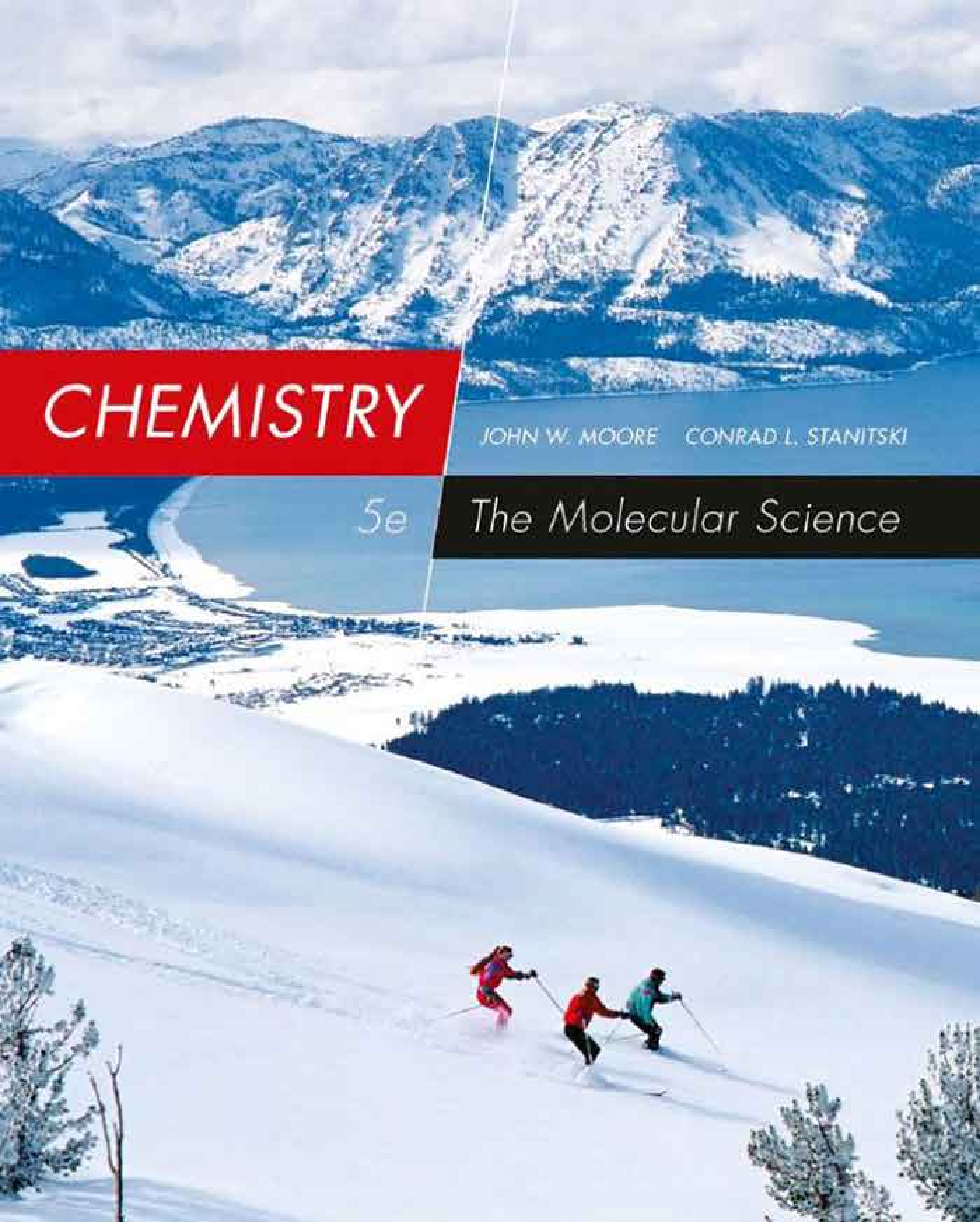
CHEMISTRY

The Molecular Science

5e

JOHN W. MOORE   CONRAD L. STANITSKI



PERIODIC TABLE OF THE ELEMENTS

KEY

An element: 79 (Atomic number) / Au (Symbol) / Gold (Name) / 196.9665 (Atomic weight)

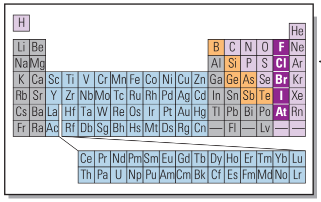
- Main group metals
- Transition metals
- Metalloids
- Nonmetals, noble gases

Period number; Group number, U.S. system; Group number, IUPAC system

Period	1A (1)	2A (2)	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	8B (9)	8B (10)	1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	1 H Hydrogen 1.0079																	2 He Helium 4.0026
2	3 Li Lithium 6.941	4 Be Beryllium 9.0122											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984	10 Ne Neon 20.1797
3	11 Na Sodium 22.9898	12 Mg Magnesium 24.3050											13 Al Aluminum 26.9815	14 Si Silicon 28.0855	15 P Phosphorus 30.9738	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.9559	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.9380	26 Fe Iron 55.845	27 Co Cobalt 58.9332	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.9216	34 Se Selenium 78.97	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.9058	40 Zr Zirconium 91.224	41 Nb Niobium 92.9064	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.9045	54 Xe Xenon 131.293
6	55 Cs Cesium 132.9055	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 195.084	79 Au Gold 196.9666	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.9804	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
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 (270)	108 Hs Hassium (277)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (281)	112 Cn Copernicium (285)	113 — — (286)	114 Fl Flerovium (287)	115 — — (289)	116 Lv Livermorium (293)	117 — — (293)	118 — — (294)

Numbers in parentheses are mass numbers of radioactive isotopes.

	Period															Period
Lanthanides	6	58 Ce Cerium 140.116	59 Pr Praseodymium 140.9077	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.9254	66 Dy Dysprosium 162.500	67 Ho Holmium 164.9303	68 Er Erbium 167.259	69 Tm Thulium 168.9342	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668	6
Actinides	7	90 Th Thorium 232.0377	91 Pa Protactinium 231.0359	92 U Uranium 238.0289	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



This icon appears throughout the book to help locate elements of interest in the periodic table. The halogen group is shown here.

Elements for which the International Union of Pure and Applied Chemistry (IUPAC) has officially sanctioned the discovery and approved a name are indicated by their chemical symbols in this table. Elements that have been reported in the literature but not yet officially sanctioned and named are indicated by atomic number.

