to relate chemistry to the real lives of our students as we develop the principles that form the foundation for the further study of chemistry, and to provide them with problem-solving skills and practice needed in their future studies. We have focused on using electronic materials to enhance the student experience. To that end we have authored and added new interactive features ourselves and enhanced our existing electronic materials to draw the students into direct involvement in an active learning experience.

Foundations of College Chemistry, 15th Edition, is intended for students who have never taken a chemistry course or those who have had a significant interruption in their studies but plan to continue with the general chemistry sequence. Since its inception, this book has helped define the preparatory chemistry course and has developed a much wider audience. In addition to preparatory chemistry, our text is used extensively in one-semester general-purpose courses (such as those for applied health fields) and in courses for nonscience majors.

Development of Problem-Solving Skills

We all want our students to develop real skills in solving problems. We believe that a key to the success of this text is the fact that our problem-solving approach works for students. It is a step-by-step process that teaches the use of units and shows the change from one unit to the next. We have used this problem-solving approach in our examples throughout the text to encourage students to think their way through each problem. In this edition we continue to use examples to incorporate fundamental mathematical skills, scientific notation, and significant figures. We have added Problem-Solving Strategy boxes in the text to highlight the steps needed to solve chemistry problems. Painstaking care has been taken to show each step in the problem-solving process and to use these steps in solving example problems. We continue to use four significant figures for atomic and molar masses for consistency and for rounding off answers appropriately. We have been meticulous in providing answers, correctly rounded, for students who have difficulty with mathematics.

FOSTERING STUDENT SKILLS *Attitude* plays a critical role in problem solving. We encourage students to learn that a systematic approach to solving problems is better than simple memorization. Throughout the book we emphasize the use of our approach to problem solving to encourage students to think through each problem. Once we have laid the foundations of concepts, we highlight the steps so students can locate them easily. Important rules and equations are highlighted for emphasis and ready reference.

STUDENT PRACTICE Practice problems follow the examples in the text, with answers provided at the end of the chapter. The end of each chapter begins with a *Chapter Review* and *Review Questions* section, which help students review key terms and concepts, as well as material presented in tables and figures. This is followed by *Paired Exercises*, covering concepts and numerical exercises, where two similar exercises are presented side by side. The section titled *Additional Exercises* includes further practice problems presented in a more random order. The final section of exercises is titled Challenge Exercises and contains problems designed to stretch the student's understanding of concepts and to integrate

concepts from other chapters. In our new edition we have changed a number of exercises per chapter, In addition we have expanded the electronic Enhanced Examples to a total of 178 throughout the chapters and developed two new electronic practice methods.

PRACTICE 7.7

Calculate the percent composition of $Ca(NO_3)_2$.

PRACTICE 7.8

Calculate the percent composition of K_2CrO_4.

Practice Problems

PROBLEM-SOLVING STRATEGY

For Calculating Percent Composition from Formula

1. Calculate the molar mass (Section 7.2).
2. Divide the total mass of each element in the formula by the molar mass and multiply by 100. This gives the percent composition:

$$\frac{\text{total mass of the element}}{\text{molar mass}} \times 100 = \text{percent of the element}$$

Problem-solving Strategy

Organization

We continue to emphasize the less theoretical aspects of chemistry early in the book, leaving the more abstract theory for later. This sequence seems especially appropriate in a course where students are encountering chemistry for the very first time. Atoms, molecules, and reactions are all an integral part of the chemical nature of matter. A sound understanding of these topics allows the student to develop a basic understanding of chemical properties and vocabulary.

Chapters 1 through 3 present the basic mathematics and the language of chemistry, including an explanation of the metric system and significant figures. We added a new section in Chapter 2 (2.7) on Percents to assist students in understanding how the concept is applied in chemistry. In Chapter 4 we present chemical properties—the ability of a substance to form new substances. Then, in Chapter 5, students encounter the history and language of basic atomic theory. In Chapter 8 we added a new section 8.3 "Why Reactions Occur" and revised the section discussing types of reactions extensively to better reflect the level and needs of our students.

