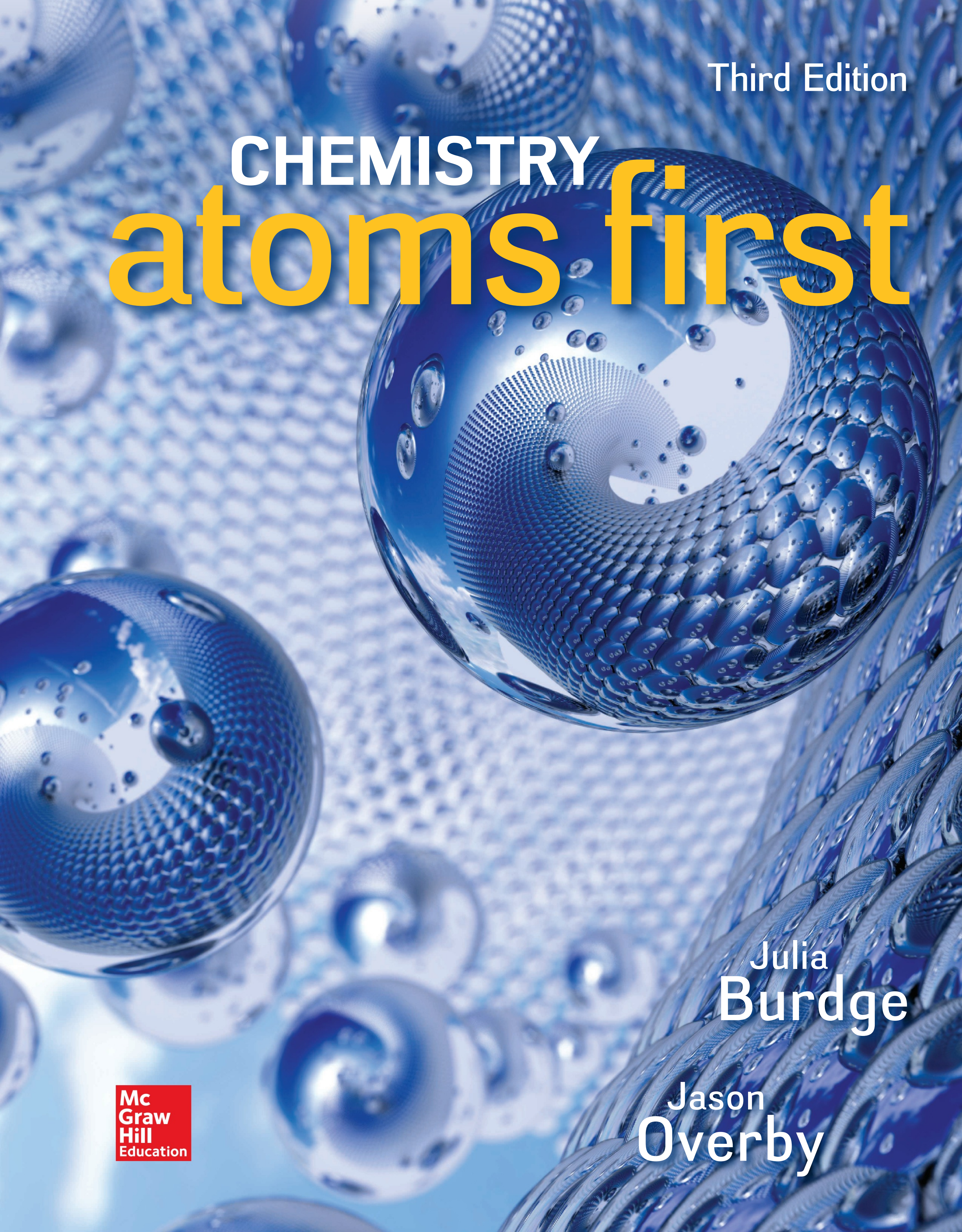
Third Edition

CHEMISTRY atoms first

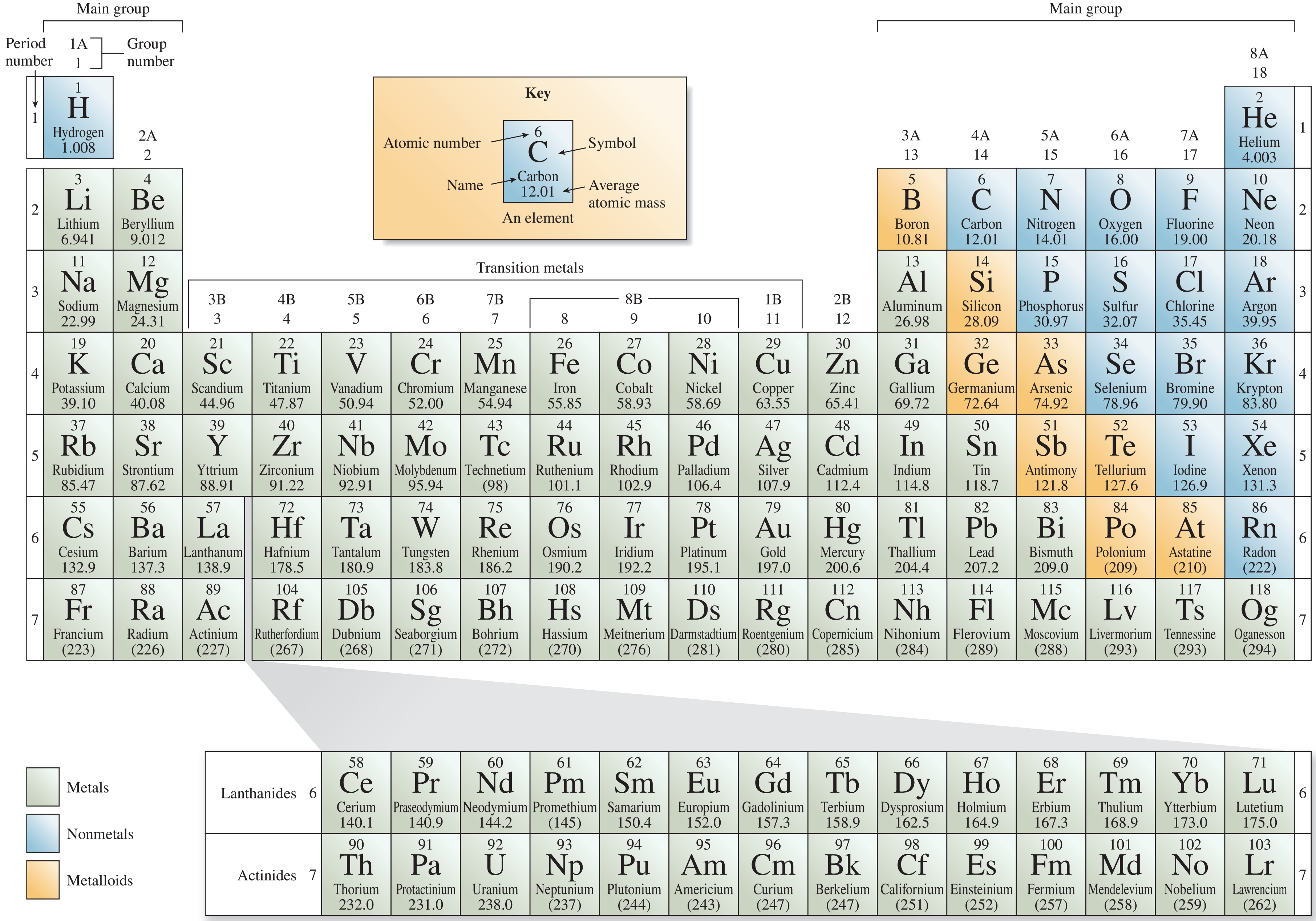


Julia Burdge

Jason Overby

McGraw Hill Education

Periodic Table of the Elements



Key

Atomic number → 6
Symbol → C
Name → Carbon
Average atomic mass → 12.01
An element

Main group | Transition metals | Main group

Period number	1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	1 H Hydrogen 1.008																	2 He Helium 4.003	1
2	3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18	2
3	11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95	3
4	19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.41	31 Ga Gallium 69.72	32 Ge Germanium 72.64	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80	4
5	37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3	5
6	55 Cs Cesium 132.9	56 Ba Barium 137.3	57 La Lanthanum 138.9	72 Hf Hafnium 178.5	73 Ta Tantalum 180.9	74 W Tungsten 183.8	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)	6
7	87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (267)	105 Db Dubnium (268)	106 Sg Seaborgium (271)	107 Bh Bohrium (272)	108 Hs Hassium (270)	109 Mt Meitnerium (276)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (280)	112 Cn Copernicium (285)	113 Nh Nihonium (284)	114 Fl Flerovium (289)	115 Mc Moscovium (288)	116 Lv Livermorium (293)	117 Ts Tennessine (293)	118 Og Oganesson (294)	7

Lanthanides 6	58 Ce Cerium 140.1	59 Pr Praseodymium 140.9	60 Nd Neodymium 144.2	61 Pm Promethium (145)	62 Sm Samarium 150.4	63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 175.0	6
Actinides 7	90 Th Thorium 232.0	91 Pa Protactinium 231.0	92 U Uranium 238.0	93 Np Neptunium (237)	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)	7

- 🟩 Metals
- 🟦 Nonmetals
- 🟧 Metalloids

At the time of this printing, the names of elements 113, 115, 117, and 118 had not yet been formally approved by the International Union of Pure and Applied Chemistry (IUPAC).

List of the Elements with Their Symbols and Atomic Masses[*]

Element	Symbol	Atomic Number	Atomic Mass[†]	Element	Symbol	Atomic Number	Atomic Mass[†]
Actinium	Ac	89	(227)	Mendelevium	Md	101	(258)
Aluminum	Al	13	26.9815386	Mercury	Hg	80	200.59
Americium	Am	95	(243)	Molybdenum	Mo	42	95.94
Antimony	Sb	51	121.760	Moscovium	Mc	115	(288)
Argon	Ar	18	39.948	Neodymium	Nd	60	144.242
Arsenic	As	33	74.92160	Neon	Ne	10	20.1797
Astatine	At	85	(210)	Neptunium	Np	93	(237)
Barium	Ba	56	137.327	Nickel	Ni	28	58.6934
Berkelium	Bk	97	(247)	Niobium	Nb	41	92.90638
Beryllium	Be	4	9.012182	Nihonium	Nh	113	(284)
Bismuth	Bi	83	208.98040	Nitrogen	N	7	14.0067
Bohrium	Bh	107	(272)	Nobelium	No	102	(259)
Boron	B	5	10.811	Oganesson	Og	118	(294)
Bromine	Br	35	79.904	Osmium	Os	76	190.23
Cadmium	Cd	48	112.411	Oxygen	O	8	15.9994
Calcium	Ca	20	40.078	Palladium	Pd	46	106.42
Californium	Cf	98	(251)	Phosphorus	P	15	30.973762
Carbon	C	6	12.0107	Platinum	Pt	78	195.084
Cerium	Ce	58	140.116	Plutonium	Pu	94	(244)
Cesium	Cs	55	132.9054519	Polonium	Po	84	(209)
Chlorine	Cl	17	35.453	Potassium	K	19	39.0983
Chromium	Cr	24	51.9961	Praseodymium	Pr	59	140.90765
Cobalt	Co	27	58.933195	Promethium	Pm	61	(145)
Copernicium	Cn	112	(285)	Protactinium	Pa	91	231.03588
Copper	Cu	29	63.546	Radium	Ra	88	(226)
Curium	Cm	96	(247)	Radon	Rn	86	(222)
Darmstadtium	Ds	110	(281)	Rhenium	Re	75	186.207
Dubnium	Db	105	(268)	Rhodium	Rh	45	102.90550
Dysprosium	Dy	66	162.500	Roentgenium	Rg	111	(280)
Einsteinium	Es	99	(252)	Rubidium	Rb	37	85.4678
Erbium	Er	68	167.259	Ruthenium	Ru	44	101.07
Europium	Eu	63	151.964	Rutherfordium	Rf	104	(267)
Fermium	Fm	100	(257)	Samarium	Sm	62	150.36
Flerovium	Fl	114	(289)	Scandium	Sc	21	44.955912
Fluorine	F	9	18.9984032	Seaborgium	Sg	106	(271)
Francium	Fr	87	(223)	Selenium	Se	34	78.96
Gadolinium	Gd	64	157.25	Silicon	Si	14	28.0855
Gallium	Ga	31	69.723	Silver	Ag	47	107.8682
Germanium	Ge	32	72.64	Sodium	Na	11	22.98976928
Gold	Au	79	196.966569	Strontium	Sr	38	87.62
Hafnium	Hf	72	178.49	Sulfur	S	16	32.065
Hassium	Hs	108	(270)	Tantalum	Ta	73	180.94788
Helium	He	2	4.002602	Technetium	Tc	43	(98)
Holmium	Ho	67	164.93032	Tellurium	Te	52	127.60
Hydrogen	H	1	1.00794	Tennessine	Ts	117	(293)
Indium	In	49	114.818	Terbium	Tb	65	158.92535
Iodine	I	53	126.90447	Thallium	Tl	81	204.3833
Iridium	Ir	77	192.217	Thorium	Th	90	232.03806
Iron	Fe	26	55.845	Thulium	Tm	69	168.93421
Krypton	Kr	36	83.798	Tin	Sn	50	118.710
Lanthanum	La	57	138.90547	Titanium	Ti	22	47.867
Lawrencium	Lr	103	(262)	Tungsten	W	74	183.84
Lead	Pb	82	207.2	Uranium	U	92	238.02891
Lithium	Li	3	6.941	Vanadium	V	23	50.9415
Livermorium	Lv	116	(293)	Xenon	Xe	54	131.293
Lutetium	Lu	71	174.967	Ytterbium	Yb	70	173.04
Magnesium	Mg	12	24.3050	Yttrium	Y	39	88.90585
Manganese	Mn	25	54.938045	Zinc	Zn	30	65.409
Meitnerium	Mt	109	(276)	Zirconium	Zr	40	91.224

---

[*] These atomic masses show as many significant figures as are known for each element. The atomic masses in the periodic table are shown to four significant figures, which is sufficient for solving the problems in this book.

[†] Approximate values of atomic masses for radioactive elements are given in parentheses.

At the time of this printing, the names of elements 113, 115, 117, and 118 had not yet been formally approved by the International Union of Pure and Applied Chemistry (IUPAC).