Standard Atomic Weights of the Elements 2009, IUPAC

Based on Relative Atomic Mass of $^{12}C = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state.[1]

Name	Symbol	Atomic Number	Atomic Weight	Name	Symbol	Atomic Number	Atomic Weight
Actinium[2]	Ac	89	(227)	Mendelevium[2]	Md	101	(258)
Aluminum	Al	13	26.981 5385(7)	Mercury	Hg	80	200.59(2)
Americium[2]	Am	95	(243)	Molybdenum	Mo	42	95.95(1)
Antimony	Sb	51	121.760(1)	Neodymium	Nd	60	144.242(3)
Argon	Ar	18	39.948(1)	Neon	Ne	10	20.1797(6)
Arsenic	As	33	74.921 595(6)	Neptunium[2]	Np	93	(237)
Astatine[2]	At	85	(210)	Nickel	Ni	28	58.6934(4)
Barium	Ba	56	137.327(7)	Niobium	Nb	41	92.906 37(2)
Berkelium[2]	Bk	97	(247)	Nitrogen	N	7	14.0067(2)
Beryllium	Be	4	9.012 1831(5)	Nobelium[2]	No	102	(259)
Bismuth	Bi	83	208.980 40(1)	Osmium	Os	76	190.23(3)
Bohrium[2]	Bh	107	(270)	Oxygen	O	8	15.9994(3)
Boron	B	5	10.811(7)	Palladium	Pd	46	106.42(1)
Bromine	Br	35	79.904(1)	Phosphorus	P	15	30.973 761 998(5)
Cadmium	Cd	48	112.414(4)	Platinum	Pt	78	195.084(9)
Calcium	Ca	20	40.078(4)	Plutonium[2]	Pu	94	(244)
Californium[2]	Cf	98	(251)	Polonium[2]	Po	84	(209)
Carbon	C	6	12.0107(8)	Potassium	K	19	39.0983(1)
Cerium	Ce	58	140.116(1)	Praseodymium	Pr	59	140.907 66(2)
Cesium	Cs	55	132.905 451 96(6)	Promethium[2]	Pm	61	(145)
Chlorine	Cl	17	35.453(2)	Protactinium[2]	Pa	91	231.035 88(2)
Chromium	Cr	24	51.9961(6)	Radium[2]	Ra	88	(226)
Cobalt	Co	27	58.933 194(4)	Radon[2]	Rn	86	(222)
Copernicium[2]	Cn	112	(285)	Rhenium	Re	75	186.207(1)
Copper	Cu	29	63.546(3)	Rhodium	Rh	45	102.905 50(2)
Curium[2]	Cm	96	(247)	Roentgenium[2]	Rg	111	(281)
Darmstadtium[2]	Ds	110	(281)	Rubidium	Rb	37	85.4678(3)
Dubnium[2]	Db	105	(268)	Ruthenium	Ru	44	101.07(2)
Dysprosium	Dy	66	162.500(1)	Rutherfordium[2]	Rf	104	(267)
Einsteinium[2]	Es	99	(252)	Samarium	Sm	62	150.36(2)
Erbium	Er	68	167.259(3)	Scandium	Sc	21	44.955 908(5)
Europium	Eu	63	151.964(1)	Seaborgium[2]	Sg	106	(271)
Fermium[2]	Fm	100	(257)	Selenium	Se	34	78.971(8)
Flerovium[2]	Fl	114	(287)	Silicon	Si	14	28.0855(3)
Fluorine	F	9	18.998 403 163(6)	Silver	Ag	47	107.8682(2)
Francium[2]	Fr	87	(223)	Sodium	Na	11	22.989 769 28(2)
Gadolinium	Gd	64	157.25(3)	Strontium	Sr	38	87.62(1)
Gallium	Ga	31	69.723(1)	Sulfur	S	16	32.065(5)
Germanium	Ge	32	72.64(1)	Tantalum	Ta	73	180.947 88(2)
Gold	Au	79	196.966 569(5)	Technetium[2]	Tc	43	(98)
Hafnium	Hf	72	178.49(2)	Tellurium	Te	52	127.60(3)
Hassium[2]	Hs	108	(277)	Terbium	Tb	65	158.925 35(2)
Helium	He	2	4.002 602(2)	Thallium	Tl	81	204.3833(2)
Holmium	Ho	67	164.930 33(2)	Thorium[2]	Th	90	232.0377(4)
Hydrogen	H	1	1.00794(7)	Thulium	Tm	69	168.934 22(2)
Indium	In	49	114.818(3)	Tin	Sn	50	118.710(7)
Iodine	I	53	126.904 47(3)	Titanium	Ti	22	47.867(1)
Iridium	Ir	77	192.217(3)	Tungsten	W	74	183.84(1)
Iron	Fe	26	55.845(2)	Uranium[2]	U	92	238.028 91(3)
Krypton	Kr	36	83.798(2)	Vanadium	V	23	50.9415(1)
Lanthanum	La	57	138.905 47(7)	Xenon	Xe	54	131.293(6)
Lawrencium[2]	Lr	103	(262)	Ytterbium	Yb	70	173.054(5)
Lead	Pb	82	207.2(1)	Yttrium	Y	39	88.905 84(2)
Lithium	Li	3	[6.941(2)]†	Zinc	Zn	30	65.38(2)
Livermorium[2]	Lv	116	(293)	Zirconium	Zr	40	91.224(2)
Lutetium	Lu	71	174.9668(1)	—[2,3]		113	(286)
Magnesium	Mg	12	24.3050(6)	—[2,3]		115	(289)
Manganese	Mn	25	54.938 044(3)	—[2,3]		117	(293)
Meitnerium[2]	Mt	109	(278)	—[2,3]		118	(294)

1. The atomic weights of many elements vary depending on the origin and treatment of the sample. This is particularly true for Li; commercially available lithium-containing materials have Li atomic weights in the range of 6.939 and 6.996. Uncertainties are given in parentheses following the last significant figure to which they are attributed.
2. Elements with no stable nuclide; the value given in parentheses is the atomic mass number of the isotope of longest known half-life. However, three such elements (Th, Pa, and U) have a characteristic terrestrial isotopic composition, and the atomic weight is tabulated for these.
3. Not yet named.

FIFTH EDITION

Chemistry

THE MOLECULAR SCIENCE

John W. Moore
University of Wisconsin–Madison

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To All Students of Chemistry

We intend that this book will help you to discover that chemistry is relevant to your lives and careers, full of beautiful ideas and phenomena, and of great benefit to society. May your study of this fascinating subject be exciting, successful, and fun!

We thank our wives—Betty (JWM) and Barbara (CLS)—for their patience, support, understanding, and love.

It does not do harm to the mystery
to know a little more about it.
—Richard Feynman

About the Authors


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John W. Moore received an A.B. magna cum laude from Franklin and Marshall College and a Ph.D. from Northwestern University. He held a National Science Foundation (NSF) postdoctoral fellowship at the University of Copenhagen and taught at Indiana University and Eastern Michigan University before joining the faculty of the University of Wisconsin–Madison in 1989. At the University of Wisconsin, Dr. Moore is W. T. Lippincott Professor of Chemistry and Director of the Institute for Chemical Education. He was Editor of the *Journal of Chemical Education* from 1996 to 2009. Among his many awards are the American Chemical Society (ACS) George C. Pimentel Award in Chemical Education, the James Flack Norris Award for Excellence in Teaching Chemistry, and the CMA CATALYST National Award for Excellence in Chemistry Teaching. He is a Fellow of the ACS and of the American Association for the Advancement of Science (AAAS). He has won two major awards from the University of Wisconsin: the Wisconsin Power and Light Underkofler Award for Excellence in Teaching (1995) and the Benjamin Smith Reynolds Award for excellence in teaching chemistry to engineering students (2003). Dr. Moore has received a series of major grants from the NSF to support development of online chemistry learning materials for the ChemEd DL and the National Science Distributed Learning (NSDL) initiative.

