GLOBAL EDITION

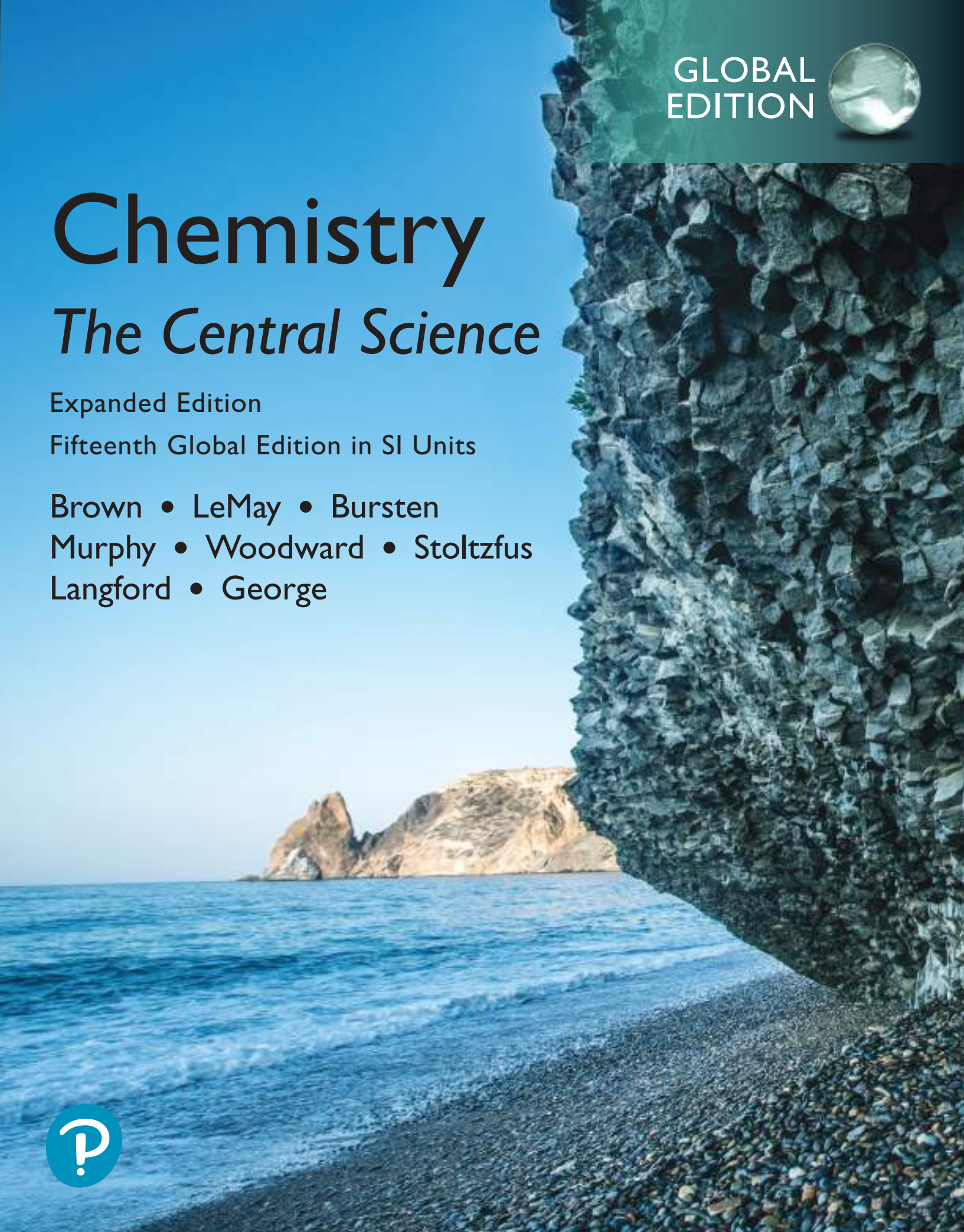
Chemistry

The Central Science

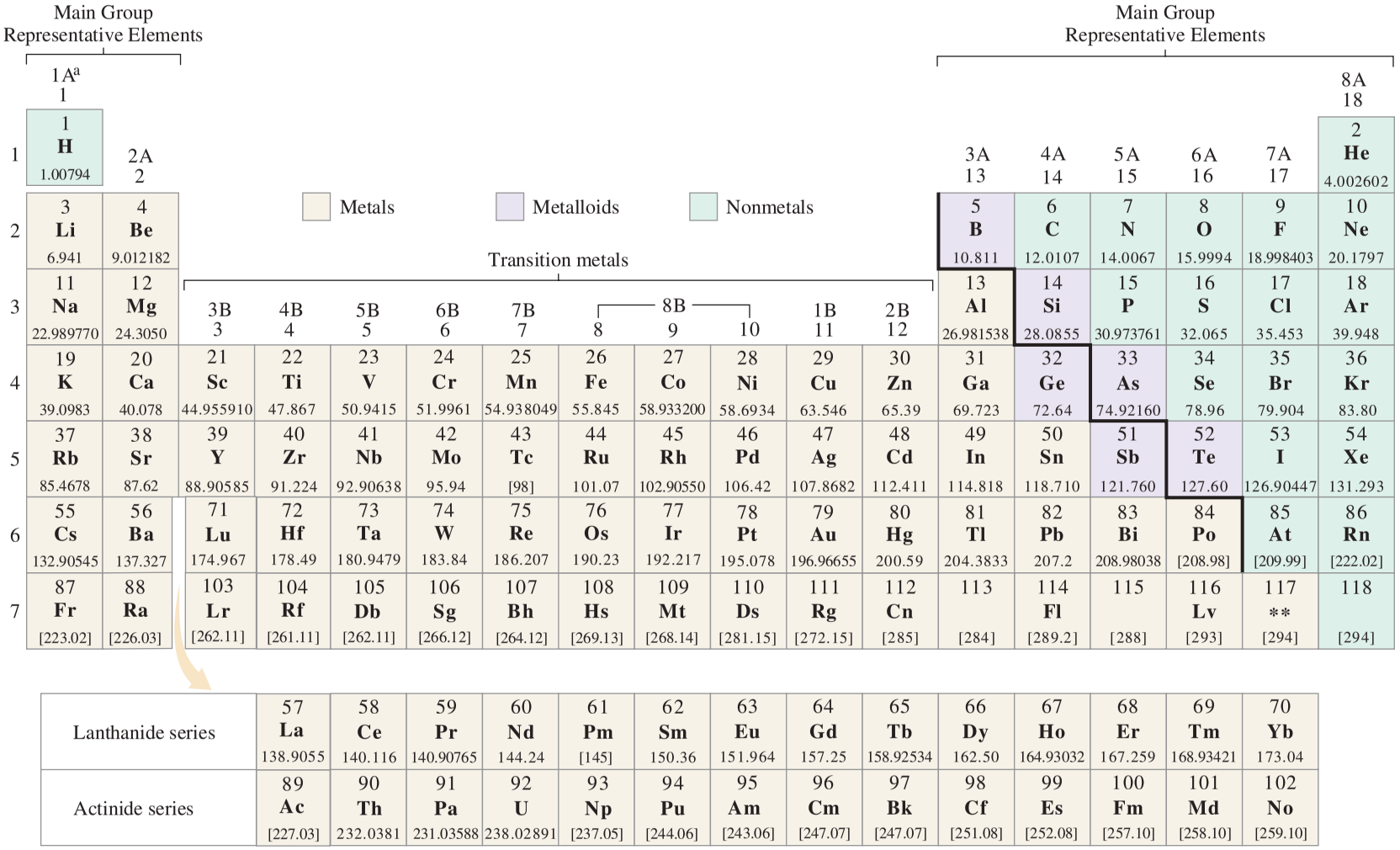
Expanded Edition

Fifteenth Global Edition in SI Units

Brown • LeMay • Bursten
Murphy • Woodward • Stoltzfus
Langford • George



Periodic Table of the Elements



[a] The labels on top (1A, 2A, etc.) are common American usage. The labels below these (1, 2, etc.) are those recommended by the International Union of Pure and Applied Chemistry (IUPAC).