Chemistry

ATOMS FIRST

THIRD EDITION

Julia Burdge
COLLEGE OF WESTERN IDAHO

Jason Overby
COLLEGE OF CHARLESTON

Mc
Graw
Hill
Education

CHEMISTRY: ATOMS FIRST, THIRD EDITION

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LWI 21 20 19 18 17

ISBN 978-1-259-63813-8
MHID 1-259-63813-8

Chief Product Officer, SVP Products & Markets: *G. Scott Virkler*
Vice President, General Manager, Products & Markets: *Marty Lange*
Vice President, Content Design & Delivery: *Betsy Whalen*
Managing Director: *Thomas Timp*
Director: *David Spurgeon, Ph.D.*
Director, Product Development: *Rose Koos*
Director of Digital Content: *Robin Reed*
Digital Product Analyst: *Patrick Diller*
Marketing Manager: *Matthew Garcia*
Director of Digital Content: *Shirley Hino, Ph.D.*
Digital Product Developer: *Joan Weber*
Director, Content Design & Delivery: *Linda Avenarius*
Program Manager: *Lora Neyens*
Content Project Managers: *Sherry Kane/Rachael Hillebrand*
Buyer: *Laura M. Fuller*
Design: *David Hash*
Content Licensing Specialists: *Carrie Burger/Lorraine Buczek*
Cover Image: @XYZ/Shutterstock.com
Compositor: *Aptara, Inc.*
Printer: *LSC Communications*

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

Library of Congress Cataloging-in-Publication Data

Names: Burdge, Julia. | Overby, Jason, 1970-
Title: Chemistry : atoms first / Julia Burdge, College of Western Idaho,
  Jason Overby, College of Charleston.
Other titles: Atoms first
Description: Third edition. | New York, NY : McGraw-Hill Education, [2017] |
  Includes index.
Identifiers: LCCN 2016033779 | ISBN 9781259638138 (alk. paper) | ISBN
  1259638138 (alk. paper)
Subjects: LCSH: Chemistry—Textbooks.
Classification: LCC QD31.3 .B87 2017 | DDC 540—dc23 LC record available at https://lccn.loc.gov/2016033779

mheducation.com/highered

To the people who will always matter the most: Katie, Beau, and Sam.
Julia Burdge

To my wonderful wife, Robin, and daughters, Emma and Sarah.
Jason Overby

About the Authors

© McGraw-Hill Education

Julia Burdge received her Ph.D. (1994) from the University of Idaho in Moscow, Idaho. Her research and dissertation focused on instrument development for analysis of trace sulfur compounds in air and the statistical evaluation of data near the detection limit.

In 1994 she accepted a position at The University of Akron in Akron, Ohio, as an assistant professor and director of the Introductory Chemistry program. In the year 2000, she was tenured and promoted to associate professor at The University of Akron on the merits of her teaching, service, and research in chemistry education. In addition to directing the general chemistry program and supervising the teaching activities of graduate students, she helped establish a future-faculty development program and served as a mentor for graduate students and post-doctoral associates. Julia has recently relocated back to the northwest to be near family. She lives in Boise, Idaho; and she holds an affiliate faculty position as associate professor in the Chemistry Department at the University of Idaho and teaches general chemistry at the College of Western Idaho.

In her free time, Julia enjoys horseback riding, precious time with her three children, and quiet time at home with Erik Nelson, her partner and best friend.

© McGraw-Hill Education

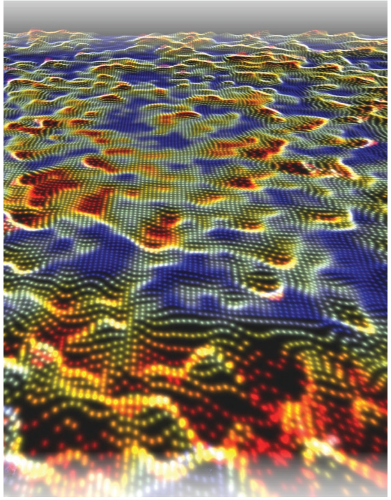
Jason Overby received his B.S. degree in chemistry and political science from the University of Tennessee at Martin. He then received his Ph.D. in inorganic chemistry from Vanderbilt University (1997) studying main group and transition metal metallocenes and related compounds. Afterwards, Jason conducted postdoctoral research in transition metal organometallic chemistry at Dartmouth College.

Jason began his academic career at the College of Charleston in 1999 as an assistant professor. Currently, he is an associate professor with teaching interests in general and inorganic chemistry. He is also interested in the integration of technology into the classroom, with a particular focus on adaptive learning. Additionally, he conducts research with undergraduates in inorganic and organic synthetic chemistry as well as computational organometallic chemistry.

In his free time, he enjoys boating, exercising, and cooking. He is also involved with USA Swimming as a nationally-certified starter and stroke-and-turn official. He lives in South Carolina with his wife Robin and two daughters, Emma and Sarah.

Brief Contents

Contents



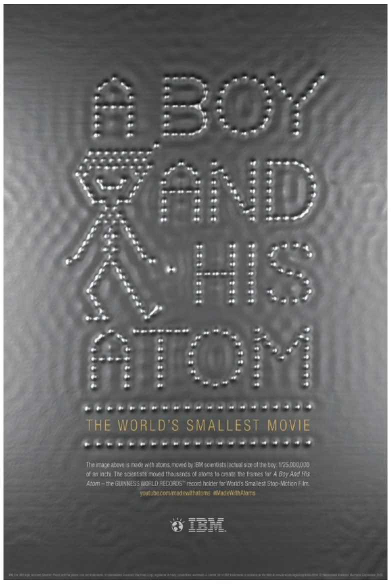
© Prof. Ali Yazdani/Princeton University

1 CHEMISTRY: THE SCIENCE OF CHANGE 2

© Science Photo Library/Science Source

2 ATOMS AND THE PERIODIC TABLE 38

3 QUANTUM THEORY AND THE ELECTRONIC STRUCTURE OF ATOMS 66



© 2013 International Business Machines Corporation

4 PERIODIC TRENDS OF THE ELEMENTS 124

© Dzhavakhadze Zurab Itar-Tass Photos/Newscom

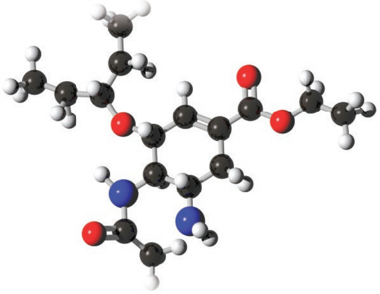
© BASF

5 IONIC AND COVALENT COMPOUNDS 162

© Brand X Pictures/PunchStock

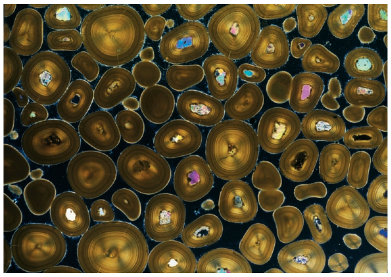
6 REPRESENTING MOLECULES 210

7 MOLECULAR GEOMETRY, INTERMOLECULAR FORCES, AND BONDING THEORIES 246


© Carol and Mike Werner/Science Source

8 CHEMICAL REACTIONS 308


© LWA/Photodisc/Getty Images



© Dirk Wiersma/Science Source

9 CHEMICAL REACTIONS IN AQUEOUS SOLUTIONS 350

© Syracuse Newspapers/J. Berry/The Image Works

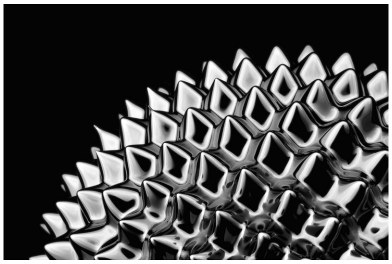
10 ENERGY CHANGES IN CHEMICAL REACTIONS 414

11 GASES 470

© Francisco Negroni/Alamy Stock Photo

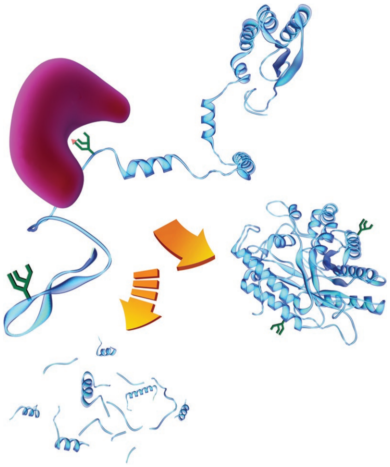
12 LIQUIDS AND SOLIDS 530

US Department of Energy/Science Source



© Shawn Knol/Getty Images

13 PHYSICAL PROPERTIES OF SOLUTIONS 574



© Kenneth Eward/Science Source

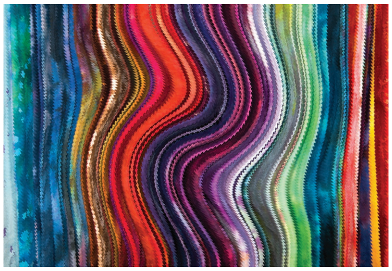
14 ENTROPY AND FREE ENERGY 618

© Richard Megna/Fundamental Photographs

15 CHEMICAL EQUILIBRIUM 654

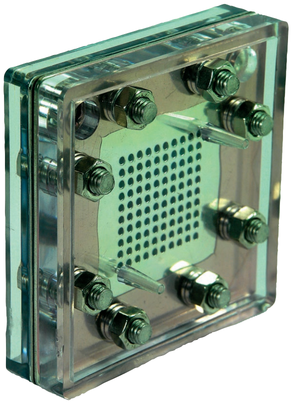
16 ACIDS, BASES, AND SALTS 716

© Purestock/Alamy Stock Photo



© Lisa Stokes/Moment Open/Getty Images

17 ACID-BASE EQUILIBRIA AND SOLUBILITY EQUILIBRIA 774



© Friedrich Saurer/Alamy Stock Photo

18 ELECTROCHEMISTRY 828

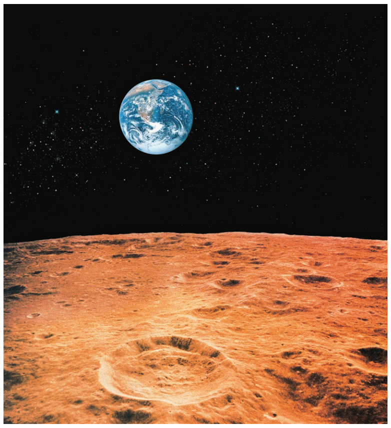
© Jonathan Nourok/Getty Images

19 CHEMICAL KINETICS 876

20 NUCLEAR CHEMISTRY 940

© Pallava Bagla/Corbis

21 ENVIRONMENTAL CHEMISTRY 974



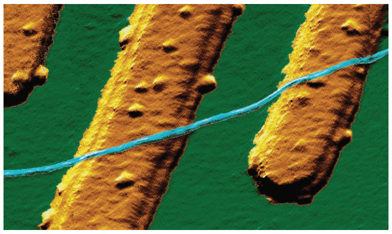
© Digital Vision/Getty Images

© Imaginechina via AP Images

22 COORDINATION CHEMISTRY 1002

© Digital Vision/Getty Images

23 ORGANIC CHEMISTRY 1026



© Delft University of Technology/Science Source

24 MODERN MATERIALS 1080

25 NONMETALLIC ELEMENTS AND THEIR COMPOUNDS (ONLINE ONLY)


© Craig Ruttle/AP Images

26 METALLURGY AND THE CHEMISTRY OF METALS (ONLINE ONLY)


© Javier Larrea/Getty Images

List of Applications

Thinking Outside the Box

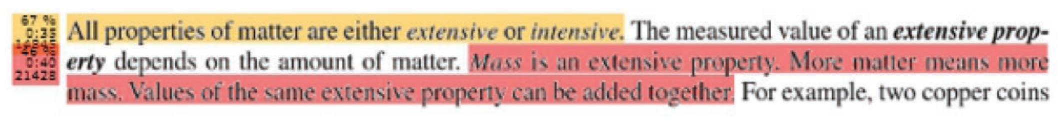
Key Skills

Preface

The third edition of *Atoms First* by Burdge and Overby continues to build on the innovative success of the first and second editions. Changes to this edition include specific refinements intended to augment the student-centered pedagogical features that continue to make this book effective and popular both with professors, and with their students.

NEW! Student Hot Spot and Student-Centered Refinements using Heat Maps

Using heat maps from the adaptive reading tool SmartBook®, and the detailed analysis of student performance it provides, we were able to target specific learning objectives for minor re-wording, further explanation, or better illustration. Because SmartBook is a dynamic learning tool, we have a multitude of live data that show us exactly where students have been struggling with content; and we have direct insight into student learning that may not always be evident through other assessment methods. The data, such as average time spent answering each question and the percentage of students who correctly answered the question on the first attempt, revealed the learning objectives that students found particularly difficult.



67 %
0:35
[illegible]
46 %
0:40
21428

All properties of matter are either *extensive* or *intensive*. The measured value of an ***extensive property*** depends on the amount of matter. *Mass* is an extensive property. More matter means more mass. Values of the same extensive property can be added together. For example, two copper coins

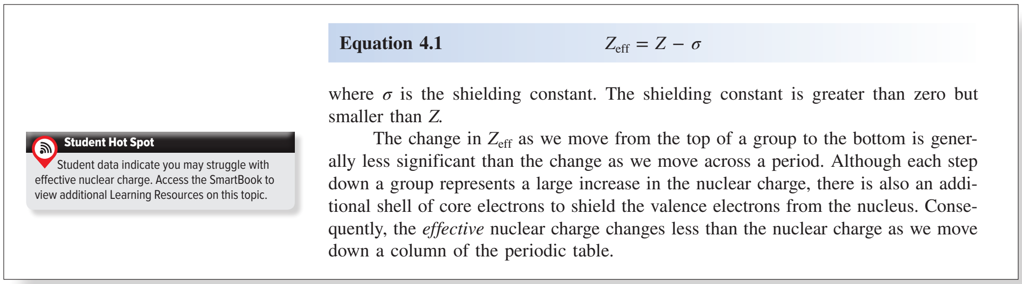
This has allowed our revisions to be truly student-centered. For example, given specific known topics where students are struggling, we are able to clarify concepts or provide visual interpretations such as the below figure.

	(a)	(b)	
Mass	25.0 g	50.0 g	Extensive properties: Measured values change with amount of water.
Volume	25.0 mL	50.0 mL	
Density	1.00 g/mL	1.00 g/mL	Intensive properties: Measured values do not change with amount of water.
Boiling point	100.0°C	100.0°C	
Freezing point	0.00°C	0.00°C	

Figure 1.12 Some extensive properties (mass and volume) and intensive properties (density, boiling point, and freezing point) of water. The measured values of the extensive properties depend on the amount of water. The measured values of the intensive properties are independent of the amount of water.