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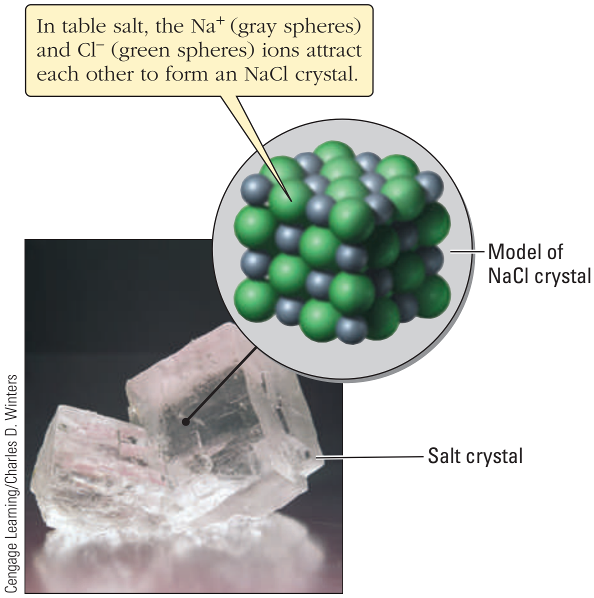

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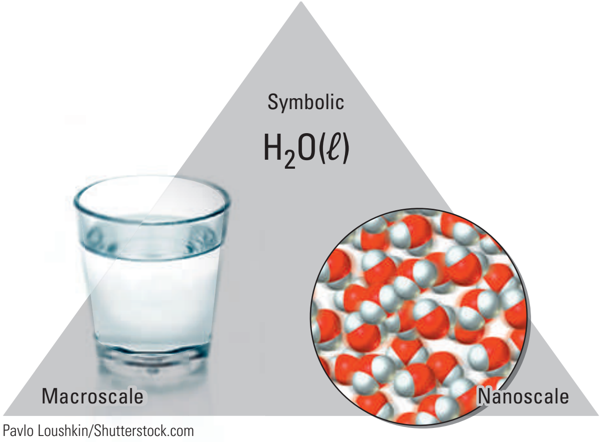

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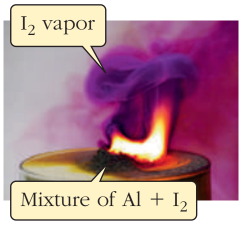

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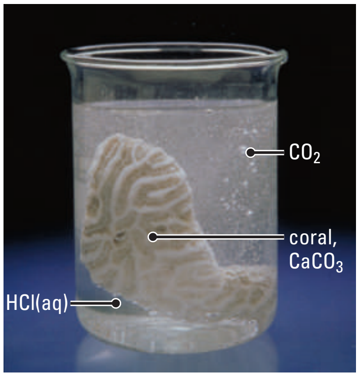

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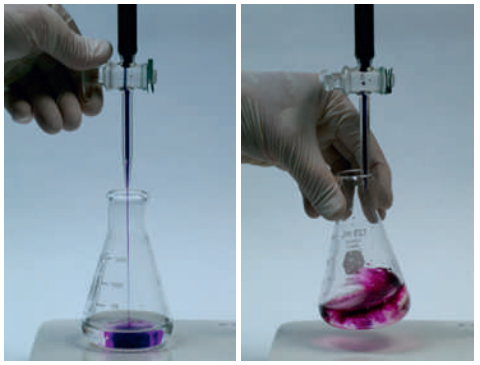
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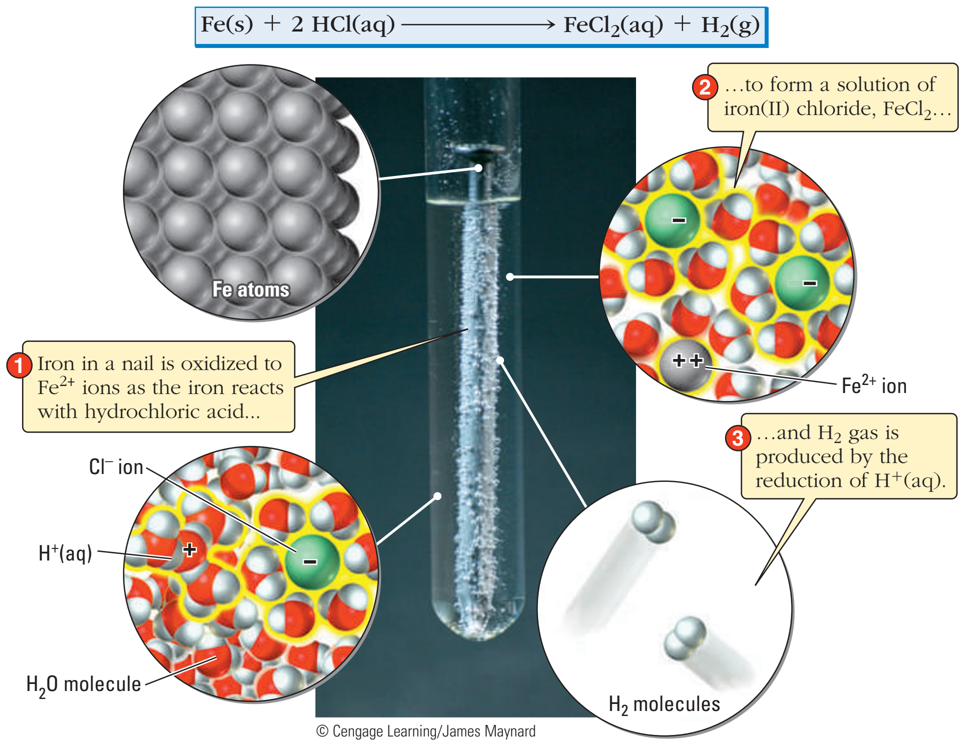

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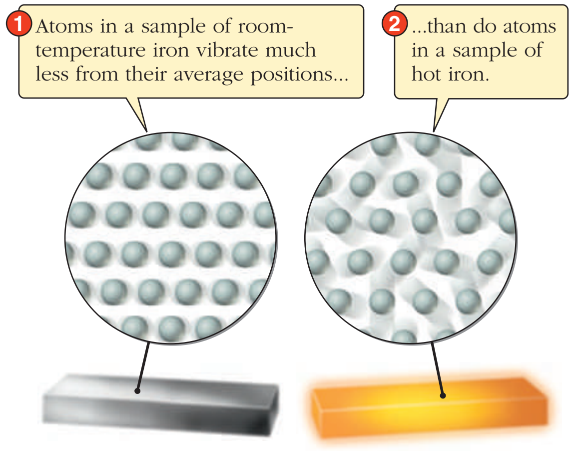

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Preface

Students have many reasons for taking a two-semester general chemistry course for science majors, but the most likely is that the course is a pre- or co-requisite for other science-related courses or careers. There are important reasons for such requirements, but they are not always obvious to students. The authors of this textbook believe very strongly that

- students need to recognize that chemical knowledge is essential for solving important problems and that chemistry makes important contributions to other disciplines; and
- it is essential that students gain a working knowledge of how chemistry principles are applied to solve problems in a broad spectrum of applications.

Examples of such applications are creating new and improving existing chemical pathways that lead to the more efficient synthesis of new pharmaceuticals; developing a deeper understanding of alternative energy sources to mitigate global warming; and understanding how new, more efficient catalysts could help to decrease air pollution and to minimize production of chemical waste from industrial processes. Knowledge of chemistry provides a way of interpreting macroscale phenomena at the molecular level that can be applied to many critical 21st-century problems, including those just given. This fifth edition of *Chemistry: The Molecular Science* continues our tradition of integrating other sciences with chemistry and has been updated to include a broad range of recent chemical innovations that illustrate the importance of multidisciplinary science.