Except for elements 114 and 116, the names and symbols for elements above 113 have not yet been decided.

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

Further information is available at http://www.webelements.com

** Discovered in 2010, element 117 is currently under review by IUPAC.

List of Elements with Their Symbols and Atomic Weights

Element	Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89	227.03a
Aluminum	Al	13	26.981538
Americium	Am	95	243.06a
Antimony	Sb	51	121.760
Argon	Ar	18	39.948
Arsenic	As	33	74.92160
Astatine	At	85	209.99a
Barium	Ba	56	137.327
Berkelium	Bk	97	247.07a
Beryllium	Be	4	9.012183
Bismuth	Bi	83	208.98038
Bohrium	Bh	107	270.1a
Boron	B	5	10.81
Bromine	Br	35	79.904
Cadmium	Cd	48	112.414
Calcium	Ca	20	40.078
Californium	Cf	98	251.08a
Carbon	C	6	12.0107
Cerium	Ce	58	140.116
Cesium	Cs	55	132.905452
Chlorine	Cl	17	35.453
Chromium	Cr	24	51.9961
Cobalt	Co	27	58.933194
Copernicium	Cn	112	285.2[a]
Copper	Cu	29	63.546
Curium	Cm	96	247.07a
Darmstadtium	Ds	110	281.2a
Dubnium	Db	105	268.1a
Dysprosium	Dy	66	162.50
Einsteinium	Es	99	252.08a
Erbium	Er	68	167.259
Europium	Eu	63	151.964
Fermium	Fm	100	257.10a
Flerovium	Fl	114	289.2a
Fluorine	F	9	18.9984016
Francium	Fr	87	223.02a
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.723
Germanium	Ge	32	72.64
Gold	Au	79	196.966569
Hafnium	Hf	72	178.49
Hassium	Hs	108	269.1a
Helium	He	2	4.002602a
Holmium	Ho	67	164.93033
Hydrogen	H	1	1.00794
Indium	In	49	114.818
Iodine	I	53	126.90447
Iridium	Ir	77	192.217
Iron	Fe	26	55.845
Krypton	Kr	36	83.80
Lanthanum	La	57	138.9055
Lawrencium	Lr	103	262.11a
Lead	Pb	82	207.2
Lithium	Li	3	6.941
Livermorium	Lv	116	293[a]
Lutetium	Lu	71	174.967
Magnesium	Mg	12	24.3050
Manganese	Mn	25	54.938044
Meitnerium	Mt	109	278.2a
Mendelevium	Md	101	258.10a
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.95
Moscovium	Mc	115	289.2a
Neodymium	Nd	60	144.24
Neon	Ne	10	20.1797
Neptunium	Np	93	237.05a
Nickel	Ni	28	58.6934
Nihonium	Nh	113	286.2[a]
Niobium	Nb	41	92.90637
Nitrogen	N	7	14.0067
Nobelium	No	102	259.10a
Oganesson	Og	118	294.2a
Osmium	Os	76	190.23
Oxygen	O	8	15.9994
Palladium	Pd	46	106.42
Phosphorus	P	15	30.973762
Platinum	Pt	78	195.078
Plutonium	Pu	94	244.06a
Polonium	Po	84	208.98a
Potassium	K	19	39.0983
Praseodymium	Pr	59	140.90766
Promethium	Pm	61	145a
Protactinium	Pa	91	231.03588
Radium	Ra	88	226.03a
Radon	Rn	86	222.02a
Rhenium	Re	75	186.207a
Rhodium	Rh	45	102.90550
Roentgenium	Rg	111	282.2a
Rubidium	Rb	37	85.4678
Ruthenium	Ru	44	101.07
Rutherfordium	Rf	104	267.1a
Samarium	Sm	62	150.36
Scandium	Sc	21	44.955908
Seaborgium	Sg	106	269.1a
Selenium	Se	34	78.97
Silicon	Si	14	28.0855
Silver	Ag	47	107.8682
Sodium	Na	11	22.989770
Strontium	Sr	38	87.62
Sulfur	S	16	32.065
Tantalum	Ta	73	180.9479
Technetium	Tc	43	98a
Tellurium	Te	52	127.60
Tennessine	Ts	117	293.2a
Terbium	Tb	65	158.92534
Thallium	Tl	81	204.3833
Thorium	Th	90	232.0377
Thulium	Tm	69	168.93422
Tin	Sn	50	118.710
Titanium	Ti	22	47.867
Tungsten	W	74	183.84
Uranium	U	92	238.02891
Vanadium	V	23	50.9415
Xenon	Xe	54	131.293
Ytterbium	Yb	70	173.04
Yttrium	Y	39	88.90584
Zinc	Zn	30	65.39
Zirconium	Zr	40	91.224