(Photos): © H.S. Photos/Alamy Stock Photo

Further, armed with this powerful insight into the places many students struggle with content, we are able to provide strategically-timed access to additional learning resources. In the text, we have identified areas of particularly difficult content as "Student Hot Spots"—and use them to direct students to a variety of learning resources specific to that content. Students will be able to access over 1,000 digital learning resources throughout this text's SmartBook. These learning resources present summaries of concepts and worked examples, including over 200 videos of chemistry faculty solving problems or modeling concepts which students can view over and over again.



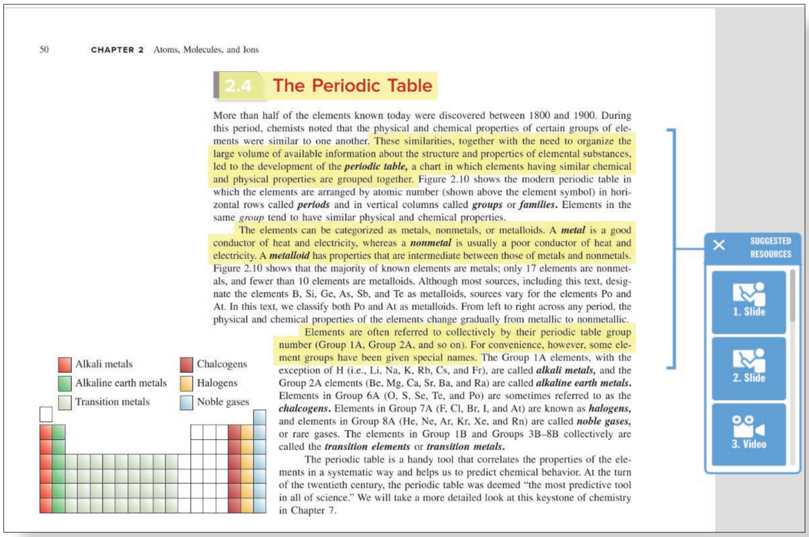
Student Hot Spot

Student data indicate you may struggle with effective nuclear charge. Access the SmartBook to view additional Learning Resources on this topic.

Equation 4.1 $Z_{\text{eff}} = Z - \sigma$

where σ is the shielding constant. The shielding constant is greater than zero but smaller than Z.

The change in Z_{eff} as we move from the top of a group to the bottom is generally less significant than the change as we move across a period. Although each step down a group represents a large increase in the nuclear charge, there is also an additional shell of core electrons to shield the valence electrons from the nucleus. Consequently, the *effective* nuclear charge changes less than the nuclear charge as we move down a column of the periodic table.



50 **CHAPTER 2** Atoms, Molecules, and Ions

2.4 The Periodic Table

More than half of the elements known today were discovered between 1800 and 1900. During this period, chemists noted that the physical and chemical properties of certain groups of elements were similar to one another. These similarities, together with the need to organize the large volume of available information about the structure and properties of elemental substances, led to the development of the ***periodic table,*** a chart in which elements having similar chemical and physical properties are grouped together. Figure 2.10 shows the modern periodic table in which the elements are arranged by atomic number (shown above the element symbol) in horizontal rows called ***periods*** and in vertical columns called ***groups*** or ***families.*** Elements in the same *group* tend to have similar physical and chemical properties.

The elements can be categorized as metals, nonmetals, or metalloids. A ***metal*** is a good conductor of heat and electricity, whereas a ***nonmetal*** is usually a poor conductor of heat and electricity. A ***metalloid*** has properties that are intermediate between those of metals and nonmetals. Figure 2.10 shows that the majority of known elements are metals; only 17 elements are nonmetals, and fewer than 10 elements are metalloids. Although most sources, including this text, designate the elements B, Si, Ge, As, Sb, and Te as metalloids, sources vary for the elements Po and At. In this text, we classify both Po and At as metalloids. From left to right across any period, the physical and chemical properties of the elements change gradually from metallic to nonmetallic.

Elements are often referred to collectively by their periodic table group number (Group 1A, Group 2A, and so on). For convenience, however, some element groups have been given special names. The Group 1A elements, with the exception of H (i.e., Li, Na, K, Rb, Cs, and Fr), are called ***alkali metals,*** and the Group 2A elements (Be, Mg, Ca, Sr, Ba, and Ra) are called ***alkaline earth metals.*** Elements in Group 6A (O, S, Se, Te, and Po) are sometimes referred to as the ***chalcogens.*** Elements in Group 7A (F, Cl, Br, I, and At) are known as ***halogens,*** and elements in Group 8A (He, Ne, Ar, Kr, Xe, and Rn) are called ***noble gases,*** or rare gases. The elements in Group 1B and Groups 3B–8B collectively are called the ***transition elements*** or ***transition metals.***

The periodic table is a handy tool that correlates the properties of the elements in a systematic way and helps us to predict chemical behavior. At the turn of the twentieth century, the periodic table was deemed "the most predictive tool in all of science." We will take a more detailed look at this keystone of chemistry in Chapter 7.

In the SmartBook version of the text, learning resources for these Student Hot Spots are embedded with the content for immediate access.

Guided by these direct student results of content understanding, we have edited the content in most of the chapters. Many of the changes are subtle, although some are more extensive. Our ability to employ live student-assessment data for revisions to address areas of common misunderstanding is unprecedented and has afforded us the opportunity to forever change how we provide the best possible learning materials to ensure that our students are optimally equipped to *engage* in chemistry.

Updated Pedagogy

At the suggestion of many users, we have changed the Section Review questions to multiple choice. This provides an inviting opportunity for self-assessment at the end of each section. Students report using these questions to determine whether or not they have mastered the necessary skills to proceed to the next section—and most consider the multiple-choice format to be especially user-friendly. In addition, over 125 of the end-of-chapter problems have been revised and/or updated to provide a refreshed set of practice opportunities.

Key Skills–Relocated!

Newly located immediately before the end-of-chapter problems, Key Skills pages are modules that provide a review of specific problem-solving techniques from that particular chapter. These are techniques the authors know are vital to success in later chapters. The Key Skills pages are designed to be easy for students to find touchstones to hone specific skills from earlier chapters—in the context of later chapters. The answers to the Key Skills Problems can be found in the Answer Appendix in the back of the book.

New and Updated Chapter Content

Chapter 1—To continue providing the best flow of atoms first content, we have reorganized Chapter 1, placing classification and properties of matter at the end of the chapter. The benefit of this change is two-fold: It puts all of the numerical introduction to measurement and units together at the beginning; and it makes the transition from Chapter 1 (concluding with matter) to Chapter 2 (atoms) a little more seamless. Additionally, we have expanded coverage of dimensional analysis especially concerning units raised to powers and added a new figure illustrating intensive and extensive properties.

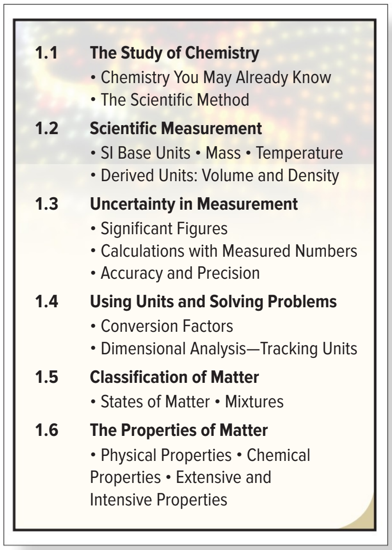
Chapter 3—Refreshed with a new introduction and opening image, our chapter on Quantum Theory and the Electronic Structure of Atoms has been updated for clarity in the introduction to energy and energy changes, discussion of the uncertainty principle, and the examination of electron configurations.

Chapter 6—We have refined discussion around several topics in the chapter on Representing Molecules, including multiple bonds, formal charge, and an introduction to resonance. Additionally, we've reordered the steps to building Lewis structures and reworked Worked Example 6.4 that demonstrates how to draw Lewis structures.

Chapter 12—We have included a new, atoms-first introduction to the packing of spheres in crystalline solids—providing a better foundation for understanding the origin of cubic packing in solid-state structures. Additional content has also been added to our section on phase changes.

Chapter 13—In this chapter, Physical Properties of Solutions, we've reworded sections 13.2 (A Molecular View of the Solution Process) and 13.3 (Concentration Units). We also have a new photo illustrating the Tyndall effect (Figure 13.13) as well as new computational end-of-chapter questions for section 13.3.

Chapter 15—In response to student data from SmartBook, we have made changes to some of the key figures in the introduction to equilibrium—improving the visual presentation in ways we believe will resonate with students. We've also updated the introduction to equilibrium constants & reaction quotients as well as the introduction to Le Châtelier's principle.



1.1 The Study of Chemistry
- Chemistry You May Already Know
- The Scientific Method

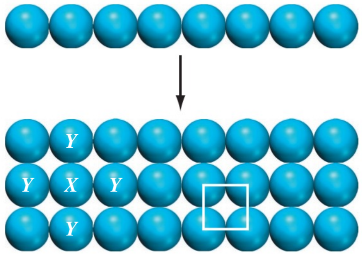
1.2 Scientific Measurement
- SI Base Units • Mass • Temperature
- Derived Units: Volume and Density

1.3 Uncertainty in Measurement
- Significant Figures
- Calculations with Measured Numbers
- Accuracy and Precision

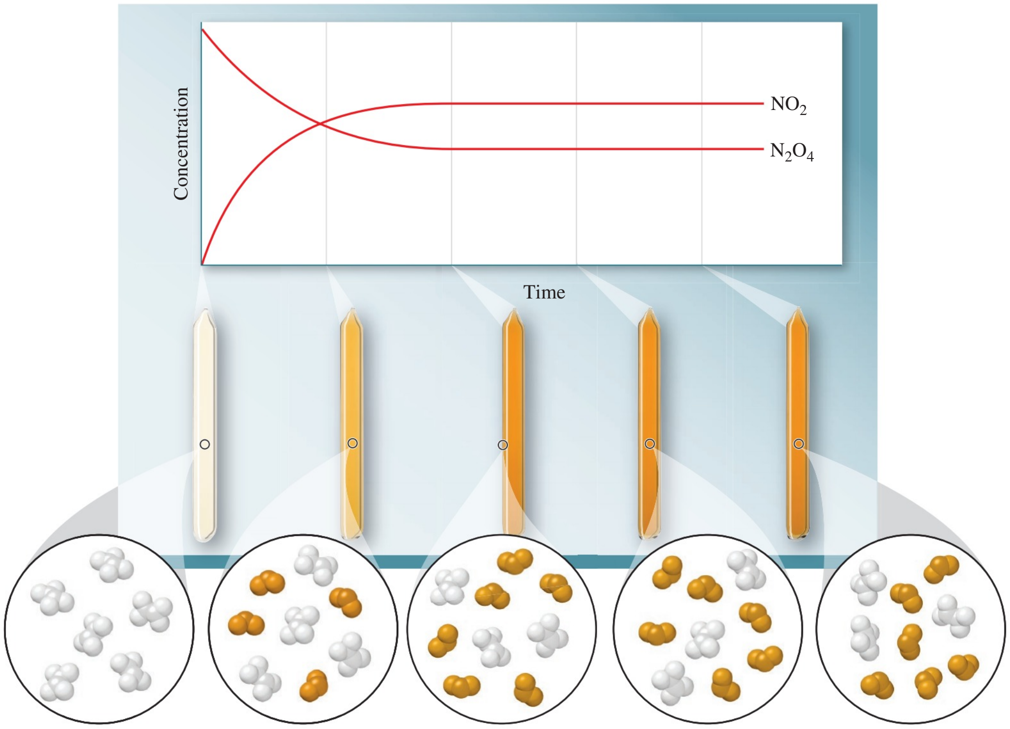
1.4 Using Units and Solving Problems
- Conversion Factors
- Dimensional Analysis—Tracking Units

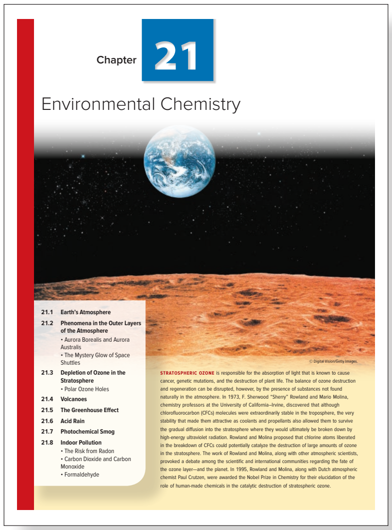
1.5 Classification of Matter
- States of Matter • Mixtures

1.6 The Properties of Matter
- Physical Properties • Chemical Properties • Extensive and Intensive Properties



square packing





Chapter 21

Environmental Chemistry

© Digital Vision/Getty Images.

STRATOSPHERIC OZONE is responsible for the absorption of light that is known to cause cancer, genetic mutations, and the destruction of plant life. The balance of ozone destruction and regeneration can be disrupted, however, by the presence of substances not found naturally in the atmosphere. In 1973, F. Sherwood "Sherry" Rowland and Mario Molina, chemistry professors at the University of California–Irvine, discovered that although chlorofluorocarbon (CFCs) molecules were extraordinarily stable in the troposphere, the very stability that made them attractive as coolants and propellants also allowed them to survive the gradual diffusion into the stratosphere where they would ultimately be broken down by high-energy ultraviolet radiation. Rowland and Molina proposed that chlorine atoms liberated in the breakdown of CFCs could potentially catalyze the destruction of large amounts of ozone in the stratosphere. The work of Rowland and Molina, along with other atmospheric scientists, provoked a debate among the scientific and international communities regarding the fate of the ozone layer—and the planet. In 1995, Rowland and Molina, along with Dutch atmospheric chemist Paul Crutzen, were awarded the Nobel Prize in Chemistry for their elucidation of the role of human-made chemicals in the catalytic destruction of stratospheric ozone.

Chapter 21—Based on numerous requests, we have added a new chapter on environmental chemistry, a timely and relevant subdiscipline of chemistry. The topics in this chapter have proven to be of interest to students and instructors alike.

Chapter 26—In response to feedback from professors and to accommodate the inclusion of a dedicated chapter on environmental chemistry, we have moved the chapter on metallurgy and the chemistry of the metals to the online material. Therefore, what was Chapter 21 in the second edition has been renumbered Chapter 26, Metallurgy and the Chemistry of Metals. Both Chapter 25 (Nonmetallic Elements and Their Compounds) and Chapter 26 are available as a free digital download via the Instructor Resources in Connect and for text customization in McGraw-Hill Create.