Goals

Our overarching goal is to involve science and engineering students in active study of what modern chemistry is, how it applies to a broad range of disciplines, and what effects it has on their own lives. We maintain a high level of rigor so that students in mainstream general chemistry courses for science majors and engineers will learn the concepts and develop the problem-solving skills essential to their future ability to use chemical ideas effectively. We have selected and carefully refined the book's many unique features in support of this goal.

More specifically, we intend that this textbook will help students develop

- a broad overview of chemistry and chemical reactions;
- an understanding of the most important concepts and models used by chemists and scientists in chemistry-related fields;
- the ability to apply the facts, concepts, and models of chemistry appropriately to new situations in chemistry, to other sciences and engineering, and to other disciplines;
- knowledge of the many practical applications of chemistry in other sciences, in engineering, and in other fields;
- an appreciation of the many ways that chemistry affects the daily lives of all people, students included; and
- motivation to study in ways that help all students achieve real learning that results in long-term retention of facts and concepts, and how to apply them.

Because modern chemistry is inextricably entwined with so many other disciplines, we have integrated organic chemistry, biochemistry, environmental chemistry, industrial chemistry, and materials chemistry into the discussions of chemical principles and facts.

Applications in these areas are discussed together with the principles on which they are based. This approach serves to motivate students whose interests lie in related disciplines and also gives a more accurate picture of the multidisciplinary collaborations so prevalent in contemporary chemical research and modern industrial chemistry.

Audience

Chemistry: The Molecular Science, Fifth Edition, is intended for mainstream general chemistry courses for students who expect to pursue further study in science, engineering, or science-related disciplines. Those planning to major in chemistry, biochemistry, biological sciences, engineering, geological sciences, environmental science, agricultural sciences, materials science, physics, and many related areas will benefit from this book and its approach. The book has an extensive glossary and an excellent index, making it especially useful as a reference for study or review for standardized examinations, such as the MCAT.

We assume that the students who use this book have a basic foundation in mathematics (algebra and geometry) and in general science. Almost all will also have had a chemistry course before coming to college. The book is suitable for the typical two-semester sequence of general chemistry, and it has also been used quite successfully in a one-semester accelerated course that presumes students have a strong background in chemistry and mathematics.

New in This Edition

This fifth edition of *Chemistry: The Molecular Science* has undergone major revisions—far more extensive than any of the previous editions, even though each of them was significantly revised. Specifically, we have made these major changes from the fourth edition:

- Evaluated all chapter-end Questions for Review and Thought and in-chapter Problem-Solving Examples and Exercises with regard to conceptual level, using Bloom's taxonomy of educational objectives and aiming for comprehensive coverage of topics and strong development of students' conceptual abilities;
- Based on the assessment of conceptual level, culled lower-level and redundant end-of-chapter questions and added 328 new questions, many of which require higher-level thinking;
- Based on the conceptual-level evaluation and modifications of chapter content, replaced or revised 17 Problem-Solving Examples, 29 Problem-Solving Practice problems, and 60 Exercises;
- Revised all Problem-Solving Examples to include explicitly our problem-solving strategy (analyze, plan, execute, and check) so that students have clear guidance in how to approach and solve problems;
- Combined Chapters 1 to 5 from the fourth edition into Chapters 1 to 3 in this edition, re-ordering and modernizing the content to improve clarity and aid learning;
- Significantly revised all other chapters; in particular, Chapters 8, 9, and 17 (fifth edition) had sections rewritten, removed, added, or re-ordered;
- Revised our award-winning art program to better suit today's visually oriented students, greatly increasing the use of text and pointers to draw students' attention to the important information in each figure;
- Enhanced our emphasis on applications of chemistry in other sciences and in daily life by incorporating suggestions of an Applications Advisory Board into the text of most chapters;
- Began each chapter with an engaging photo accompanied by a series of related questions that are designed to pique students' interest and that are answered in the chapter;

- Continued to use published research as a guide, for example, in changing notation for the solvated proton from H_3O^+(aq) to H^+(aq) (see *Journal of Chemical Education*, Vol. 88, No. 7, p. 875, 2011);
- Removed from the printed text two features, *Chemistry in the News* and *Chemistry You Can Do,* making them available online;
- Developed many new *Chemistry in the News* items;
- Updated all *Tools of Chemistry* features and added new *Portrait of a Scientist* items to include more that feature members of groups underrepresented in science;
- Updated thermodynamic notation to reflect IUPAC conventions (such as $\Delta_r H°$ for reaction enthalpy change) and revised unit conventions for reaction enthalpies and Gibbs free energies to include units per mole.

A hallmark of this book is its emphasis on conceptual understanding as opposed to memorization or rote answering of questions. To enhance this approach, Dr. Kristin Briney evaluated the conceptual level of every chapter's content and every set of chapter-end problems. She categorized all problems using Bloom's Taxonomy of educational objectives, identifying areas where new conceptual problems were needed and determining whether all concepts included in each chapter were assessed by chapter-end problems. Based on this analysis, we have written new chapter-end questions, exercises, and problem-solving practice problems. Where Dr. Briney identified redundancies in chapter-end questions, we deleted questions to make room for the newly written items. This analysis has provided excellent guidance and greatly enhanced an already strong feature of the book.

Our revision of Chapters 1 to 5 (which are now Chapters 1 to 3) involved far more than simply combining the content of five chapters and reapportioning it into three. For example, material about the periodic table from Chapters 2 and 3 is now in Chapter 1, where it helps students to see how the field of chemistry is organized. We also modernized our approach to chemical reactions, categorizing them as precipitation, acid-base, gas forming, and redox with less emphasis on combination, exchange, etc. Combining Chapters 1 to 5 also reduced their length from 210 pages to 169 pages—a welcome change in this era of long, expensive textbooks.

The art in this textbook has been a strong point from the first edition, which won an award for excellence. In this fifth edition every figure and photograph has been re-examined to enhance its pedagogical impact. Related figures have been combined; diagrams that were too complex have been broken into two separate figures. We continue to have many figures that emphasize the macroscopic, symbolic, and nanoscale views of chemical processes, and we have increased our use of balloon text and pointers to emphasize what students should be looking at (see p. xxv). Often this has allowed us to shorten the written text, bearing out the adage that a picture is worth 1000 words. These enhanced figures are also very important in the online version of this text, consolidating text and images so that students have less reading on a computer screen.

To support our emphasis on developing students' ability to approach problems systematically and logically, we have revised all Problem-Solving Examples with subheadings to remind students that they should analyze the problem, plan a solution, execute the plan, and check that the result is reasonable. This strategy is also emphasized in the solutions manuals developed by Dr. Judy Ozment. We have added 328 new questions at the ends of the chapters and have paid special attention to the section headed More Challenging Questions, to which we have added a significant number of new questions in nearly every chapter. To help students develop their conceptual problem-solving skills, we have created 29 new Problem-Solving Practice problems and 60 new Exercises.

Our emphasis on applications of chemistry in other disciplines and in daily life has been enhanced through many suggestions from an Applications Advisory Board. We have incorporated the board's recommendations in the text. We have also carefully selected chapter-opening photographs that relate to each chapter's concepts; in the captions of these photos we ask questions about what is shown that are designed to pique students' interest in the chapter; all such questions are answered later in the chapter.