[a]Mass of longest-lived or most important isotope.

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Theodore L. Brown
University of Illinois at Urbana-Champaign

H. Eugene LeMay, Jr.
University of Nevada, Reno

Bruce E. Bursten
Worcester Polytechnic Institute

Catherine J. Murphy
University of Illinois at Urbana-Champaign

Patrick M. Woodward
The Ohio State University

Matthew W. Stoltzfus
The Ohio State University

Adrian V. George
University of Sydney

Steven J. Langford
Swinburne University of Technology

With contributions by

Michael W. Lufaso
University of North Florida

Pearson

Pearson Education Limited

KAO Two
KAO Park
Hockham Way
Harlow
CM17 9SR
United Kingdom

and Associated Companies throughout the world

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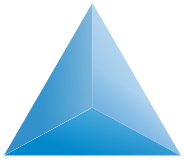

To our students,
whose enthusiasm and curiosity
have often inspired us,
and whose questions and suggestions
have sometimes taught us.

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PREFACE

To the Instructor

Philosophy

We the authors of *Chemistry: The Central Science* are delighted and honored that you have chosen us as your instructional partners for your chemistry class. Collectively we have taught chemistry to multiple generations of students. So we understand the challenges and opportunities of teaching a class that so many students take. We have also been active researchers who appreciate both the learning and the discovery aspects of the chemical sciences. Our varied, wide-ranging experiences have formed the basis of the close collaborations we have enjoyed as coauthors. In writing our book, our focus is on the students: we try to ensure that the text is not only accurate and up-to-date but also clear and readable. We strive to convey the breadth of chemistry and the excitement that scientists experience in making new discoveries that contribute to our understanding of the physical world. We want the student to appreciate that chemistry is not a body of specialized knowledge that is separate from most aspects of modern life, but central to any attempt to address a host of societal concerns, including renewable energy, environmental sustainability, and improved human health.

Publishing the fifteenth edition of this text bespeaks an exceptionally long record of successful textbook writing. We are appreciative of the loyalty and support the book has received over the years, and mindful of our obligation to justify each new edition. We begin our approach to each new edition with an intensive author retreat, in which we ask ourselves the deep questions that we must answer before we can move forward. What justifies yet another edition? What is changing in the world not only of chemistry, but with respect to science education and the qualities of the students we serve? How can we help your students not only learn the principles of chemistry, but also become critical thinkers who can think more like chemists? The answers lie only partly in the changing face of chemistry itself. The introduction of many new technologies has changed the landscape in the teaching of sciences at all levels. The use of the Internet in accessing information and presenting learning materials has markedly changed the role of the textbook as one element among many tools for student learning. Our challenge as authors is to maintain the text as the primary source of chemical knowledge and practice while at the same time integrating it with the new avenues for learning made possible by technology. This edition continues to incorporate a number of those new methodologies, including use of computer-based classroom tools, such as Learning Catalytics™, a cloud-based active learning analytics and assessment system, and web-based tools, particularly Pearson Mastering Chemistry, which is continually evolving to provide more effective means of testing and evaluating student performance, while giving the student immediate and helpful feedback. Pearson Mastering Chemistry not only provides feedback on a question by question basis but, using Knewton-enhanced adaptive follow-up assignments, it now continually adapts to each student, offering a personalized learning experience.