The Construction of a Learning System

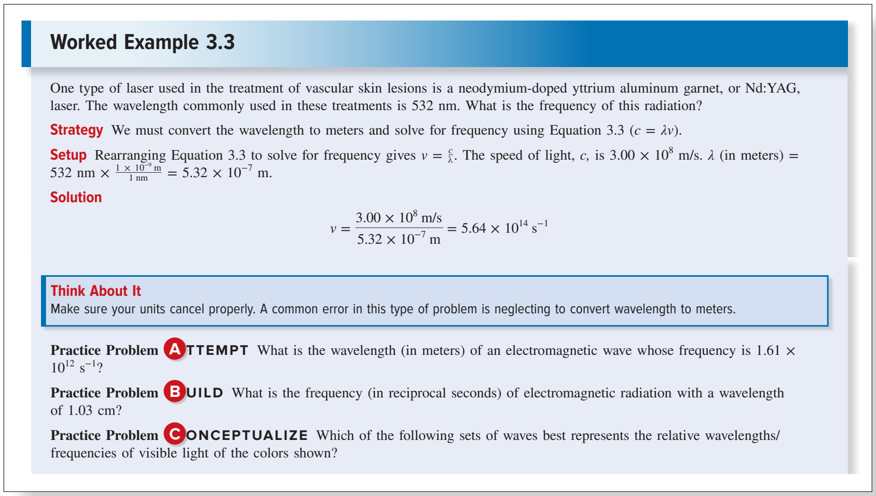
Writing a textbook and its supporting learning tools is a multifaceted process. McGraw-Hill's 360° Development Process is an ongoing, market-oriented approach to building accurate and innovative learning systems. It is dedicated to continual large scale and incremental improvement, driven by multiple customer feedback loops and checkpoints.

This is initiated during the early planning stages of new products and intensifies during the development and production stages. The 360° Development Process then begins again upon publication, in anticipation of the next version of each print and digital product. This process is designed to provide a broad, comprehensive spectrum of feedback for refinement and innovation of learning tools for both student and instructor. The 360° Development Process includes market research, content reviews, faculty and student focus groups, course- and product-specific symposia, accuracy checks, and art reviews, all guided by carefully selected Content Advisors.

The Learning System Used in *Chemistry: Atoms First*

Building Problem-Solving Skills. The entirety of the text emphasizes the importance of problem solving as a crucial element in the study of chemistry. Beginning with Chapter 1, a basic guide fosters a consistent approach to solving problems throughout the text. Each **Worked Example** is divided into four consistently applied steps: *Strategy* lays the basic framework for the problem; *Setup* gathers the necessary information for solving the problem; *Solution* takes us through the steps and calculations; *Think About It* makes us consider the feasibility of the answer or information illustrating the relevance of the problem.

After working through this problem-solving approach in the Worked Examples, there are three Practice Problems for students to solve. *Practice Problem A* (Attempt) is always very similar to the Worked Example and can be solved using the same strategy and approach.



Worked Example 3.3

One type of laser used in the treatment of vascular skin lesions is a neodymium-doped yttrium aluminum garnet, or Nd:YAG, laser. The wavelength commonly used in these treatments is 532 nm. What is the frequency of this radiation?

Strategy We must convert the wavelength to meters and solve for frequency using Equation 3.3 ($c = \lambda\nu$).

Setup Rearranging Equation 3.3 to solve for frequency gives $\nu = \frac{c}{\lambda}$. The speed of light, c, is 3.00×10^8 m/s. λ (in meters) = 532 nm $\times \frac{1 \times 10^{-9}\text{ m}}{1\text{ nm}} = 5.32 \times 10^{-7}$ m.

Solution

$$\nu = \frac{3.00 \times 10^8\text{ m/s}}{5.32 \times 10^{-7}\text{ m}} = 5.64 \times 10^{14}\text{ s}^{-1}$$

Think About It
Make sure your units cancel properly. A common error in this type of problem is neglecting to convert wavelength to meters.

Practice Problem Ⓐ**TTEMPT** What is the wavelength (in meters) of an electromagnetic wave whose frequency is 1.61×10^{12} s^{-1}?

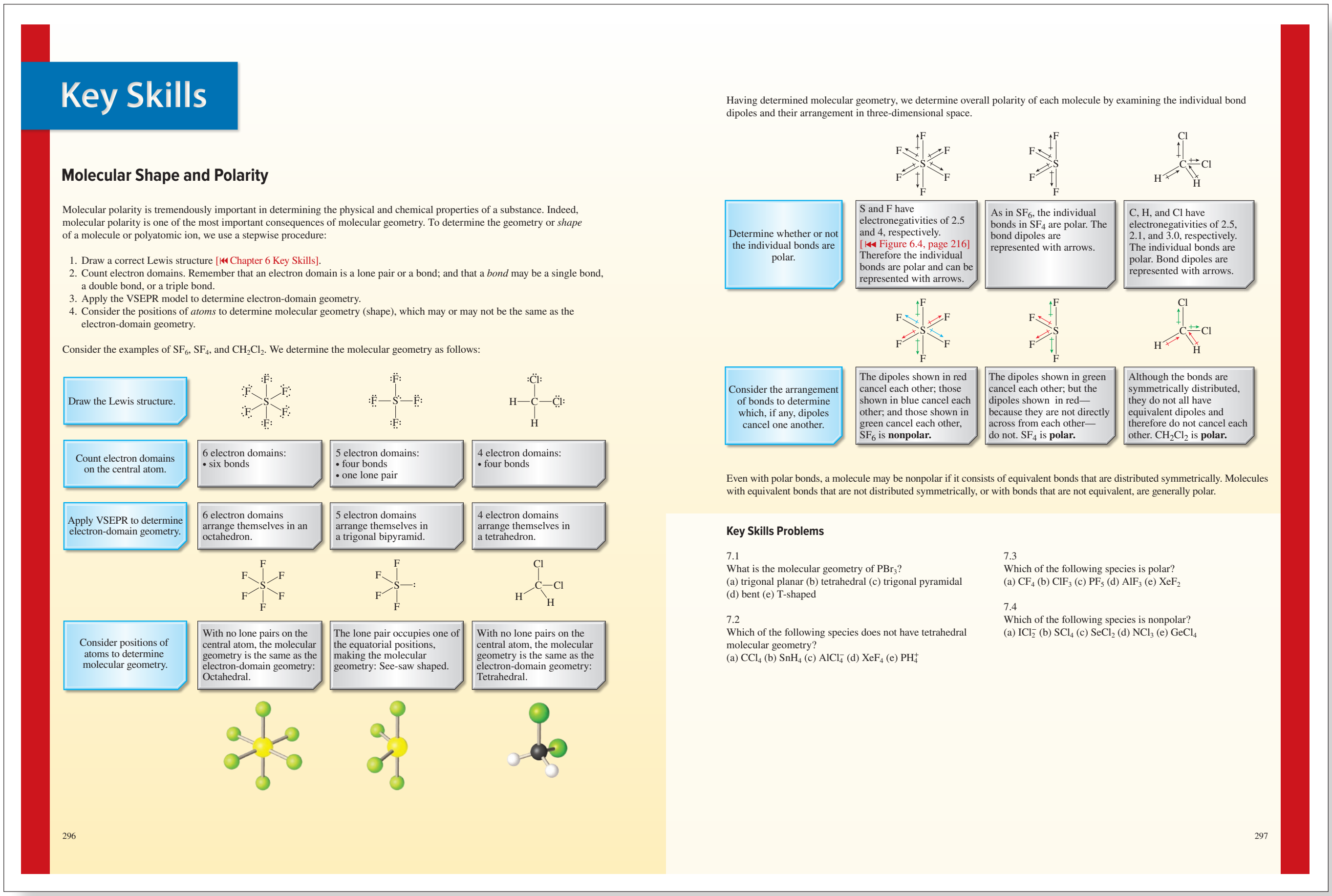
Practice Problem Ⓑ**UILD** What is the frequency (in reciprocal seconds) of electromagnetic radiation with a wavelength of 1.03 cm?

Practice Problem Ⓒ**ONCEPTUALIZE** Which of the following sets of waves best represents the relative wavelengths/frequencies of visible light of the colors shown?

Although *Practice Problem B* (Build) probes comprehension of the same concept as Practice Problem A, it generally is sufficiently different in that it cannot be solved using the exact approach used in the Worked Example. Practice Problem B takes problem solving to another level by requiring students to develop a strategy independently. *Practice Problem C* (Conceptualize) provides an exercise that further probes the student's conceptual understanding of the material and many employ concept and molecular art. The regular use of the Worked Example and Practice Problems in this text will help students develop a robust and versatile set of problem-solving skills.

Section Review. Every section of the book that contains Worked Examples and Practice Problems ends with a Section Review. The Section Review enables the student to evaluate whether they understand the concepts presented in the section.

Key Skills. Newly located immediately before end-of-chapter problems, Key Skills are easy to find review modules where students can return to refresh and hone specific skills that the authors know are vital to success in later chapters. The answers to the Key Skills can be found in the Answer Appendix in the back of the book.



Key Skills

Molecular Shape and Polarity

Molecular polarity is tremendously important in determining the physical and chemical properties of a substance. Indeed, molecular polarity is one of the most important consequences of molecular geometry. To determine the geometry or *shape* of a molecule or polyatomic ion, we use a stepwise procedure:

1. Draw a correct Lewis structure [⏮ Chapter 6 Key Skills].
2. Count electron domains. Remember that an electron domain is a lone pair or a bond; and that a *bond* may be a single bond, a double bond, or a triple bond.
3. Apply the VSEPR model to determine electron-domain geometry.
4. Consider the positions of *atoms* to determine molecular geometry (shape), which may or may not be the same as the electron-domain geometry.

Consider the examples of SF_6, SF_4, and CH_2Cl_2. We determine the molecular geometry as follows:

Draw the Lewis structure.			
Count electron domains on the central atom.	6 electron domains: • six bonds	5 electron domains: • four bonds • one lone pair	4 electron domains: • four bonds
Apply VSEPR to determine electron-domain geometry.	6 electron domains arrange themselves in an octahedron.	5 electron domains arrange themselves in a trigonal bipyramid.	4 electron domains arrange themselves in a tetrahedron.
Consider positions of atoms to determine molecular geometry.	With no lone pairs on the central atom, the molecular geometry is the same as the electron-domain geometry: Octahedral.	The lone pair occupies one of the equatorial positions, making the molecular geometry: See-saw shaped.	With no lone pairs on the central atom, the molecular geometry is the same as the electron-domain geometry: Tetrahedral.

296

Having determined molecular geometry, we determine overall polarity of each molecule by examining the individual bond dipoles and their arrangement in three-dimensional space.

Determine whether or not the individual bonds are polar.	S and F have electronegativities of 2.5 and 4, respectively. [⏮ Figure 6.4, page 216] Therefore the individual bonds are polar and can be represented with arrows.	As in SF_6, the individual bonds in SF_4 are polar. The bond dipoles are represented with arrows.	C, H, and Cl have electronegativities of 2.5, 2.1, and 3.0, respectively. The individual bonds are polar. Bond dipoles are represented with arrows.
Consider the arrangement of bonds to determine which, if any, dipoles cancel one another.	The dipoles shown in red cancel each other; those shown in blue cancel each other; and those shown in green cancel each other, SF_6 is **nonpolar.**	The dipoles shown in green cancel each other; but the dipoles shown in red—because they are not directly across from each other—do not. SF_4 is **polar.**	Although the bonds are symmetrically distributed, they do not all have equivalent dipoles and therefore do not cancel each other. CH_2Cl_2 is **polar.**

Even with polar bonds, a molecule may be nonpolar if it consists of equivalent bonds that are distributed symmetrically. Molecules with equivalent bonds that are not distributed symmetrically, or with bonds that are not equivalent, are generally polar.

Key Skills Problems

7.1
What is the molecular geometry of PBr_3?
(a) trigonal planar (b) tetrahedral (c) trigonal pyramidal
(d) bent (e) T-shaped

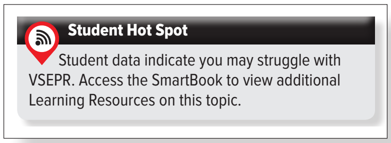
7.2
Which of the following species does not have tetrahedral molecular geometry?
(a) CCl_4 (b) SnH_4 (c) $AlCl_4^-$ (d) XeF_4 (e) PH_4^+

7.3
Which of the following species is polar?
(a) CF_4 (b) ClF_3 (c) PF_5 (d) AlF_3 (e) XeF_2

7.4
Which of the following species is nonpolar?
(a) ICl_2^- (b) SCl_4 (c) $SeCl_2$ (d) NCl_3 (e) $GeCl_4$

297

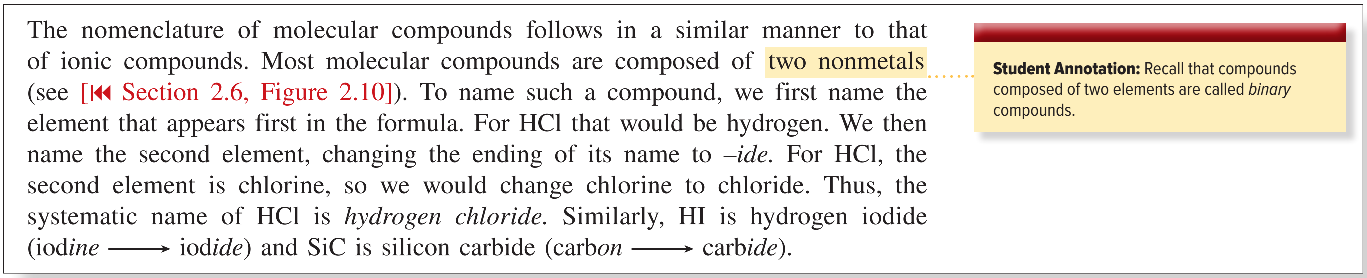
Student Hot Spots. In the text, we have identified areas of particularly difficult content as "Student Hot Spots"—and use them to direct students to a variety of learning resources specific to that content. Students will be able to access over 1,000 digital learning resources throughout this text's SmartBook. These learning resources present summaries of concepts and worked examples, including over 200 videos of chemistry faculty solving problems or modeling concepts which students can view over and over again.



Student Hot Spot

Student data indicate you may struggle with VSEPR. Access the SmartBook to view additional Learning Resources on this topic.