We continue to present new material at a level appropriate for the beginning student by emphasizing nomenclature, composition of compounds, and reactions in Chapters 6 through 9 before moving into the details of modern atomic theory. Some applications of the Periodic Table are shown in early chapters and discussed in detail in Chapters 10 and 11. Students gain confidence in their own ability to identify and work with chemicals in the laboratory before tackling the molecular models of matter. As practicing chemists we have little difficulty connecting molecular models and chemical properties. Students, especially those with no prior chemistry background, may not share this ability to connect the molecular models and the macroscopic properties of matter. Those instructors who feel it is essential to teach atomic theory and bonding early in the course can cover Chapters 10 and 11 immediately following Chapter 5.

New to This Edition

In the Fifteenth Edition we have tried to build on the strengths of the previous editions. We have added a new author, **Cary Willard**, from Grossmont College in California. Cary revised the end-of-chapter materials and added exercises, including many applications in fields of interest for our students. She has focused on expanding and developing important and

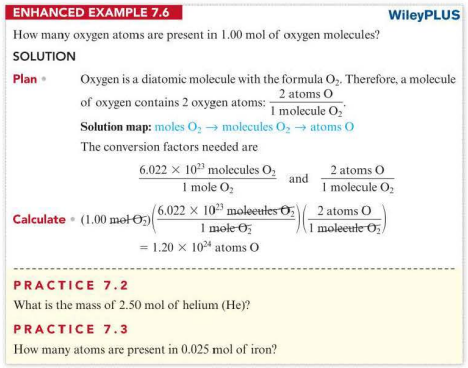
meaningful media assets for the *WileyPLUS* course. Her focus has created deeper synergies between the content in print format and the electronic resources in our *WileyPLUS* course.

We continually strive to keep the material at the same level so that students can easily read and use the text and supplemental material to learn chemistry. With a focus on problem solving, student engagement, and clarity, some of the specific changes are highlighted below:

- Chemistry In Action boxes have been updated, and new boxes have been added to include different applications of the concepts in the text.
- Some of the older industrial chemistry applications have been removed and newer applications added as appropriate throughout the text.
- 229 Check Your Understanding Questions appear throughout the text to provide an opportunity for the students to determine their level of understanding of concepts. These are highlighted in the margins and refer the student to *WileyPlus* for completion.

CHECK YOUR UNDERSTANDING
7.6 Molecules and Formula Units
WileyPLUS

- 178 Enhanced Examples are also located in *WileyPlus* and provide a more interactive experience and practice. Students receive immediate feedback on their answers and proceed stepwise through the example to its conclusion.


ENHANCED EXAMPLE 7.6 WileyPLUS

How many oxygen atoms are present in 1.00 mol of oxygen molecules?

SOLUTION

Plan • Oxygen is a diatomic molecule with the formula O_2. Therefore, a molecule of oxygen contains 2 oxygen atoms: $\frac{2 \text{ atoms O}}{1 \text{ molecule } O_2}$.

Solution map: moles O_2 → molecules O_2 → atoms O

The conversion factors needed are

$$\frac{6.022 \times 10^{23} \text{ molecules } O_2}{1 \text{ mole } O_2} \quad \text{and} \quad \frac{2 \text{ atoms O}}{1 \text{ molecule } O_2}$$

Calculate • $(1.00 \cancel{\text{mol } O_2})\left(\frac{6.022 \times 10^{23} \cancel{\text{molecules } O_2}}{1 \cancel{\text{mole } O_2}}\right)\left(\frac{2 \text{ atoms O}}{1 \cancel{\text{molecule } O_2}}\right)$

$= 1.20 \times 10^{24}$ atoms O

PRACTICE 7.2
What is the mass of 2.50 mol of helium (He)?

PRACTICE 7.3
How many atoms are present in 0.025 mol of iron?