In addition to these global changes, revisions specific to each chapter include

Chapter 1

- Replaced Section 1-2 with an entirely new example of how chemistry is applied to societal problems;
- Added five new questions about real-world situations that are answered later in the book;
- Revised or replaced three Exercises and one Problem-Solving Practice problem;
- Added, revised, or replaced 12 figures;
- Added a new section, Measurements, Units, and Calculations, that includes SI units and significant digits;
- Emphasized a general approach to solving problems and demonstrated how to apply it to a specific problem;
- Added two new sections, The Periodic Table and The Biological Periodic Table; and
- Added 15 new end-of-chapter questions, 10 of which are More Challenging Questions.

Chapter 2

- Combined content from fourth-edition Chapters 2 and 3;
- Deleted sections on units and significant figures, which are now in Chapter 1;
- Changed order of presentation so that ions and ionic compounds precede molecular compounds;
- Enhanced discussion of identifying ionic and molecular compounds and relating compound type to properties;
- Juxtaposed discussion of amount of substance, molar mass, composition and formulas, and determining formulas;
- Added, revised, or replaced 12 figures;
- Revised or replaced seven Exercises and eight Problem-Solving Practice problems; and
- Added 40 new end-of-chapter questions and deleted 137 that were in the fourth edition Chapters 2 and 3.

Chapter 3

- Combined content from fourth-edition Chapters 4 and 5 in this chapter;
- Reorganized so the order is now chemical equations and balancing; precipitation, acid-base, and redox reactions; stoichiometry, limiting reactant, percent yield, and formula from mass composition; and solution stoichiometry;
- De-emphasized nomenclature of combination, decomposition, displacement, and exchange reactions;
- Revised or replaced 11 Exercises and six Problem-Solving Practice problems;
- Added, revised, or replaced 20 figures; and
- Added 13 new end-of-chapter questions; deleted 131 questions that were in the fourth edition Chapters 4 and 5.

Chapter 4

- Revised or replaced eight figures; deleted five figures;
- Revised or replaced seven Exercises and two Problem-Solving Practice problems;
- Added subsection on power and unit W;
- Added new Section 4-3, Keeping Track of Energy Transfers;

- Deleted Section 6.5, Thermochemical Expressions, and incorporated material into Section 4-5;
- Consolidated Sections 6.11 and 6.12 into new Section 4-11; reduced coverage of food and fuel slightly;
- Replaced an *Estimation* feature; and
- Added seven new end-of-chapter questions; deleted 58 questions.

Chapter 5

- Revised or replaced 25 figures; deleted 3 figures;
- Revised material on waves and moved it before electromagnetic radiation;
- Revised or replaced four Exercises;
- Added Section 5-5e to separate discussion of one-electron atoms/ions from discussion of atoms/ions with more than a single electron;
- Revised discussion of quantum numbers to emphasize electron shells and placed summary at end;
- Moved discussion of paramagnetism before section on ion electron configurations so that paramagnetic experimental results could be used in both atoms and ions; and
- Expanded discussion of effective nuclear charge and improved figures showing periodic trends;
- Explicitly introduced the idea that radii are based on the assumption that atoms and ions are spherical;
- Added one end-of-chapter learning goal and significantly modified several others; and
- Added 30 new end-of-chapter questions; deleted 43 questions.

Chapter 6

- Revised or replaced 11 figures;
- Revised or replaced two Problem-Solving Practice problems;
- Revised Section 6-1 extensively, explicitly defining valence bond theory;
- Added a new Problem-Solving Example;
- Revised tables showing formal charges to better relate formal charge to structure;
- Revised material on molecular orbital (MO) theory to better show formation of MOs, to better define bond order, and to more clearly show formation of sigma and pi orbitals;
- Revised discussion of electron delocalization by deleting nitrate and expanding ozone discussion;
- Revised several learning goals and added seven key terms; and
- Added 20 new end-of-chapter questions; deleted 31 questions.

Chapter 7

- Revised or replaced 17 figures;
- Major revision of Section 7-1 involved deleting some text and replacing it with balloon text in figures;
- Revised discussion of VSEPR to explain more explicitly how electron-region geometry defines molecular geometry;
- Moved discussion of hydrocarbons with many C atoms to section on molecules with more than a single central atom;
- Revised Sections 7-3a, 7-3b, and 7-3c to reduce text length and use text in figures to explain hybrid orbital formation;
- Introduced figures with balloon text to explain sideways overlap of *p* orbitals and to show sigma framework and pi framework in multiple bonds;

- Revised text and figure to better explain alignment of polar molecules in electric field; added figure showing why CO_2 is nonpolar and SO_2 is polar;
- Revised definition of hydrogen bond to agree with new IUPAC definition and to introduce the idea that there is a covalent component in a hydrogen bond;
- Included more questions about molecular geometry in Summary Problem; and
- Added 15 new end-of-chapter questions; deleted 17 questions.

Chapter 8

- Revised or added 14 figures;
- Revised or replaced seven Exercises and six Problem-Solving Practice problems;
- Revised or added three Problem-Solving Examples;
- Revised the introduction, which now notes similarity of physical behavior of gases, contrasting with the lack of similarity in solids and liquids;
- Revised the section on gas pressure;
- Used kinetic-molecular theory early but moved more detailed treatment to Section 8-7;
- Revised treatment of combined gas law to include *n*;
- Moved gas density and molar mass to directly follow the ideal gas law;
- Shifted Law of Combining Volumes into a revised section on gases in chemical reactions;
- Applied gas theory to new context: self-contained self-rescue breathing devices;
- Moved discussion of the atmosphere later in the chapter and used it to introduce an updated and enhanced discussion of stratospheric ozone depletion, greenhouse gases and climate change, and tropospheric air pollution; and
- Added 23 new end-of-chapter questions; deleted 35 questions.

Chapter 9

- Revised or replaced 24 figures;
- Revised or replaced four Exercises and six Problem-Solving Practice problems;
- Added three new Problem-Solving Examples;
- Wrote a new introduction that compares two important differences between properties of gases and properties of liquids and solids: molar volumes and intermolecular forces;
- Reorganized to increase coverage of intermolecular forces and to move material on surface tension, capillary action, and meniscuses to the section on unusual properties of water;
- Incorporated a new vapor pressure section that includes polar and nonpolar compounds; revised the discussion of the Clausius-Clapeyron equation;
- Separated vaporization/condensation from melting/freezing and sublimation/deposition; discussed critical *T* and *P* as properties of liquids, not just in phase diagrams;
- Moved discussion of types of solids earlier so that phase diagrams make more sense; moved phase diagram of water to section on special properties of water;
- Revised table showing types of solids to include images of example solids and diagrams of nanoscale structures;
- Reorganized the discussion of crystalline solids and calculations related to unit cells;
- Introduced Nobel Prize work of Daniel Shechtman on quasicrystals;
- Added new Estimation box;
- Revised the Summary Problem: Parts I and II are new;
- Added two new learning goals; and
- Added 22 new end-of-chapter questions; deleted 20 questions.

Chapter 10

- Revised or replaced 17 figures;
- Revised or replaced four Exercises and three Problem-Solving Practice problems;
- Updated one table;
- Updated information on reformulated gasolines, energy sources, recycling of plastics;
- Added a subsection on hydraulic fracturing (fracking);
- Reduced text in Section 10-1, letting figures tell the story of distillation, cracking, and reforming in petroleum refining;
- More clearly defined each organic functional group at the beginning of its section;
- Added discussion of planarity of peptide bond;
- Added one learning goal and deleted one that was low in Bloom's taxonomy;
- Added nine new Key Terms; and
- Added 11 new end-of-chapter questions (six more challenging); rewrote 25 questions.