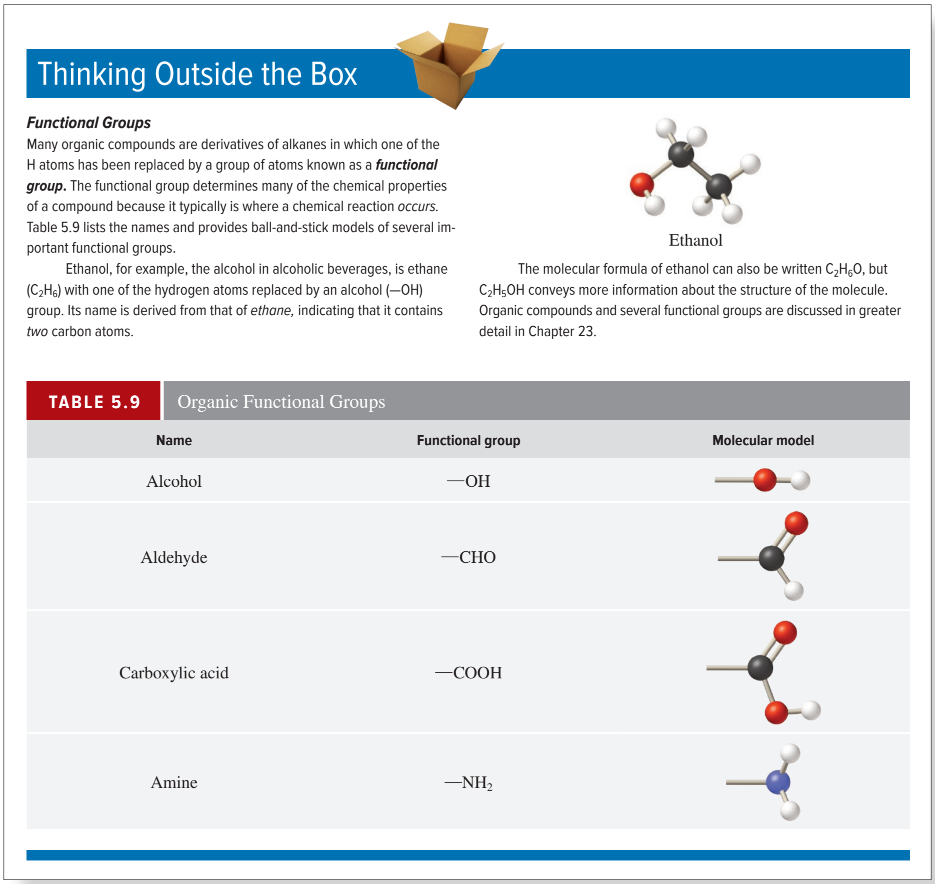
Applications. Each chapter offers a variety of tools designed to help facilitate learning. *Student Annotations* provide helpful hints and simple suggestions to the student.



The nomenclature of molecular compounds follows in a similar manner to that of ionic compounds. Most molecular compounds are composed of two nonmetals (see [⏮ Section 2.6, Figure 2.10]). To name such a compound, we first name the element that appears first in the formula. For HCl that would be hydrogen. We then name the second element, changing the ending of its name to *–ide*. For HCl, the second element is chlorine, so we would change chlorine to chloride. Thus, the systematic name of HCl is *hydrogen chloride*. Similarly, HI is hydrogen iodide (iod*ine* ⟶ iod*ide*) and SiC is silicon carbide (carb*on* ⟶ carb*ide*).

Student Annotation: Recall that compounds composed of two elements are called *binary* compounds.

Thinking Outside the Box is an application providing a more in-depth look into a specific topic. *Learning Outcomes* provide a brief overview of the concepts the student should understand after reading the chapter. It's an opportunity to review areas that the student does not feel confident about upon reflection.



Thinking Outside the Box

Functional Groups

Many organic compounds are derivatives of alkanes in which one of the H atoms has been replaced by a group of atoms known as a ***functional group.*** The functional group determines many of the chemical properties of a compound because it typically is where a chemical reaction *occurs.* Table 5.9 lists the names and provides ball-and-stick models of several important functional groups.

Ethanol, for example, the alcohol in alcoholic beverages, is ethane (C_2H_6) with one of the hydrogen atoms replaced by an alcohol (—OH) group. Its name is derived from that of *ethane,* indicating that it contains *two* carbon atoms.

Ethanol

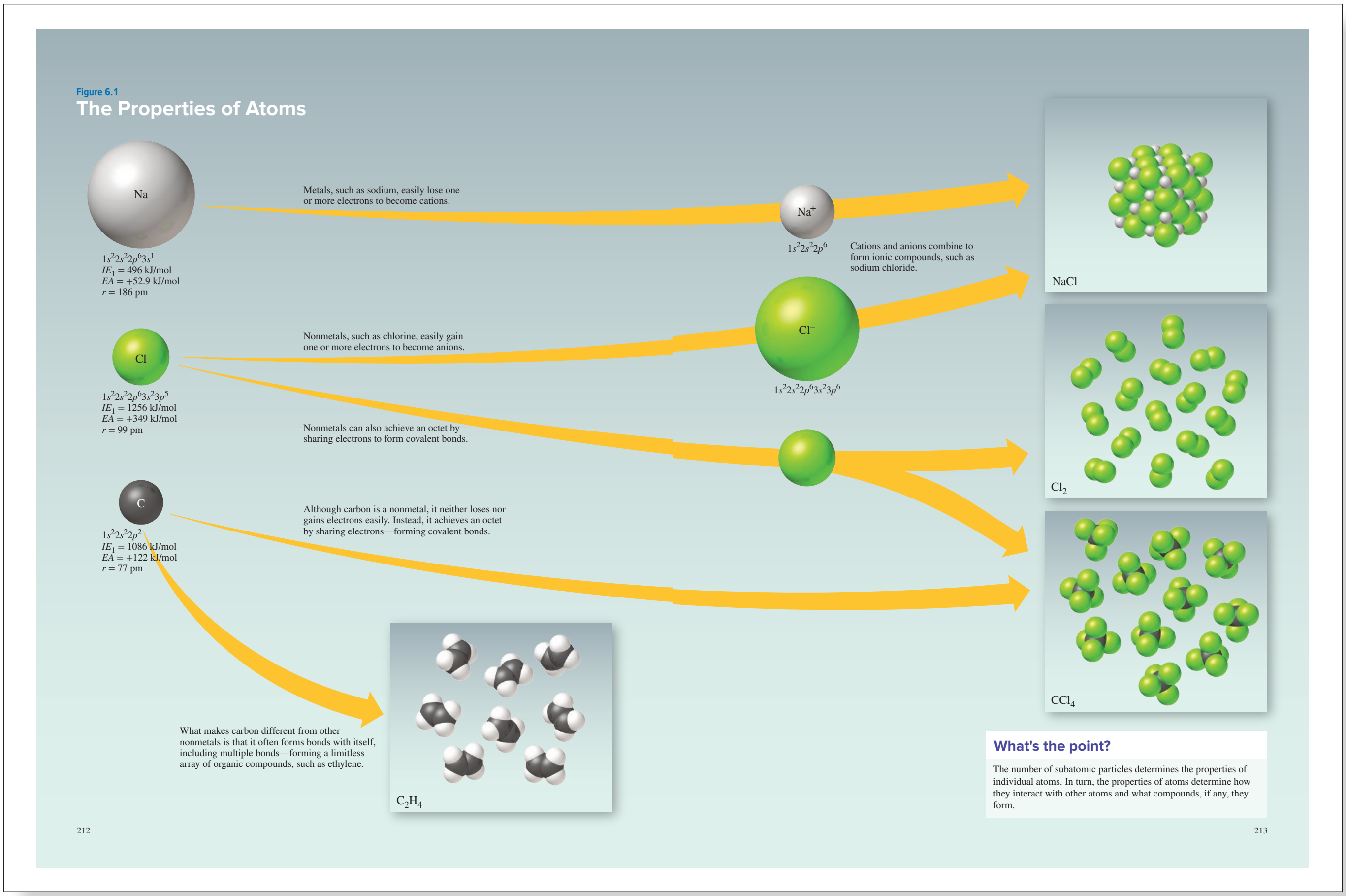
The molecular formula of ethanol can also be written C_2H_6O, but C_2H_5OH conveys more information about the structure of the molecule. Organic compounds and several functional groups are discussed in greater detail in Chapter 23.

TABLE 5.9 Organic Functional Groups

Name	Functional group	Molecular model
Alcohol	—OH	
Aldehyde	—CHO	
Carboxylic acid	—COOH	
Amine	$—NH_2$	

Visualization. This text seeks to enhance student understanding through a variety of both unique and conventional visual techniques. A truly unique element in this text is the inclusion of a distinctive feature entitled **Visualizing Chemistry.** These two-page spreads appear as needed to emphasize fundamental, vitally important principles of chemistry. Setting them apart visually makes them easier to find and revisit as needed throughout the course term. Each Visualizing Chemistry feature concludes with a "What's the Point?" box that emphasizes the correct take-away message.

There is a series of conceptual end-of-chapter problems for each Visualizing Chemistry piece. The answers to the Visualizing Chemistry problems, Key Skills problems, and all odd-numbered end of chapter Problems can be found in the Answer Appendix at the end of the text.



$1s^22s^22p^63s^1$
IE_1 = 496 kJ/mol
EA = +52.9 kJ/mol
r = 186 pm

$1s^22s^22p^63s^23p^5$
IE_1 = 1256 kJ/mol
EA = +349 kJ/mol
r = 99 pm

$1s^22s^22p^2$
IE_1 = 1086 kJ/mol
EA = +122 kJ/mol
r = 77 pm

$1s^22s^22p^6$

$1s^22s^22p^63s^23p^6$

Metals, such as sodium, easily lose one or more electrons to become cations.

Nonmetals, such as chlorine, easily gain one or more electrons to become anions.

Nonmetals can also achieve an octet by sharing electrons to form covalent bonds.

Although carbon is a nonmetal, it neither loses nor gains electrons easily. Instead, it achieves an octet by sharing electrons—forming covalent bonds.

Cations and anions combine to form ionic compounds, such as sodium chloride.

What makes carbon different from other nonmetals is that it often forms bonds with itself, including multiple bonds—forming a limitless array of organic compounds, such as ethylene.

What's the point?

The number of subatomic particles determines the properties of individual atoms. In turn, the properties of atoms determine how they interact with other atoms and what compounds, if any, they form.

Flow Charts and a variety of inter-textual materials such as *Rewind* and *Fast Forward Buttons* and *Section Review* are meant to enhance student understanding and comprehension by reinforcing current concepts and connecting new concepts to those covered in other parts of the text.

Media. Many Visualizing Chemistry pieces have been made into captivating and pedagogically-effective *animations* for additional reinforcement of subject matter first encountered in the textbook. Each Visualizing Chemistry animation is noted by an icon.

Video 7.8
Chemical bonding—formation of molecular orbitals.

Integration of Electronic Homework. You will find the *electronic homework* integrated into the text in numerous places. All Practice Problem B's are available in our electronic homework program for practice or assignments. A large number of the end-of-chapter problems are in the electronic homework system ready to assign to students.

For us, this text will always remain a work in progress. We encourage you to contact us with any comments or questions.

Julia Burdge
juliaburdge@hotmail.com

Jason Overby
overbyj@cofc.edu

connect

Required=Results


©Getty Images/iStockphoto

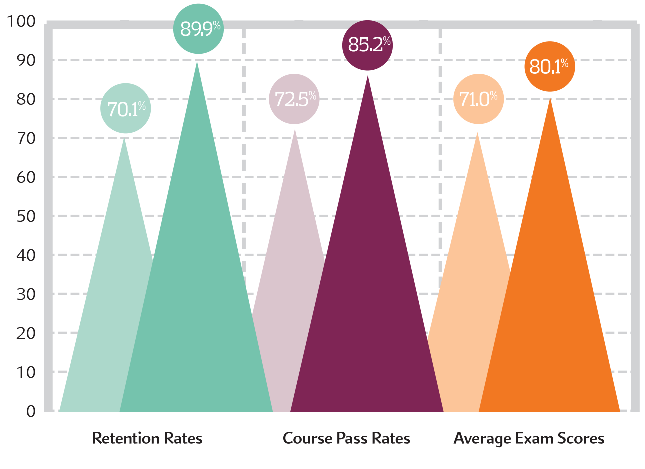
McGraw-Hill Connect®
Learn Without Limits

Connect is a teaching and learning platform that is proven to deliver better results for students and instructors.

Connect empowers students by continually adapting to deliver precisely what they need, when they need it, and how they need it, so your class time is more engaging and effective.

> 73% of instructors who use **Connect** require it; instructor satisfaction **increases** by 28% when **Connect** is required.

Connect's Impact on Retention Rates, Pass Rates, and Average Exam Scores



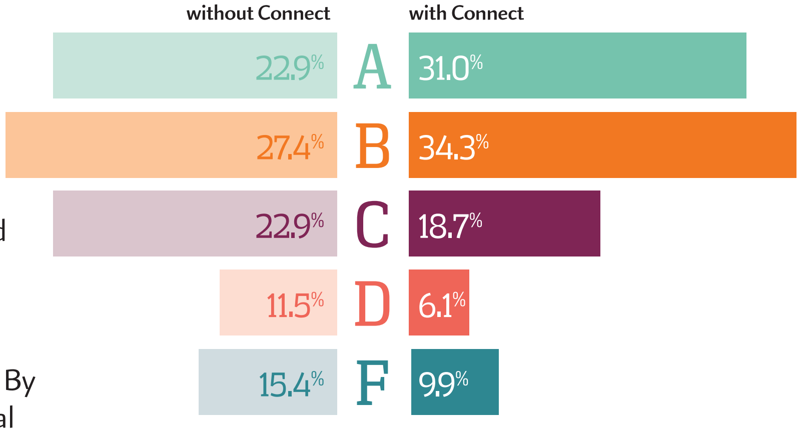
Using **Connect** improves passing rates by **12.7%** and retention by **19.8%.**

Analytics

Connect Insight®

Connect Insight is Connect's new one-of-a-kind visual analytics dashboard—now available for both instructors and students—that provides at-a-glance information regarding student performance, which is immediately actionable. By presenting assignment, assessment, and topical performance results together with a time metric that is easily visible for aggregate or individual results, Connect Insight gives the user the ability to take a just-in-time approach to teaching and learning, which was never before available. Connect Insight presents data that empowers students and helps instructors improve class performance in a way that is efficient and effective.

Impact on Final Course Grade Distribution



> Students can view their results for any **Connect** course.

Adaptive

©Getty Images/iStockphoto

THE **ADAPTIVE READING EXPERIENCE** DESIGNED TO TRANSFORM THE WAY STUDENTS READ

> More students earn **A's** and **B's** when they use McGraw-Hill Education **Adaptive** products.

SmartBook®

Proven to help students improve grades and study more efficiently, SmartBook contains the same content within the print book, but actively tailors that content to the needs of the individual. SmartBook's adaptive technology provides precise, personalized instruction on what the student should do next, guiding the student to master and remember key concepts, targeting gaps in knowledge and offering customized feedback, and driving the student toward comprehension and retention of the subject matter. Available on smartphones and tablets, SmartBook puts learning at the student's fingertips—anywhere, anytime.