- 131 new Online Learning Modules movies provide a one-on-one learning experience that mimics the assistance an instructor provides in a help session. The modules are paired with in-text examples to provide an alternative way to learn problem solving.
- Each chapter is complemented by ORION, an adaptive learning module, available within *WileyPLUS*. These can be used individually for student review or can be assigned by instructors as a specific review assignment tailored to the chapters and sections on an exam.


ONLINE LEARNING MODULE
Finding Molecules in Moles of a Diatomic Substance
WileyPLUS

- Chapters 19 and 20 (Introduction to Organic Chemistry and Introduction to Biochemistry) are now available online only. This provides an option for those desiring a shorter version of the text and for those wishing to cover this material in their course.
- The Putting It Together sections have been removed in order to provide a more flexible review source for students and instructors. This new resource is called Orion and is found on *WileyPlus*.
- New, modern design. The entire text has been redesigned to foster greater accessibility and increase student engagement. New icons and notes direct students to *WileyPlus* for more individual direct interaction with the material.
- Appendix II: Using a Scientific Calculator has been removed because most students begin using calculators in elementary school and there are so many kinds of calculators that specific instruction on their use is no longer possible.

Learning Aids

To help the beginning student gain the confidence necessary to master technical material, we have refined and enhanced a series of learning aids:

- **Learning Objectives** highlight the concept being taught in each section. These objectives are tied to **Example**, **Practice Problems**, **Review Exercises**, and **Exercises** to assist the student in mastering each concept module and objective.
- Important **terms** are set off in bold type where they are defined and are listed in gray at the beginning of each section. All **Key Terms** listed in the **Chapter Review** are also defined in the **Glossary**.
- Worked **examples** show students the how of problem solving using **Problem-Solving Strategies** and **Solution Maps** before they are asked to tackle problems on their own.
- **Practice problems** permit immediate reinforcement of a skill shown in the example problems. Answers are provided at the end of the chapter to encourage students to check their problem solving immediately.

- **Marginal notations** help students understand basic concepts and problem-solving techniques. These are printed in blue to clearly distinguish them from text and vocabulary terms.

LEARNING AIDS: MATH SKILLS For students who may need help with the mathematical aspects of chemistry, the following learning aids are available:

- A **Review of Mathematics**, covering the basic functions, is provided in Appendix I.
- **Math Survival Guide: Tips and Tricks for Science Students**, 2nd Edition, by Jeffrey R. Appling and Jean C. Richardson, a brief paperback summary of basic skills that can be packaged with the text, provides an excellent resource for students who need help with the mathematical aspects of chemistry.

Supplements Package

FOR THE STUDENT **Study Guide** by Rachael Henriques Porter is a self-study guide for students. For each chapter, the **Study Guide** includes a self-evaluation section with student exercises, a summary of chapter concepts, one or more "challenge problems," and answers and solutions to all **Study Guide** exercises.

Math Survival Guide: Tips and Tricks for Science Students, 2nd Edition, by Jeffrey Appling and Jean Richardson, is a paperback summary of basic skills, with practice exercises in every chapter.

Foundations of Chemistry in the Laboratory, 14th Edition, by Morris Hein, Judith N. Peisen, and Robert L. Miner includes 28 experiments for a laboratory program that may accompany the lecture course. Featuring updated information on waste disposal and emphasizing safe laboratory procedures, the lab manual also includes study aids and exercises.

FOR THE INSTRUCTOR **Test Bank**, by Harpreet Malhotra, includes chapter tests with additional test questions and answers to all test questions.

Computerized Test Bank. The test bank contains true-false, multiple-choice, and open-ended questions and is available in two formats.

Digital Image Library: Images from the text are available online in JPEG format. Instructors may use these to customize their presentations and to provide additional visual support for quizzes and exams.

Power Point Lecture Slides: Updated for this version by William Douglas Urban, these slides contain lecture outlines and key topics from each chapter of the text, along with supporting artwork and figures from the text.

WileyPLUS

WileyPLUS is an innovative, research-based online environment for effective teaching and learning.