Chapter 11

- Revised or replaced 16 figures;
- Revised or replaced one Exercise;
- Revised one Problem-Solving Example;
- Updated one table;
- Updated text description of reason for activation energy in Section 11-4; and
- Revised presentation of Step 3 in mechanism in Section 11-7 based on student questions;
- Updated information on catalyst usage in industry;
- Added one learning goal and revised three others; and
- Reduced the number of end-of-chapter questions by 37 (to 122).

Chapter 12

- Revised or replaced 12 figures;
- Revised one Problem-Solving Example;
- Updated one table;
- Revised example in Section 12-6a involving dissolution of carbonates; related it to ocean acidification and coral reefs;
- Revised Section 12-6b to provide a different example of changing solution volume;
- Added a completely new Summary Problem; and
- Reduced the number of end-of-chapter questions to 125 (from 158); reordered questions to better fit topic headings.

Chapter 13

- Revised or replaced 24 figures;
- Revised one Problem-Solving Example;
- Added table of freezing point and boiling point constants in Section 13-7;
- Reorganized Sections 1 to 3 to make better use of entropy as a means of explaining solubility and better delineate enthalpy and entropy of solution based on prior discussion in Chapter 12;
- Expanded discussion of solubility of ionic solids and repositioned it to precede solubility of gases;

- Revised discussion of softening water using ion exchange;
- Modified Summary Problem; and
- Added 16 new end-of-chapter questions; deleted nine questions.

Chapter 14

- Revised or replaced 25 figures; added five new figures;
- Revised or replaced three Exercises and one Problem-Solving Practice problem;
- Added new Section 14-6e on periodic variation of acid-base properties of oxides;
- To reinforce pedagogy, added color coding to section teaching how to solve equilibrium problems;
- Included method of successive approximations for solving equilibrium problems; emphasized 5% rule more explicitly;
- Added one learning goal;
- Added three new Key Terms; and
- Replaced 20 end-of-chapter questions with new ones more relevant to chapter topics and higher in Bloom's taxonomy.

Chapter 15

- Revised or replaced 25 figures; added one new figure to better explain buffers;
- Revised one Exercise;
- Revised two Problem-Solving Examples;
- Revised one table;
- Consolidated Sections 15-1e and 15-1f;
- Updated data on sulfur and nitrogen oxide emissions and distribution of acid rain;
- Added a second part to the Summary Problem; and
- Added 15 new end-of-chapter questions; modified 15 questions; deleted four questions.

Chapter 16

- Revised or replaced 17 figures;
- Revised Estimation box;
- Revised one Problem-Solving Example;
- Rewrote introduction to better accommodate new chapter-opening photo and caption;
- Defined third law of thermodynamics more explicitly;
- Shortened text in Section 16-3b because Figure 16.3 tells the story;
- Rewrote Section 16-8a to use electric cars as example of charge/discharge battery cycle;
- Updated correlations of end-of-chapter questions with learning goals;
- Added three new Key Terms; and
- Added one new end-of-chapter question; deleted 16 questions.

Chapter 17

- Revised or replaced 20 figures; added 11 new ones;
- Added two new Problem-Solving Examples; modified two others;
- Revised or replaced three Exercises and added five new Exercises; added two new Problem-Solving Practice problems;

- Added one new table;
- Added a new Estimation box and a new Portrait of a Scientist;
- Moved material on balancing redox equations to Appendix F;
- Moved section on neuron cells to online only;
- Added subsection and figure to explain shorthand cell notation;
- Wrote new introduction to using standard half-cell potentials;
- Revised pH meter section;
- Deleted discussion of mercury cells and non-alkaline dry cells; explained why NiCads need to be recycled;
- Added new material on lithium-ion batteries and plug-in hybrid electric vehicles;
- Replaced Summary Problem with a new one; and
- Added 12 new end-of-chapter questions; deleted five questions.

Chapter 18

- Revised or replaced eight figures; added three new figures;
- Revised or replaced four Exercises;
- Revised two tables;
- Revised Section 18-3b to define nuclear binding energy analogously to bond energy;
- Revised discussion of $E = mc^2$ to make equivalence of mass and energy clearer;
- Shortened discussion of half-life and related it better to kinetics chapter;
- Added information on newly synthesized elements;
- Added new sections on nuclear power plant accidents including Fukushima, and nuclear power pros and cons;
- Deleted one Estimation box;
- Replaced Summary Problem; and
- Added 18 new end-of-chapter questions, one of them more challenging.

Chapter 19

- Added two new figures; revised 19 figures;
- Added two new Exercises; modified one Exercise; deleted one Exercise;
- De-emphasized Frasch process because it currently produces very little sulfur;
- Replaced Summary Problem; and
- Added 22 new end-of-chapter questions; revised 10 questions.

Chapter 20

- Revised or replaced one figure;
- Added one new learning goal;
- Revised Summary Problem; and
- Added 22 new end-of-chapter questions; revised 10 questions.

Appendices

- Updated Appendix C to include latest values of physical constants and references to sources of data;
- Updated Appendix D with most recent references on electron configurations of the elements;
- Created new Appendix F: Balancing Redox Equations; and
- Combined former Appendix F with Appendix G so that all acid/base ionization constants are in a single appendix.

Features

We strongly encourage students to understand concepts and to learn to apply those concepts to problem solving. We believe that such understanding is essential if students are to be able to use what they learn from this book in subsequent courses and in their future careers. All too often we hear professors in courses for which general chemistry is a prerequisite complain that students have not retained what they were taught in general chemistry. This book is unique in its thoughtful choice of features that address this issue and help students achieve long-term retention of the material.

Problem Solving

This book places major emphasis on helping students learn to approach and solve real problems. Problem solving is introduced in Chapter 1, and a framework is built there that is followed throughout the book. Four important components of our strategy for teaching problem solving are

- *Problem-Solving Example/Problem-Solving Practice* problems that outline how to approach and solve a specific problem, check the answer, and practice a similar problem;
- *Estimation* boxes that help students learn how to do back-of-the-envelope calculations and apply concepts to new situations;
- *Exercises,* many of which deal with conceptual learning and are identified as *Conceptual Exercises,* that follow introduction of new material and for which answers are not immediately available, forcing students to work out the Exercise before seeing the answer; and
- *General Questions, Applying Concepts, More Challenging Questions,* and *Conceptual Challenge Problems* at the end of each chapter that are not keyed to specific textual material and require integration of concepts and out-of-the-box thinking to solve.

Problem-Solving Example/Problem-Solving Practice Each chapter contains many worked-out *Problem-Solving Examples*—a total of 242 in the book as a whole. Most consist of seven parts:

- a *Question* (problem);
- a *Result,* stated briefly;
- an *Analyze* section that outlines one approach to analyzing the problem;
- a *Plan* section that illustrates how to plan a solution;
- an *Execute* section that shows how the plan can be carried out;
  (The preceding three sections are designed to provide pedagogically sound help for students whose answer did not agree with ours.)
- a *Reasonable Result Check* section marked with a ☑ that indicates how a student could check whether a result is reasonable; and
- a companion *Problem-Solving Practice* that directly provides a similar question or questions, with answers appearing only in Appendix K.