> Over **5.7 billion questions** have been answered, making McGraw-Hill Education products more intelligent, reliable, and precise.

www.mheducation.com

STUDENTS WANT

SMARTBOOK®

95% of students reported **SmartBook** to be a more effective way of reading material

100% of students want to use the Practice Quiz feature available within **SmartBook** to help them study

100% of students reported having reliable access to off-campus wifi

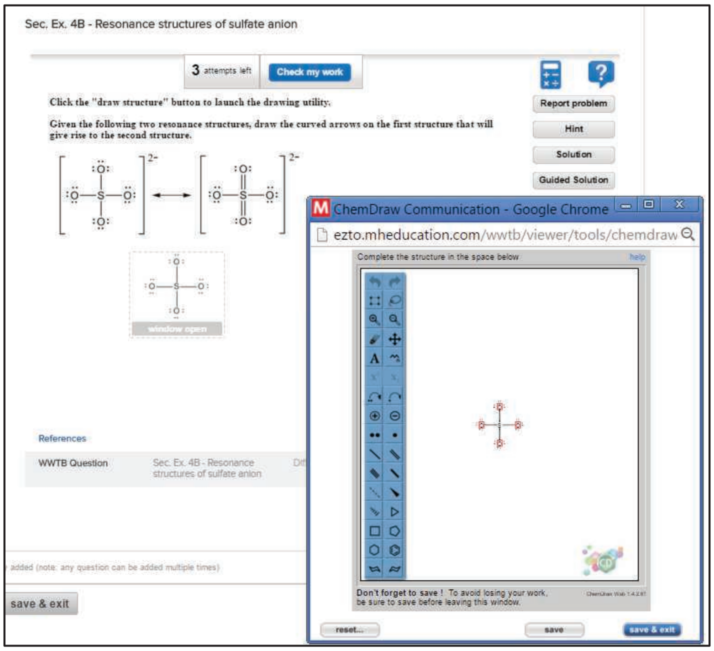
90% of students say they would purchase **SmartBook** over print alone

95% reported that **SmartBook** would impact their study skills in a positive way

*Findings based on a 2015 focus group survey at Pellissippi State Community College administered by McGraw-Hill Education

Instructor and Student Resources

A robust set of questions, problems, and interactive figures are presented and aligned with the textbook's learning goals. The integration of **ChemDraw by PerkinElmer,** the industry standard in chemical drawing software, allows students to create accurate chemical structures in their online homework assignments. As an instructor, you can edit existing questions and write entirely new problems. Track individual student performance—by question, assignment, or in relation to the class overall—with detailed grade reports. Integrate grade reports easily with Learning Management Systems (LMS), such as WebCT and Blackboard—and much more. Also available within Connect, our adaptive SmartBook has been supplemented with additional learning resources tied to each learning objective to provide point-in-time help to students who need it. To learn more, visit www.mheducation.com.



Sec. Ex. 4B - Resonance structures of sulfate anion

Click the "draw structure" button to launch the drawing utility.

Given the following two resonance structures, draw the curved arrows on the first structure that will give rise to the second structure.

Complete the structure in the space below

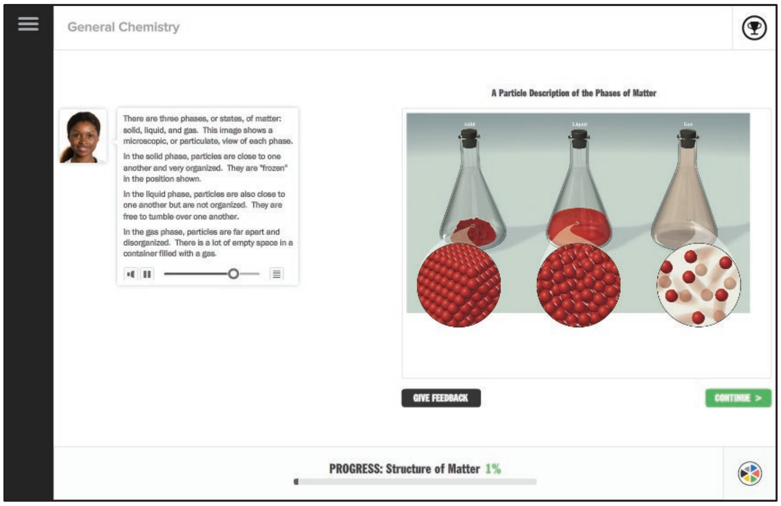
Don't forget to save ! To avoid losing your work, be sure to save before leaving this window.

added (note: any question can be added multiple times)

Instructors have access to the following instructor resources through Connect.

- **Art** Full-color digital files of all illustrations, photos, and tables in the book can be readily incorporated into lecture presentations, exams, or custom-made classroom materials. In addition, all files have been inserted into PowerPoint slides for ease of lecture preparation.
- **Animations** Numerous full-color animations illustrating important processes are also provided. Harness the visual impact of concepts in motion by importing these files into classroom presentations or online course materials.
- **PowerPoint Lecture Outlines** Ready-made presentations that combine art and lecture notes are provided for each chapter of the text.
- **Computerized Test Bank** Over 3,000 test questions that accompany *Chemistry: Atoms First* are available utilizing the industry-leading test generation software TestGen. These same questions are also available and assignable through Connect for online tests.
- **Instructor's Solutions Manual** This supplement contains complete, worked-out solutions for the Practice Problem C questions, Key Skills questions, and *all* the end-of-chapter problems in the text.

Fueled by LearnSmart—the most widely used and intelligent adaptive learning resource—**LearnSmart Prep** is designed to get students ready for a forthcoming course by quickly and effectively addressing prerequisite knowledge gaps that may cause problems down the road. By distinguishing what students know from what they don't, and honing in on concepts they are most likely to forget, LearnSmart Prep maintains a continuously adapting learning path individualized for each student, and tailors content to focus on what the student needs to master in order to have a successful start in the new class.



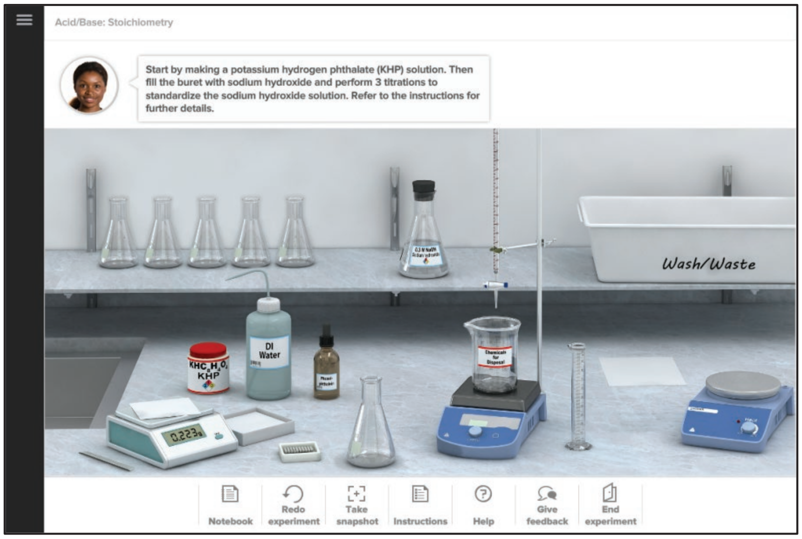
There are three phases, or states, of matter: solid, liquid, and gas. This image shows a microscopic, or particulate, view of each phase.

In the solid phase, particles are close to one another and very organized. They are "frozen" in the position shown.

In the liquid phase, particles are also close to one another but are not organized. They are free to tumble over one another.

In the gas phase, particles are far apart and disorganized. There is a lot of empty space in a container filled with a gas.

Based on the same world-class, superbly adaptive technology as LearnSmart, **McGraw-Hill LearnSmart Labs** is a must-see, outcomes-based lab simulation. It assesses a student's knowledge and adaptively corrects deficiencies, allowing the student to learn faster and retain more knowledge with greater success. First, a student's knowledge is adaptively leveled on core learning outcomes: Questioning reveals knowledge deficiencies that are corrected by the delivery of content that is conditional on a student's response. Then, a simulated lab experience requires the student to think and act like a scientist: Recording, interpreting, and analyzing data using simulated equipment found in labs and clinics. The student is allowed to make mistakes—a powerful part of the learning experience! A virtual coach provides subtle hints when needed, asks questions about the student's choices, and allows the student to reflect on and correct those mistakes. Whether your need is to overcome the logistical challenges of a traditional lab, provide better lab prep, improve student performance, or make your online experience one that rivals the real world, LearnSmart Labs accomplishes it all.



Start by making a potassium hydrogen phthalate (KHP) solution. Then fill the buret with sodium hydroxide and perform 3 titrations to standardize the sodium hydroxide solution. Refer to the instructions for further details.

McGraw-Hill Create™

With **McGraw-Hill Create,** you can easily rearrange chapters, combine material from other content sources, and quickly upload content you have written, like your course syllabus or teaching notes. Find the content you need in Create by searching through thousands of leading McGraw-Hill textbooks. Arrange your book to fit your teaching style. Create even allows you to personalize your book's appearance by selecting the cover and adding your name, school, and course information. Order a Create book and you'll receive a complimentary print review copy in 3–5 business days or a complimentary electronic review copy (eComp) via email in minutes. Go to ww.mcgrawhillcreate.com today and register to experience how McGraw-Hill Create empowers you to teach *your* students *your* way. www.mcgrawhillcreate.com

My Lectures—Tegrity®

McGraw-Hill Tegrity records and distributes your class lecture with just a click of a button. Students can view anytime/anywhere via computer, iPod, or mobile device. It indexes as it records your PowerPoint® presentations and anything shown on your computer so students can use keywords to find exactly what they want to study. Tegrity is available as an integrated feature of McGraw-Hill Connect Chemistry and as a standalone.

Student Solutions Manual

Students will find answers to the Visualizing Chemistry and Key Skills questions and detailed solutions and explanations for the odd-numbered problems from the text in the solutions manual.

Laboratory Manual

Laboratory Manual to Accompany Chemistry: Atoms First by Gregg Dieckmann and John Sibert from the University of Texas at Dallas. This laboratory manual presents a lab curriculum that is organized around an atoms-first approach to general chemistry. The philosophy behind this manual is to (1) provide engaging experiments that tap into student curiosity, (2) emphasize topics that students find challenging in the general chemistry lecture course, and (3) create a laboratory environment that encourages students to "solve puzzles" or "play" with course content and not just "follow recipes." The laboratory manual represents a terrific opportunity to get students turned on to science while creating an environment that connects the relevance of the experiments to a greater understanding of their world. This manual has been written to provide instructors with tools that engage students, while providing important connections to the material covered in an atoms-first lecture course.

Important features of this laboratory manual:

- Early experiments focus on topics introduced early in an atoms-first course—properties of light and the use of light to study nanomaterials, line spectra and the structure of atoms, periodic trends, etc.
- Prelab or *foundation* exercises encourage students to understand the important concepts/calculations/procedures in the experiment through working together.
- Postlab or *reflection* exercises put the lab content in the context of a larger chemistry/science picture.
- Instructor's resources (found in the Instructor Resources on Connect®) provided with each experiment outline variations that can be incorporated to enrich the student experience or tailor the lab to the resources/equipment available at the institution.

Acknowledgments

We wish to thank the many people—past and present—who have contributed to the development of this new text.

Titus Vasile Albu, *University of Tennessee–Chattanooga*
Mohd Asim Ansari, *Fullerton College*
Andrew Axup, *St. Ambrose University*
Mary Fran Barber, *Wayne State University*
David L. Boatright, *University of West Georgia*
Michael Bukowski, *Penn State University–Altoona*
Jerry Burns, *Pellissippi State Community College*
Tara Carpenter, *University of Maryland–BC*
David Carter, *Angelo State University*
David Carter, *Angelo State*
Gezahegn Chaka, *Collin County Community College*
Ngee Sing Chong, *Middle Tennessee State University*
Allen Clabo, *Francis Marion University*
Colleen Craig, *University of Washington*
Guy Dadson, *Fullerton College*
David Dearden, *Brigham Young University*
Mark Dibben, *USAFA Preparatory School*
Gregg Dieckmann, *University of Texas–Dallas*
Stephen Drucker, *University of Wisconsin–Eau Claire*
Ronald Duchovic, *Indiana University Purdue University–Fort Wayne*
Jack Eichler, *University of California–Riverside*
Anthony Fernandez, *Merrimack College*
Lee Friedman, *University of Maryland–College Park*
Rachel Garcia, *San Jacinto College*
Kate Graham, *College of St. Benedict/St. John's University*
Patrick Greco, *Sinclair Community College*
Tracy Hamilton, *University of Alabama at Birmingham*
Susan Hendrickson, *University of Colorado–Boulder*
Christine Hrycyna, *Purdue University*
James Jeitler, *Marietta College*
Scott Kennedy, *Anderson University*
Farooq A. Khan, *University of West Georgia*
William Kuhn, *USAFA Preparatory School*
Joseph Langat, *Florida State College at Jacksonville*
John Lee, *University of Tennessee–Chattanooga*
Debbie Leedy, *Glendale Community College*
Yinfa Ma, *Missouri University of Science and Technology*
Helene Maire-Afeli, *University of South Carolina–Union*
John Marvin, *Brescia University*
Roy McClean, *United States Naval Academy*
Anna McKenna, *College of St. Benedict/St. John's University*
Jack McKenna, *St. Cloud State University*
Jeremy Mitchell-Koch, *Emporia State University*
Matt Morgan, *Hamline University*
Douglas Mulford, *Emory University*
Patricia Muisener, *University of South Florida*
Chip Nataro, *Lafayette College*
Anne-Marie Nickel, *Milwaukee School of Engineering*
Delana Nivens, *Armstrong Atlantic State University*
Edith Osborne, *Angelo State University*
Hansa Pandya, *Richland College*
Katherine Parks, *Motlow College*
Mike Rennekamp, *Columbus State Community College*
Dawn Richardson, *Collin College–Frisco*
John Richardson, *Austin College*
Dawn Rickey, *Colorado State University*
Raymond Sadeghi, *University of Texas at San Antonio*
Nicholas Schlotter, *Hamline University*
Sarah Schmidtke, *The College of Wooster*
Jacob Schroeder, *Clemson University*
Stephen Schvaneveldt, *Clemson University*
John Sibert, *University of Texas–Dallas*
Regina Stevens-Truss, *Kalamazoo College*
John Stubbs, *University of New England*
Katherine Stumpo, *University of Tennessee–Martin*
Steve Theberge, *Merrimack College*
Lori Van Der Sluys, *Penn State University*
Jason Vohs, *St. Vincent College*
Stan Whittingham, *Binghamton University*
Nathan Winter, *St. Cloud State University*
Kimberly Woznack, *California University of Pennsylvania*

Raymond Chang's contributions have been invaluable. His unfaltering diligence and legendary attention to detail have added immeasurably to the quality of this book.