WileyPLUS builds students' confidence because it takes the guesswork out of studying by providing students with a clear roadmap: **what to do, how to do it, if they did it right**. This interactive approach focuses on:

CONFIDENCE: Research shows that students experience a great deal of anxiety studying. That's why we provide a structured learning environment that helps students focus on **what to do**, along with the support of immediate resources.

MOTIVATION: To increase and sustain motivation throughout the semester, *WileyPLUS* helps students learn **how to do it** at a pace that's right for them. Our integrated resources—available 24/7—function like a personal tutor, directly addressing each student's demonstrated needs with specific problem-solving techniques.

WileyPLUS is now equipped with an adaptive learning module called ORION.

WileyPLUS with ORION is:

BEGIN

A **personalized study guide** that helps students understand both strengths and areas where they need to invest more time, especially in preparation for quizzes and exams.

PRACTICE

For each topic, students can either Study or Practice. **Study** directs the student to the specific topic they choose in *WileyPLUS*, where they can read from the e-textbook, or use the variety of relevant resources available there. Students can also **practice**, using questions and feedback powered by ORION's adaptive learning engine.

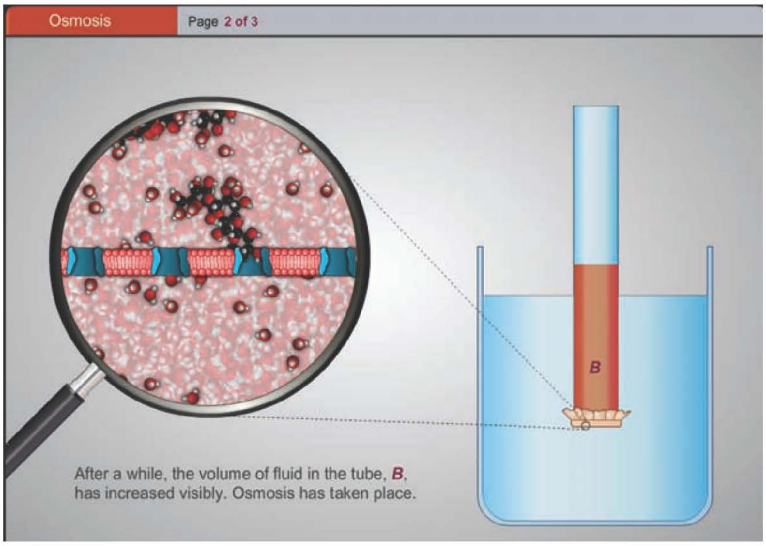
MAINTAIN

ORION includes a number of reports and ongoing recommendations for students to help them maintain their proficiency over time for each topic.

Students can easily access ORION from within *WileyPLUS*. It does not require any additional registration, and there is no additional charge for students using this adaptive learning system.

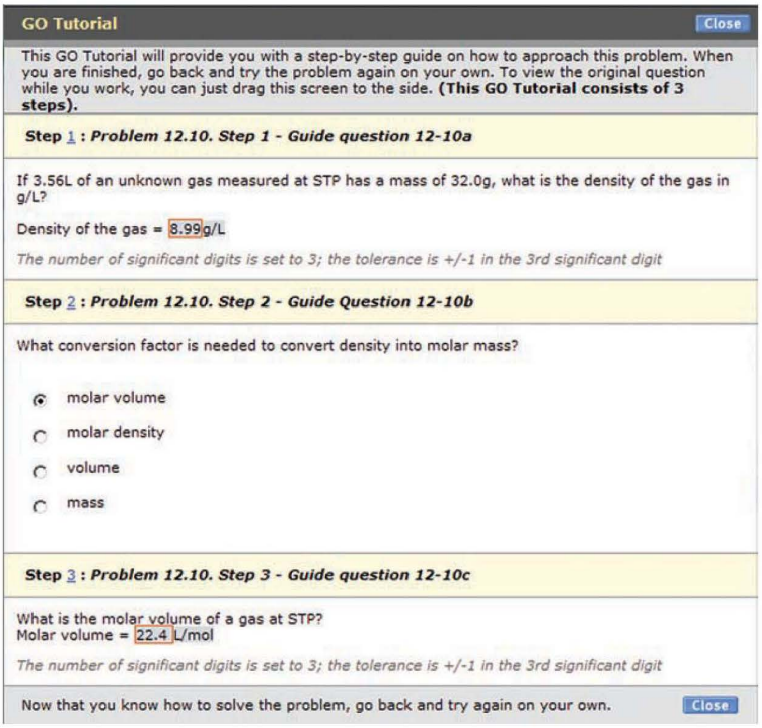
What Do Students Receive with *WileyPLUS*?