We encourage students to first work out an answer without looking at either the Result or the Analyze, Plan, and Execute sections, and only then to compare their answer with ours. If their answer did not agree with ours, students are asked to repeat their work. Only then do we suggest that they look at the Analyze, Plan, and Execute sections, which are couched in conceptual as well as numeric terms to improve students' understanding, not just their ability to answer an identical question on an exam. The Reasonable Result Check section helps students learn how to use estimated results and other criteria to decide whether a result is reasonable, an ability that will serve them well in the future. By providing related *Problem-Solving Practice* problems that are answered only in the back of the book, we encourage students to immediately consolidate their thinking and improve their ability to apply their new understanding to other problems based on the same concept.

The first Problem-Solving Example and Problem-Solving Practice in Chapter 1 is shown below. It explicitly describes the strategy of analyzing the problem, planning a solution, executing the plan, checking that the answer is reasonable, and solving another similar problem. In a section of the text immediately following this example, we explicitly point out this problem-solving strategy and how the structure of the problem-solving examples supports it.

PROBLEM-SOLVING EXAMPLE 1.1

Density

In an old movie, thieves are shown running off with pieces of gold bullion that are about a foot long and have a square cross section of about six inches. The volume of each piece of gold is 7000 mL. Is what the movie shows physically possible? [Hint: calculate the mass of gold and express the result in pounds (lb). 1 lb = 454 g.]

Result Probably not; 1.4×10^5 g; 300 lb

Strategy and Explanation A good approach to problem solving is to (1) analyze the problem, (2) plan a solution, (3) execute the plan, and (4) check your result to see whether it is reasonable. (These four steps are described in more detail in Appendix A-1.)

Analyze the problem.

Step 1: *Analyze the problem.* You are asked to calculate the mass of the gold, and you know the volume is 7000 mL (one significant figure).

Plan a solution.

Step 2: *Plan a solution.* Density relates mass and volume and is the appropriate proportionality factor, so look up the density in a table. Mass is proportional to volume, so the volume either has to be multiplied by the density or divided by the density. Use the units to decide which. Use the information that 1 lb = 454 g to obtain a conversion factor for the units.

Execute the plan.

Step 3: *Execute the plan.* According to Table 1.1, the density of gold is 19.32 g/mL. Setting up the calculation so that the unit (milliliter) cancels gives

$$7000 \text{ mL} \times \frac{19.32 \text{ g}}{1 \text{ mL}} = 1.35 \times 10^5 \text{ g}$$

This can be converted to pounds

$$1.35 \times 10^5 \text{ g} \times \frac{1 \text{ lb}}{454 \text{ g}} = 297 \text{ lb which rounds to 300 lb}$$

Notice that the result is expressed to one significant figure, because the volume was given to only one significant figure and only multiplications and divisions were done. The intermediate result, 1.35×10^5 g, was expressed to more significant figures because rounding should only be done at the end of a calculation.

Check that the result is reasonable.

☑ **Reasonable Result Check** The units are mass units, so they are reasonable. Gold is nearly 20 times denser than water. A liter (1000 mL) of water is about a quart and a quart of water (two pints) weighs about two pounds. Seven liters (7000 mL) of water should weigh 14 lb, and 20 times 14 gives 280 lb, which rounds to 300 lb, so 300 lb is reasonable. The movie is not—few people could run while carrying a 300-lb object!

PROBLEM-SOLVING PRACTICE 1.1

Solve another related problem.

Calculate the volume occupied by a 4.33-g sample of benzene.

Estimation Enhancing students' abilities to estimate results is the goal of the *Estimation* boxes found in most chapters. These are a unique feature of this book. Each Estimation poses a problem that relates to the content of the chapter in which it appears and for which an approximate solution suffices. Students gain knowledge of various means of approximation, such as back-of-the-envelope calculations and graphing, and are encouraged to use diverse sources of information, such as encyclopedias, handbooks, and the Internet.

Exercises To further ensure that students do not merely memorize algorithmic solutions to specific problems, we provide 353 *Exercises,* which immediately follow introduction of new concepts within each chapter. Often the results that students obtain from a numeric Exercise provide insights into the concepts. Most Exercises are thought provoking and require that students apply conceptual thinking. Exercises that are conceptual rather than mathematical are clearly designated as shown below.

CONCEPTUAL EXERCISE 5.13

_h_ Atomic Orbitals

Using the same reasoning developed for *s, p, d,* and *f* atomic orbitals, determine the *n* value of the first shell that could contain *h* atomic orbitals. How many *h* atomic orbitals are in that shell?

Exercises that are designed to test understanding of a concept are identified as conceptual.

Problem-Solving Examples, Problem-Solving Practice problems, Estimation boxes, and Exercises are all designed to stimulate active thinking and participation by students as they read the text and to help them hone their understanding of concepts. The grand total of more than 600 of these **active-learning items** exceeds the number found in any similar textbook.

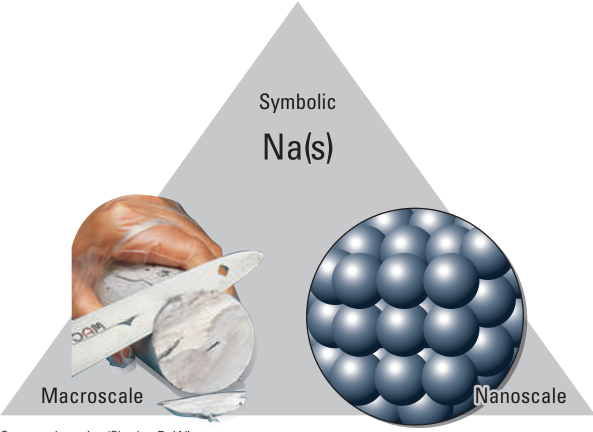
End-of-Chapter Questions At the end of each chapter we provide *Review Questions, Topical Questions, General Questions, Applying Concepts, More Challenging Questions,* and *Conceptual Challenge Problems.* Topical Questions are keyed to the sections in the chapter and to the learning goals in the "Having studied this chapter you should be able to" section at the end of each chapter. General Questions typically involve only one concept or topic, but students are required to think about which concept is needed to answer the question; no immediate indication is given regarding where to look in the chapter for the concept. Applying Concepts questions explicitly require conceptual thinking instead of numerical calculations and are designed to test students' understanding of concepts. It has been clearly established by research on cognition in both chemistry and physics that many students can correctly answer numerical-calculation questions, yet not understand concepts well enough to answer simple conceptual questions. Applying Concepts questions have been designed to address this issue. More Challenging Questions are provided so that students' minds can be stretched to link two or more concepts and apply them to a problem. Conceptual Challenge Problems require out-of-the-box thinking and are suitable for group work by students.

Conceptual Understanding

We believe that a sound conceptual foundation is the best means by which students can approach and solve a wide variety of real-world problems. This approach is supported by considerable evidence in the literature: Students learn better and retain what they learn longer when they have mastered fundamental concepts. Chemistry requires familiarity with at least three conceptual levels:

- **Macroscale** (laboratory and real-world phenomena)
- **Nanoscale** (models involving particles: atoms, molecules, and ions)
- **Symbolic** (chemical formulas and equations, as well as mathematical equations)

These three conceptual levels are explicitly defined in Chapter 1 (see the figure below). This chapter emphasizes the value of the chemist's unique perspective on science and the world with a specific example of how chemical thinking can help solve a real-world problem—how tube wells in Bangladesh that were designed to prevent disease



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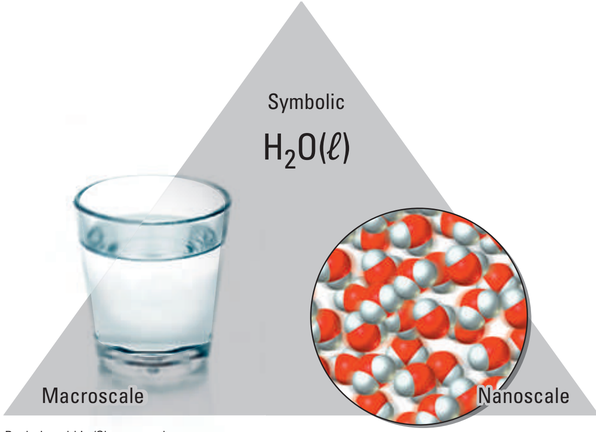

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resulted in arsenic contamination and how that contamination is being mitigated. This theme of conceptual understanding and its application to problems continues throughout the book. Many of the problem-solving features already mentioned have been specifically designed to support conceptual understanding.