The following individuals helped write and review learning goal-oriented content for LearnSmart: David G Jones, Vistamar School and Adam I. Keller, Columbus State Community College.

We both thank and acknowledge our families for their continued and devoted support.

Finally, we must acknowledge our McGraw-Hill family for their inspiration, excitement, and support of this project: Managing Director Thomas Timp; Director of Chemistry David Spurgeon, PhD; Associate Director of Digital Content Robin Reed; Content Project Manager Sherry Kane; Senior Designer David Hash; Senior Director of Digital Content Shirley Hino and Senior Marketing Manager Matthew Garcia.

Chemistry

ATOMS FIRST

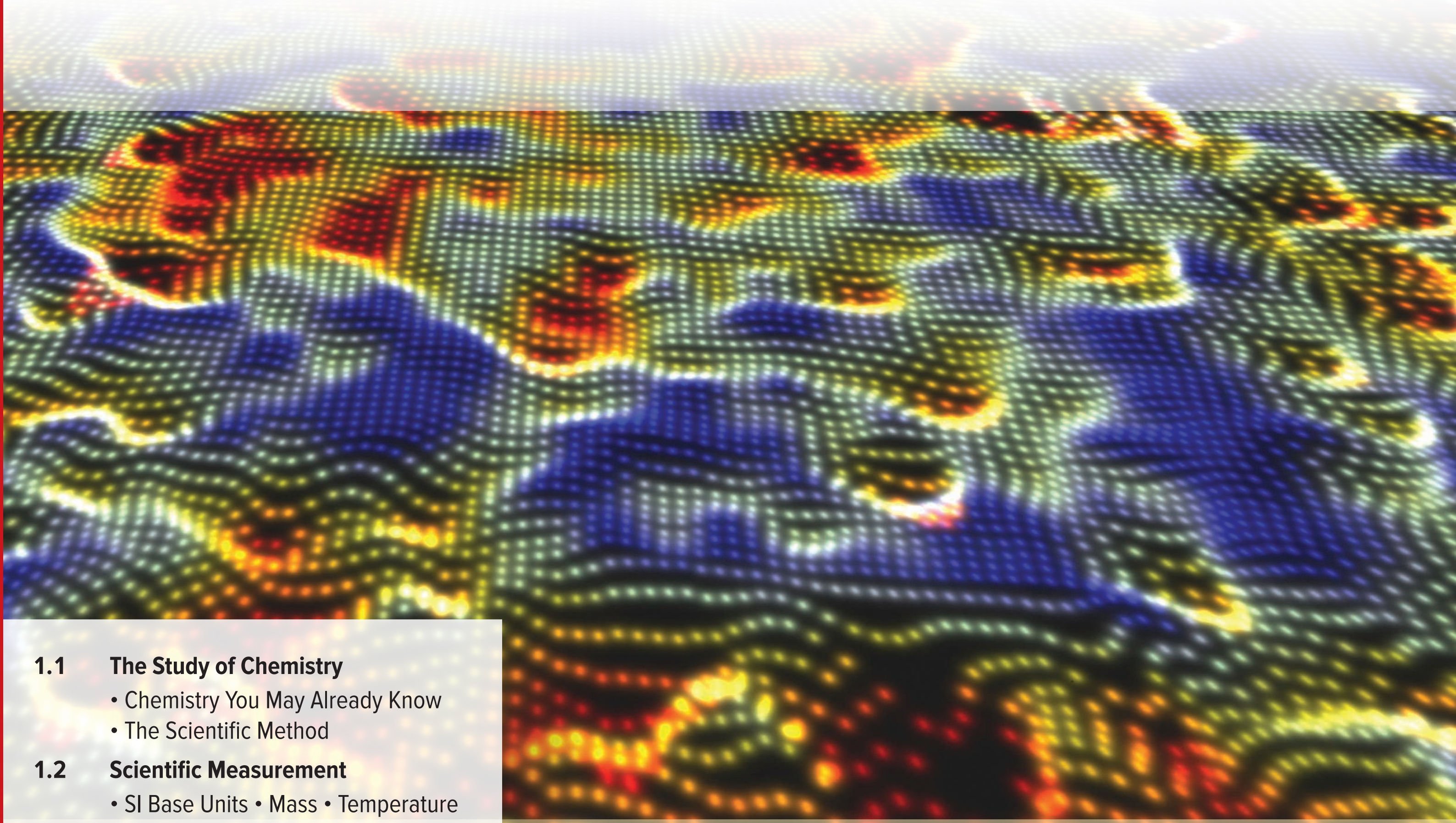
THIRD EDITION

Julia Burdge
COLLEGE OF WESTERN IDAHO

Jason Overby
COLLEGE OF CHARLESTON

Chapter 1

Chemistry: The Science of Change



© Prof. Ali Yazdani/Princeton University

RECENT STUDIES of interactions involving nanoparticles of noble metals, including gold, silver, and platinum, have enabled scientists to explain and exploit something known as *localized surface plasmon resonances,* depicted here. Among other things, this work has led to the development of photothermal ablation—a novel treatment for certain cancers. Specially designed gold nanoshells are injected into the patient and preferentially attach themselves to the target tumor cells. Near-infrared radiation (light of slightly longer wavelength than can be detected by the human eye) is then directed at the tumor, causing the gold nanoshells to emit heat. This heat destroys the tumor cells to which the nanoshells are attached, leaving the surrounding and nearby healthy cells unharmed.

Before You Begin, Review These Skills

- Basic algebra
- Scientific notation [⏮ Appendix 1]

1.1 THE STUDY OF CHEMISTRY

Chemistry often is called the *central science* because knowledge of the principles of chemistry can facilitate understanding of other sciences, including physics, biology, geology, astronomy, oceanography, engineering, and medicine. ***Chemistry*** is the study of *matter* and the *changes* that matter undergoes. Matter is what makes up our bodies, our belongings, our physical environment, and in fact our entire universe. ***Matter*** is anything that has mass and occupies space.

Chemistry You May Already Know

You may already be familiar with some of the terms used in chemistry. Even if this is your first chemistry course, you may have heard of *molecules* and know them to be tiny pieces of a substance—much too tiny to see. Further, you may know that molecules are made up of *atoms,* even smaller pieces of matter. And even if you don't know what a *chemical formula* is, you probably know that H_2O is water. You may have used, or at least heard, the term *chemical reaction;* and you are undoubtedly familiar with a variety of common processes that are chemical reactions, such as those shown in Figure 1.1. Don't worry if you are not familiar with these terms; they will be defined in the early chapters of this book.

The processes in Figure 1.1 are all things that you can observe at the *macroscopic level.* In other words, these processes and their results are visible to the human eye. In studying chemistry, you will learn to visualize and understand these same processes at the *submicroscopic* or *molecular level.*

Student Annotation: Macroscopic means *large enough to be seen with the unaided eye.*

Student Annotation: Submicroscopic means *too small to be seen, even with a microscope.* Atoms and molecules are *submicroscopic.*

The Scientific Method

Advances in our understanding of chemistry (and other sciences) are the result of scientific experiments. Although scientists do not all take the same approach to experimentation, they must follow a set of guidelines known as the ***scientific method*** to have their results added to the larger body of knowledge within a given field. The flowchart in Figure 1.2 illustrates this basic process. The method begins with the gathering of data via observations and experiments. Scientists study these data and try to identify *patterns* or *trends.* When they find a pattern or trend, they may summarize their findings with a ***law,*** a concise verbal or mathematical statement of a reliable relationship between phenomena. Scientists may then formulate a ***hypothesis,*** a tentative explanation for their observations. Further experiments are designed to test the hypothesis. If experiments indicate that the hypothesis is incorrect, the scientists go back to the drawing board, try to come up with a different interpretation of their data, and formulate a new hypothesis. The new hypothesis will then be tested by experiment. When a hypothesis stands the test of extensive experimentation, it may evolve into a theory. A ***theory*** is a unifying principle that explains a body of experimental observations and the laws that are based on them. Theories can also be used to predict related phenomena, so theories are constantly being tested. If a theory is disproved by experiment, then it must be discarded or modified so that it becomes consistent with experimental observations.

(a) (c) (b) (d)

Figure 1.1 Many familiar processes are chemical reactions: (a) The flame of a gas stove is the combustion of natural gas, which is primarily methane. (b) The bubbles produced when Alka-Seltzer dissolves in water are carbon dioxide, produced by a chemical reaction between two ingredients in the tablets. (c) The formation of rust is a chemical reaction that occurs when iron, water, and oxygen are all present. (d) Many baked goods "rise" as the result of a chemical reaction that produces carbon dioxide.

(a): © fStop/PunchStock; (b): © Brand X Pictures/PunchStock; (c): © Image Source/Corbis; (d): © Sharon Dominick/Getty

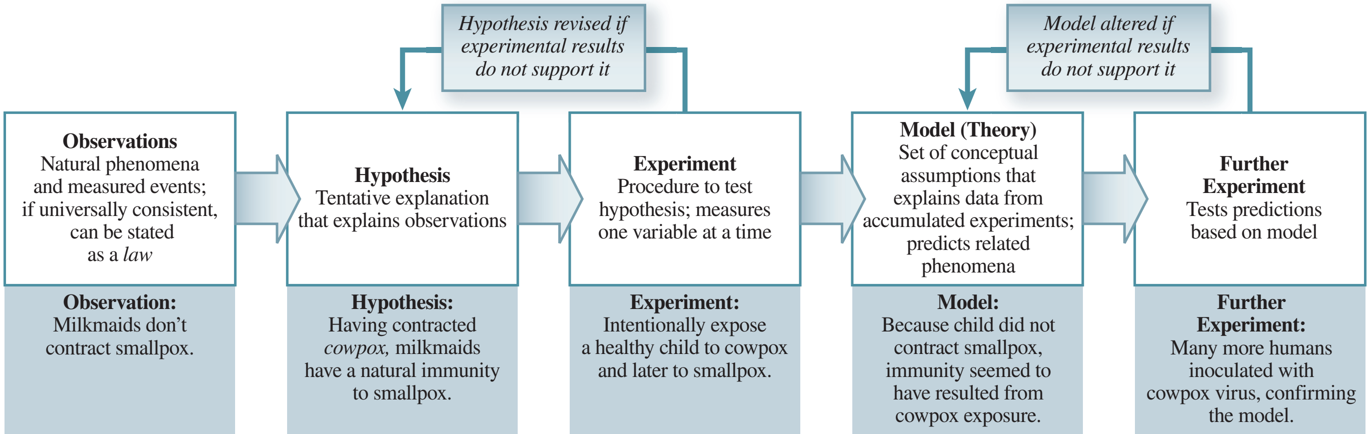


Figure 1.2 Flowchart of the scientific method.

A fascinating example of the use of the scientific method is the story of how smallpox was eradicated. Late in the eighteenth century, an English doctor named Edward Jenner observed that even during outbreaks of smallpox in Europe, milkmaids seldom contracted the disease. He reasoned that when people who had frequent contact with cows contracted *cowpox,* a similar but far less harmful disease, they developed a natural immunity to smallpox. He predicted that intentional exposure to the cowpox virus would produce the same immunity. In 1796, Jenner exposed an 8-year-old boy to the cowpox virus using pus from the cowpox lesions of an infected milkmaid. Six weeks later, he exposed the boy to the *smallpox* virus and, as Jenner had predicted, the boy did *not* contract the disease. Subsequent experiments using the same technique (later dubbed *vaccination* from the Latin *vacca* meaning *cow*) confirmed that immunity to smallpox could be induced.

A superbly coordinated international effort on the part of healthcare workers was successful in eliminating smallpox worldwide. In 1980, the World Health Organization declared smallpox officially eradicated. This historic triumph over a dreadful disease, one of the greatest medical advances of the twentieth century, began with Jenner's astute observations, inductive reasoning, and careful experimentation—the essential elements of the *scientific method.*

Until recently, almost everyone had a smallpox vaccine scar—usually on the upper arm.

© Chris Livingston/Getty Images

Student Annotation: The last naturally occurring case was in 1977 in Somalia.

1.2 SCIENTIFIC MEASUREMENT

Scientists use a variety of devices to measure the properties of matter. A meterstick is used to measure length; a burette, pipette, graduated cylinder, and volumetric flask are used to measure volume (Figure 1.3); a balance is used to measure mass; and a thermometer is used to measure temperature. Properties that can be measured are called *quantitative* properties because they are expressed using numbers. When we express a measured quantity with a number, though, we must always include the appropriate unit; otherwise, the measurement is meaningless. For example, to say that the depth of a swimming pool is 3 is insufficient to distinguish between one that is 3 *feet* (0.9 meter) and one that is 3 *meters* (9.8 feet) deep. Units are essential to reporting measurements correctly.

The two systems of units with which you are probably most familiar are the *English system* (foot, gallon, pound, etc.) and the *metric system* (meter, liter, kilogram, etc.). Although there has been an increase in the use of metric units in the United States in recent years, English units still are used commonly. For many years, scientists recorded measurements in metric units, but in 1960, the General Conference on Weights and Measures, the international authority on units, proposed a revised metric system for universal use by scientists. We will use both metric and revised metric (SI) units in this book.

Student Annotation: According to the U.S. Metric Association (USMA), the United States is "the only significant holdout" with regard to adoption of the metric system. The other countries that continue to use traditional units are Myanmar (formerly Burma) and Liberia.