- The complete digital textbook, saving students up to 50% off the cost of a printed text.
- Math Skills module provides a comprehensive review of topics including: ratios, scientific notation, significant figures, and graphing.
- The Check Your Understanding Questions, Enhanced Examples, and Online Learning Modules outlined above are available by default to students for self-study, no instructor set-up is required.
- Visualizations of key concepts with audio narration.



What Do Instructors Receive with *WileyPLUS*?

- All end-of-chapter questions are available for assignment and automatic grading.
- Every assignable question has been enhanced with additional content such as hints, solutions, and guided tutorials which can be made available to students at the instructor's discretion.



- Pre-built assignments with two options per chapter that can be assigned with a single click.
- Prelecture checkpoint questions
- The complete instructor ancillary package can be accessed directly from *WileyPLUS* including: Lecture PowerPoints, Solutions Manual, Classroom Response System (Clickers) questions and Test Bank.
- *WileyPLUS* can be integrated with many popular Learning Management Systems such as BlackBoard and Canvas. Integration allows for single-sign-on and gradebook synchronization.

Customization and Flexible Options to Meet Your Needs

Wiley Custom Select allows you to create a textbook with precisely the content you want, in a simple, three-step online process that brings your students a cost-efficient alternative to a traditional textbook. Select from an extensive collection of content at **http://custom-select.wiley.com**, upload your own materials as well, and select from multiple delivery formats—full color or black and white print with a variety of binding options, or eBook. Preview the full text online, get an instant price quote, and submit your order; we'll take it from there. *WileyFlex* offers content in flexible and cost-saving options to students. Our goal is to deliver our learning materials to our customers in the formats that work best for them, whether it's traditional text, eTextbook, *WileyPLUS*, loose-leaf binder editions, or customized content through Wiley Custom Select.

Acknowledgments

Books are the result of a collaborative effort of many talented and dedicated people. We particularly want to thank our editor, Nick Ferrari, who guided the project through revision with the challenge of creating several new electronic features. We are grateful to Mary Ann

Price, Senior Photo Editor, for finding new and interesting photos that add so much to the pages of our text. We also want to thank Elizabeth Swain, Senior Production Editor, who kept us on track and production running smoothly. Sofia Buono, Project Manager/Copy Editor, in Italy was amazing and turned our revisions into the beautiful text in our 15th edition. We also especially appreciate the work of Sean Hickey, Product Designer, who helped us with the Online Learning Modules and incorporating new Check Your Understanding questions into *WileyPlus*. Thanks to others who provided valuable assistance on this revision, including Senior Marketing Manager, Kristine Ruff, Senior Designer, Maureen Eide, and Mallory Fryc, Senior Market Solutions Assistant, who was always ready to find an answer to anything we needed. We are grateful for the many helpful comments from colleagues and students who, over the years, have made this book possible. We hope they will continue to share their ideas for change with us, either directly or through our publisher.

We are especially thankful for the help and support of Tom Martin, our developmental editor. His positive attitude, attention to detail, efficiency, good humor, and willingness to help in any way were indispensable in this revision.

Our sincere appreciation goes to the following reviewers who were kind enough to read and give their professional comments.