The entire book has been assessed with respect to conceptual level by Dr. Kristin Briney. Using Bloom's Taxonomy as a guide, she analyzed Problem-Solving Examples, Exercises, learning goals at the end of each chapter, and the organization and content of end-of-chapter questions. All of these have been revised in response to this analysis. We believe that the conceptual level and consistency of this textbook make it significantly better than others.

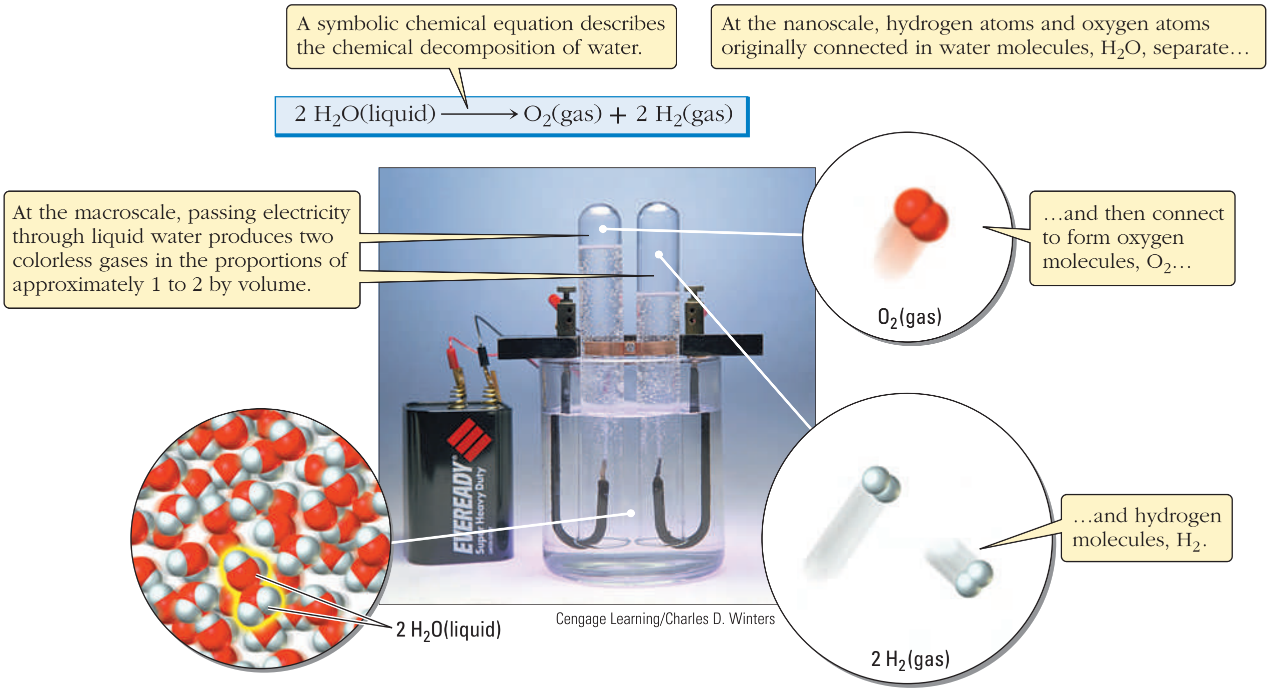
Units are introduced on a need-to-know basis at the first point in the book where they contribute to the discussion. Units for length, mass, volume, and density are defined in Chapter 1, in the discussion of the international system of units. Energy units are defined in Chapter 4, where they are first needed to deal with kinetic and potential energy, work, and heat. In each case, defining units at the time when the need for them can be made clear allows definitions that would otherwise appear pointless and arbitrary to support the development of closely related concepts.

We use real chemical systems in examples and problems whenever possible, both in the text and in the end-of-chapter questions. In the kinetics chapter, for example, the text and problems utilize real reactions and real data from which to determine reaction rates or orders. Instead of $A + B \rightarrow C + D$, students will find $I^- + CH_3Br \rightarrow CH_3I + Br^-$. Data have been taken from the recent research literature. The same approach is employed in many other chapters, where real chemical systems are used as examples.

Most important, we provide **clear, direct, thorough, and understandable explanations** of all topics, including those such as stoichiometry, chemical kinetics, chemical thermodynamics, chemical equilibrium, and electrochemistry that many students find daunting. The methods of science and concepts such as chemical and physical properties; purification and separation; the relation of macroscale, nanoscale, and symbolic representations; elements and compounds; and kinetic-molecular theory are introduced in Chapter 1 so that they can be used throughout the later discussion. Rather than being bogged down with discussions of units and nomenclature, students begin this book with an overview of what real chemistry is about—together with fundamental ideas that they will need to understand it.

Visualization for Understanding

The **illustrations** in *Chemistry: The Molecular Science* have been designed to engage today's visually oriented students. The success of the illustration program is exemplified by the fact that the first edition was awarded a national prize for visual excellence.



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Nevertheless, for this edition we have re-examined carefully each piece of art and revised more than 300 figures. In most cases these revisions have expanded the use of macroscale/nanoscale illustrations of the type shown here and there has been much more use of text and pointers to call students' attention to the important ideas or observations in each figure. Illustrations help students to visualize atoms and molecules and to make connections among macroscale observations, nanoscale models, and symbolic representations of chemistry. Excellent color photographs of substances and reactions, many by Charles D. Winters and James L. Maynard, are presented together with greatly magnified illustrations of the atoms, molecules, and/or ions involved. Often these are accompanied by the symbolic formula for a substance or equation for a reaction, as in the example shown. These **nanoscale views of atoms, molecules, and ions** have been generated with molecular modeling software and then combined by a skilled artist with the photographs and formulas or equations. Similar illustrations appear in exercises, examples, and end-of-chapter problems, thereby ensuring that students are tested on the ideas the illustrations represent. Consistent color-coding is used throughout, as illustrated in the Style Key. This provides an exceptionally effective way for students to learn how chemists think about the nanoscale world of atoms, molecules, and ions.

Often the story is carried solely by an illustration that includes text and pointers to indicate the most important parts of the figure. This too is illustrated in the example figure. Text and pointers are also used to explain the operation of instruments, apparatus, and experiments; to clarify the development of a mathematical derivation; or to point out salient features of graphs or nanoscale pictures. Throughout the book visual interest is high, and visualizations of many kinds are used to support conceptual development. This more effective use of illustrations has enabled us to reduce the length of textual descriptions and explanations.

Interdisciplinary Applications

Whenever possible we include **practical applications**, especially those applications that students will revisit when they study other natural science and engineering disciplines. To enhance and improve this aspect of the book, we have asked for advice from an