SI Base Units

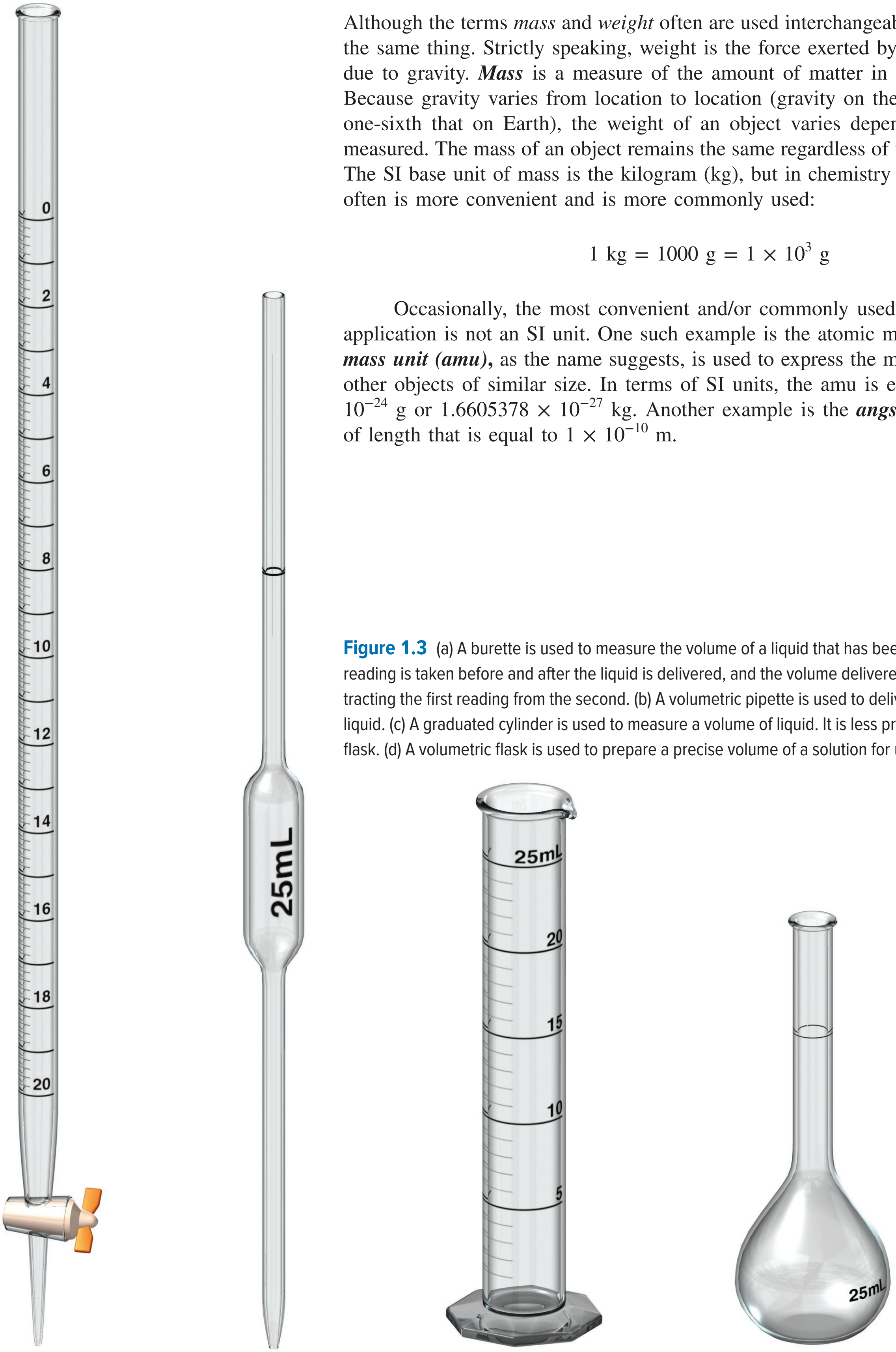
The revised metric system is called the ***International System of Units*** (abbreviated SI, from the French *Système Internationale d'Unités*). Table 1.1 lists the seven SI base units. All other units of measurement can be derived from these base units. The ***SI unit*** for *volume,* for instance, is derived by cubing (raising to the power 3) the SI base unit for *length.* The prefixes listed in Table 1.2 are used to denote decimal fractions and decimal multiples of SI units. The use of these prefixes enables scientists to tailor the magnitude of a unit to a particular application. For example, the meter (m) is appropriate for describing the dimensions of a classroom, but the kilometer (km), 1000 m, is more appropriate for describing the distance between two cities. Units that you will encounter frequently in the study of chemistry include those for mass, temperature, volume, and density.

Mass

Although the terms *mass* and *weight* often are used interchangeably, they do not mean the same thing. Strictly speaking, weight is the force exerted by an object or sample due to gravity. ***Mass*** is a measure of the amount of matter in an object or sample. Because gravity varies from location to location (gravity on the moon is only about one-sixth that on Earth), the weight of an object varies depending on where it is measured. The mass of an object remains the same regardless of where it is measured. The SI base unit of mass is the kilogram (kg), but in chemistry the smaller gram (g) often is more convenient and is more commonly used:

$$1 \text{ kg} = 1000 \text{ g} = 1 \times 10^3 \text{ g}$$

Occasionally, the most convenient and/or commonly used unit for a particular application is not an SI unit. One such example is the atomic mass unit. The ***atomic mass unit (amu),*** as the name suggests, is used to express the masses of atoms—and other objects of similar size. In terms of SI units, the amu is equal to $1.6605378 \times 10^{-24}$ g or $1.6605378 \times 10^{-27}$ kg. Another example is the ***angstrom (Å),*** a measure of length that is equal to 1×10^{-10} m.



Burette
(a)

Volumetric pipette
(b)

Graduated cylinder
(c)

Volumetric flask
(d)

Figure 1.3 (a) A burette is used to measure the volume of a liquid that has been added to a container. A reading is taken before and after the liquid is delivered, and the volume delivered is determined by subtracting the first reading from the second. (b) A volumetric pipette is used to deliver a precise amount of liquid. (c) A graduated cylinder is used to measure a volume of liquid. It is less precise than the volumetric flask. (d) A volumetric flask is used to prepare a precise volume of a solution for use in the laboratory.

TABLE 1.1 Base SI Units

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

TABLE 1.2 Prefixes Used with SI Units

Prefix	Symbol	Meaning	Example
Tera-	T	1×10^{12} (1,000,000,000,000)	1 teragram (Tg) = 1×10^{12} g
Giga-	G	1×10^{9} (1,000,000,000)	1 gigawatt (GW) = 1×10^{9}
Mega-	M	1×10^{6} (1,000,000)	1 megahertz (MHz) = 1×10^{6}
Kilo-	k	1×10^{3} (1,000)	1 kilometer (km) = 1×10^{3} m
Deci-	d	1×10^{-1} (0.1)	1 deciliter (dL) = 1×10^{-1} L
Centi-	c	1×10^{-2} (0.01)	1 centimeter (cm) = 1×10^{-2} m
Milli-	m	1×10^{-3} (0.001)	1 millimeter (mm) = 1×10^{-3} m
Micro-	μ	1×10^{-6} (0.000001)	1 microliter (μL) = 1×10^{-6} L
Nano-	n	1×10^{-9} (0.000000001)	1 nanosecond (ns) = 1×10^{-9} s
Pico-	p	1×10^{-12} (0.000000000001)	1 picogram (pg) = 1×10^{-12} g

Temperature

There are two temperature scales used in chemistry: the *Celsius* scale and the *absolute* or *Kelvin* scale. Their units are the *degree Celsius* (°C) and the *kelvin* (K), respectively. The ***Celsius*** scale [named after Swedish physicist Ander Celsius (1701–1744)] was originally defined using the freezing point (0°C) and the boiling point (100°C) of pure water at sea level. As Table 1.1 shows, the SI base unit of temperature is the ***kelvin.*** Kelvin is also known as the *absolute* temperature scale because the lowest temperature theoretically possible is 0 K, a temperature referred to as *absolute zero.* No *degree* sign (°) is used to represent a temperature on the Kelvin scale.

Units of the Celsius and Kelvin scales are equal in magnitude, so *a degree Celsius* is equivalent to a *kelvin.* Thus, if the temperature of an object increases by 5°C, it also increases by 5 K. Absolute zero on the Kelvin scale is equivalent to −273.15°C on the Celsius scale. We use the following equation to convert a temperature from units of degrees Celsius to kelvins:

$$\text{K} = {}^\circ\text{C} + 273.15 \qquad \textbf{Equation 1.1}$$

Worked Example 1.1 illustrates conversions between these two temperature scales.

Student Annotation: There is no such thing as a negative temperature on the Kelvin scale.

Student Annotation: The theoretical basis of the Kelvin scale has to do with the behavior of gases. [Chapter 11]

Student Annotation: Depending on the precision required, the conversion from degrees Celsius to kelvins often is done simply by adding 273, rather than 273.15.

Worked Example 1.1

Normal human body temperature can range over the course of the day from about 36°C in the early morning to about 37°C in the afternoon. Express these two temperatures and the range that they span using the Kelvin scale.

Strategy Use Equation 1.1 to convert temperatures from the Celsius scale to the Kelvin scale. Then convert the range of temperatures from degrees Celsius to kelvins, keeping in mind that 1°C is equivalent to 1 K.

Setup Equation 1.1 is already set up to convert the two temperatures from degrees Celsius to kelvins. No further manipulation of the equation is needed. The range in kelvins will be the same as the range in degrees Celsius.

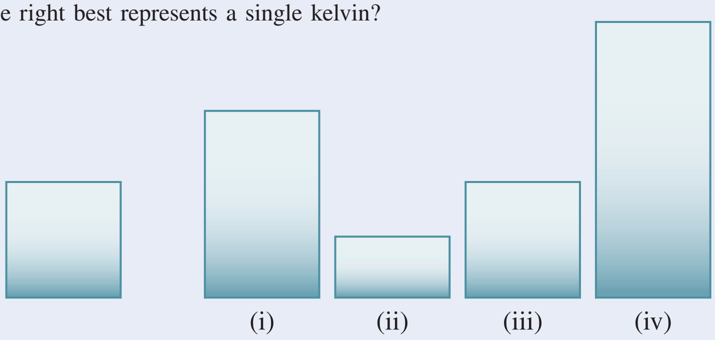
Solution 36°C + 273 = 309 K, 37°C + 273 = 310 K, and the range of 1°C is equal to a range of 1 K.

Think About It
Check your math and remember that converting a temperature from degrees Celsius to kelvins is different from converting a *difference* in temperature from degrees Celsius to kelvins.

Practice Problem ATTEMPT Express the freezing point of water (0°C), the boiling point of water (100°C), and the range spanned by the two temperatures using the Kelvin scale.

Practice Problem BUILD According to the website of the National Aeronautics and Space Administration (NASA), the average temperature of the universe is 2.7 K. Convert this temperature to degrees Celsius.

Practice Problem CONCEPTUALIZE If a single degree on the Celsius scale is represented by the rectangle on the left, which of the rectangles on the right best represents a single kelvin?



Outside of scientific circles, the Fahrenheit temperature scale is the one most used in the United States. Before the work of Daniel Gabriel Fahrenheit (German physicist, 1686–1736), there were numerous different, arbitrarily defined temperature scales, none of which gave consistent measurements. Accounts of exactly how Fahrenheit devised his temperature scale vary from source to source. In one account, in 1724, Fahrenheit labeled as 0° the lowest artificially attainable temperature at the time (the temperature of a mixture of ice, water, and a substance called *ammonium chloride*). Using a traditional scale consisting of 12 degrees, he labeled the temperature of a healthy human body as the twelfth degree. On this scale, the freezing point of water occurred at the fourth degree. For better resolution, each degree was further divided into eight smaller degrees. This convention makes the freezing point of water 32°F and normal body temperature 96°F. (Today we consider normal body temperature to be somewhat higher than 96°F.)

The boiling point of water on the Fahrenheit scale is 212°, meaning that there are 180 degrees (212°F minus 32°F) between the freezing and boiling points. This separation is considerably more degrees than the 100 between the freezing point and boiling point of water on the Celsius scale. Thus, the size of a degree on the Fahrenheit scale is only 100/180 or five-ninths of a degree on the Celsius scale. Equation 1.2 gives the relationship between temperatures on the Fahrenheit and Celsius scales.

Equation 1.2 $$\text{temperature in } ^\circ\text{F} = \frac{9^\circ\text{F}}{5^\circ\text{C}} \times (\text{temperature in } ^\circ\text{C}) + 32^\circ\text{F}$$

Worked Example 1.2 lets you practice converting from Celsius to Fahrenheit.

Worked Example 1.2

A body temperature above 39°C constitutes a high fever. Convert this temperature to the Fahrenheit scale.

Strategy We are given a temperature in degrees Celsius and are asked to convert it to degrees Fahrenheit.

Setup We use Equation 1.2:

$$\text{temperature in Fahrenheit} = \frac{9°\text{F}}{5°\text{C}} \times (\text{temperature in degrees Celsius}) + 32°\text{F}$$

Solution

$$\text{temperature in Fahrenheit} = \frac{9°\text{F}}{5°\text{C}} \times (39°\text{C}) + 32°\text{F} = 102°\text{F}$$

Think About It

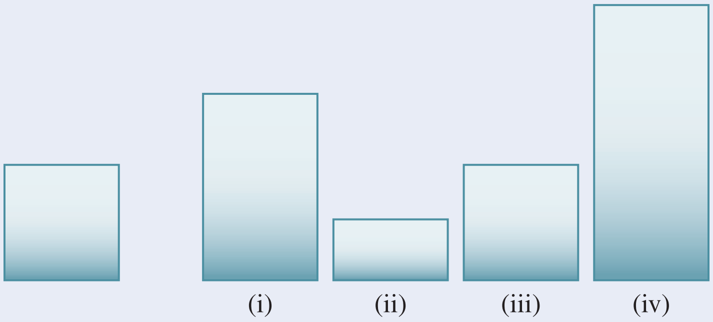
Knowing that "normal" body temperature on the Fahrenheit scale is approximately 99°F (98.6°F is the number most often cited), 102°F seems like a reasonable answer.

Practice Problem ATTEMPT The average temperature at the summit of Mt. Everest ranges from −36°C during the coldest month (January) and −19°C during the warmest month (July). Convert these temperatures and the range they span to Fahrenheit.

Practice Problem BUILD The average surface temperatures of planets in our solar system range from 867°F on Venus to −330°F on Neptune. Convert these temperatures and the range they span to Celsius.

Student Annotation: The average surface temperature of Pluto is −375°F, but Pluto is no longer classified as a planet.

Practice Problem CONCEPTUALIZE If a single degree on the Fahrenheit scale is represented by the rectangle on the left, which of the rectangles on the right best represents a single degree on the Celsius scale? Which best represents a single kelvin?



Derived Units: Volume and Density

There are many quantities, such as volume and density, that require units not included in the base SI units. In these cases, we must combine base units to *derive* appropriate units.

The derived SI unit for volume, the meter cubed (m^3), is a much larger volume than is usually convenient. The more commonly used metric unit, the *liter* (L), is derived by cubing the *decimeter* (one-tenth of a meter) and is therefore also referred to as the cubic decimeter (dm^3). Another commonly used metric unit of volume is the *milliliter* (mL), which is derived by cubing the centimeter (1/100 of a meter). The milliliter is also referred to as the cubic centimeter (cm^3). Figure 1.4 illustrates the relationship between the liter (or dm^3) and the milliliter (or cm^3).

Density is the ratio of mass to volume. A familiar demonstration of density is the attempt to mix water and oil. Oil floats on water because, in addition to not *mixing* with water, oil has a lower *density* than water. That is, given *equal volumes*