Reviewers

FOR THE15TH EDITION

Jing Yi Chin
Suffolk County Community College

Kara Kuvakas
Brandman University

Ralph Morasch
Pierce College

Rajiv Narula
SUNY Canton

Alexander Nazarenko
SUNY Buffalo State

Ethel Owusu-Nukunya
Santa Fe College

Sharadha Sambasivan
Suffolk County Community College

Anne Marie Sokol
SUNY Buffalo State

FOR THE14TH EDITION

Jeffrey Allison
Austin Community College

Jeanne Arquette
Phoenix College

Rebecca Broyer
University of Southern California

Michael Byler
Community College of Philadelphia

Kevin Cannon
Penn State Abington

Rong Cao
Community College of Allegheny City

Ken Capps
College of Central Florida

Charles Carraher
Florida Atlantic University

Loretta Dorn
Fort Hays State University

Robert Eves
Southern Utah University

Mitchel Fedak
Duquesne University

Paul Fox
Danville Community College

Erick Fuoco
Richard J. Daley College

Amy Grant
El Camino College

Tamara Hanna
Texas Tech Lubbock

Chris Hamaker
Illinois State University

Claudia Hein
Diablo Valley College

Donna Iannotti
Brevard Community College

Crystal Jenkins
Santa Ana College

Jodi Kreiling
University of Nebraska at Omaha

Julie Larson
Bemidji State University

Anne Lerner
Santa Fe College

Lauren McMills
Ohio University—Main Campus

Mitchel Millan
Casper College

Timothy Minger
Mesa Community College

Franklin Ow
East LA City College

Ethel (April) Owusu
Santa Fe College

Fumin Pan
Mohawk Valley Community College

David Peitz
Wayne State College

Sharadha Sambasivan
Suffolk Community College

Hussein Samha
Southern Utah University

Mary Shoemaker
Pennsylvania State University—University Park

Lee Silverberg
Penn State—Schuylkill

Gabriela Smeureanu
Hunter College

Sunanda Sukumar
Albany College of Pharmacy

Paris Svoronos
QCC of Cuny

Susan Thomas
University of Texas—San Antonio

Sergey Trusov
Oxnard College

Elaine Vickers
Southern Utah University

Loretta Vogel
Ocean County College

Liwen Yu
Inver Hills Community College

Karl Wallace
University of Southern Mississippi

This page intentionally left blank

1

An Introduction to Chemistry

Jon Hilmasson/Getty Images

CHAPTER OUTLINE

Do you know how the beautiful, intricate fireworks displays are created? Have you ever wondered how a tiny seedling can grow into a cornstalk taller than you in just one season? Perhaps you have been mesmerized by the flames in your fireplace on a romantic evening as they change color and form. The spectacular colors of the aurora borealis shown above are the result of chemistry in our atmosphere. And think of your relief when you dropped a container and found that it was plastic, not glass. These phenomena are the result of chemistry that occurs all around us, all the time. Chemical changes bring us beautiful colors, warmth, light, and products to make our lives function more smoothly. Understanding, explaining, and using the diversity of materials we find around us is what chemistry is all about.

1.1 The Nature of Chemistry

LEARNING OBJECTIVE State the definition of chemistry and why the study of chemistry is important.

KEY TERM
Chemistry

A knowledge of chemistry is useful to virtually everyone—we see chemistry occurring around us every day. An understanding of chemistry is useful to engineers, teachers, health care professionals, attorneys, homemakers, businesspeople, firefighters, and environmentalists, just to name a few. Even if you're not planning to work in any of these fields, chemistry is important and is used by people every day. Learning about the benefits and risks associated with chemicals will help you to be an informed citizen, able to make intelligent choices concerning the world around you. Studying chemistry teaches you to solve problems and communicate with others in an organized and logical manner. These skills will be helpful in college and throughout your career.

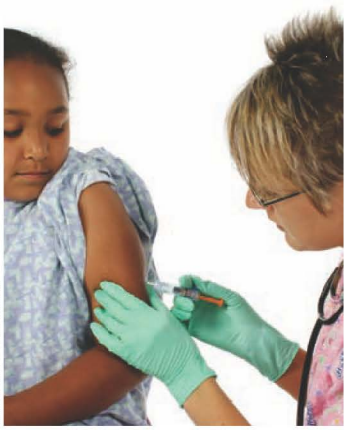
Key terms are **highlighted in bold** to alert you to new terms defined in the text.

What is chemistry? One dictionary gives this definition: "**Chemistry** is the science of the composition, structure, properties, and reactions of matter, especially of atomic and molecular systems." A somewhat simpler definition is "Chemistry is the science dealing with the composition of *matter* and the changes in composition that matter undergoes." Neither of these definitions is entirely adequate. Chemistry and physics form a fundamental branch of knowledge. Chemistry is also closely related to biology, not only because living organisms are made of material substances but also because life itself is essentially a complicated system of interrelated chemical processes.

The scope of chemistry is extremely broad. It includes the whole universe and everything, animate and inanimate, in it. Chemistry is concerned with the composition and changes in the composition of matter and also with the energy and energy changes associated with matter. Through chemistry we seek to learn and to understand the general principles that govern the behavior of all matter.

The chemist, like other scientists, observes nature and attempts to understand its secrets: What makes a tulip red? Why is sugar sweet? What is occurring when iron rusts? Why is carbon monoxide poisonous? Problems such as these—some of which have been solved, some of which are still to be solved—are all part of what we call chemistry.

A chemist may interpret natural phenomena, devise experiments that reveal the composition and structure of complex substances, study methods for improving natural processes, or synthesize substances. Ultimately, the efforts of successful chemists advance the frontiers of knowledge and at the same time contribute to the well-being of humanity.



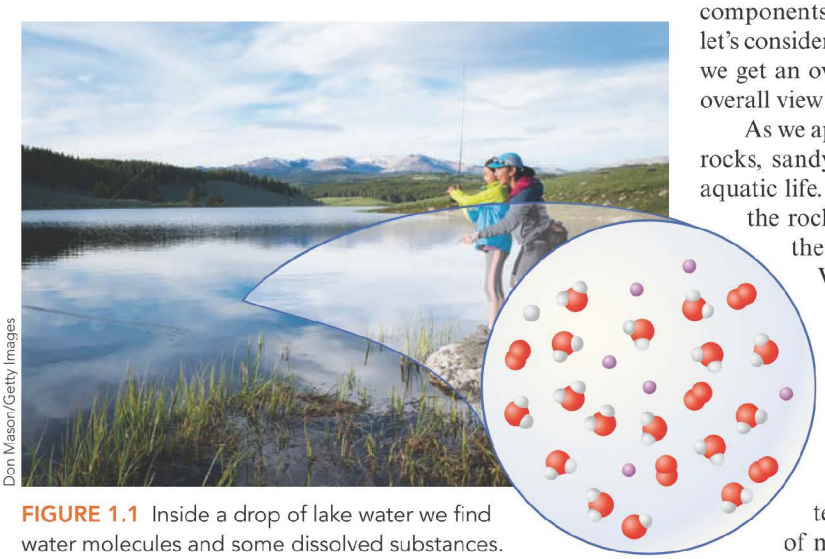
EM Arts/ Shutterstock

A health care professional needs to understand chemistry in order to administer the correct dose of medication.

Thinking Like a Chemist

Chemists take a special view of things in order to understand the nature of the chemical changes taking place. Chemists "look inside" everyday objects to see how the basic components are behaving. To understand this approach, let's consider a lake. When we view the lake from a distance, we get an overall picture of the water and shoreline. This overall view is called the *macroscopic* picture.

As we approach the lake we begin to see more details—rocks, sandy beach, plants submerged in the water, and aquatic life. We get more and more curious. What makes the rocks and sand? What kind of organisms live in the water? How do plants survive underwater? What lies hidden in the water? We can use a microscope to learn the answers to some of these questions. Within the water and the plants, we can see single cells and inside them organelles working to keep the organisms alive. For answers to other questions, we need to go even further inside the lake. A drop of lake water can itself become a mysterious and fascinating *microscopic* picture full of molecules and motion. (FIGURE 1.1) A chemist



Don Mason/Getty Images

FIGURE 1.1 Inside a drop of lake water we find water molecules and some dissolved substances.