As authors, we want this text to be a central, indispensable learning tool for students. Whether as a physical book or in electronic form, it can be carried everywhere and used at any time. It is the best resource for students to obtain the information outside of the classroom needed for learning, skill development, reference, and test preparation. The text, more effectively than any other instrument, provides the depth of coverage and coherent background in modern chemistry that students need to serve their professional interests and, as appropriate, to prepare for more advanced chemistry courses.

If the text is to be effective in supporting your role as instructor, it must be addressed to the students. We have done our best to keep our writing clear and interesting and the book attractive and well illustrated. The book has numerous in-text study aids for students including carefully placed descriptions of problem-solving strategies. We hope that our cumulative experiences as teachers is evident in our pacing, choice of examples, and the kinds of study aids and motivational tools we have employed. We believe students are more enthusiastic about learning chemistry when they see its importance relative to their own goals and interests; therefore, we have highlighted many important applications of chemistry in everyday life. We hope you make use of this material.

It is our philosophy, as authors, that the text and all the supplementary materials provided to support its use must work in concert with you, the instructor. A textbook is only as useful to students as the instructor permits it to be. This book is replete with features that help students learn and that can guide them as they acquire both conceptual understanding and problem-solving skills. There is a great deal here for the students to use, too much for all of it to be absorbed by any student in a one-year course. You will be the guide to the best use of the book. Only with your active help will the students be able to utilize most effectively all that the text and its supplements offer. Students care about grades, of course, and with encouragement they will also become interested in the subject matter and care about learning. Please consider emphasizing features of the book that can enhance student appreciation of chemistry, such as the *Chemistry Put To Work* and *Chemistry and Life* boxes that show how chemistry impacts modern life and its relationship to health and life processes. Also consider emphasizing conceptual understanding (placing less emphasis on simple manipulative, algorithmic problem solving) and urging students to use the rich online resources available.

Organization and Contents

The first five chapters give a largely macroscopic, phenomenological view of chemistry. The basic concepts introduced—such as nomenclature, stoichiometry, and thermochemistry—provide necessary background for many of the laboratory experiments usually performed in chemistry. We believe that an early introduction to thermochemistry is desirable because so much of our understanding of chemical processes is based on considerations of energy changes. As before, we discuss bond enthalpies in the Thermochemistry chapter to emphasize the connection between the macroscopic properties of substances and the submicroscopic world of atoms and bonds. We believe this enables an effective, balanced approach to teaching thermodynamics in general chemistry, as well as provides students with an introduction to some of the global issues involving energy production and consumption. It is no easy matter to walk the narrow pathway between—on the one hand—trying to teach too much at too high a level and—on the other hand—resorting to oversimplifications. As with the book as a whole, the emphasis has been on imparting *conceptual* understanding, as opposed to presenting equations into which students are supposed to plug numbers.

The next four chapters (Chapters 6–9) deal with electronic structure and bonding. For more advanced students, *A Closer Look* boxes in Chapters 6 and 9 highlight radial probability functions and the phases of orbitals. Our approach of placing this latter discussion in *A Closer Look* box in Chapter 9 enables those who wish to cover this topic to do so, while others may wish to bypass it.

In Chapters 10–13, the focus of the text changes to the next level of the organization of matter: examining the states of matter. Chapters 10 and 11 deal with gases, liquids, and intermolecular forces, while Chapter 12 is devoted to solids, presenting a contemporary view of the solid state as well as of modern materials accessible to general chemistry students. The chapter provides an opportunity to show how abstract chemical bonding concepts impact real-world applications. The modular organization of the chapter allows instructors to tailor coverage to focus on the materials (semiconductors, polymers, nanomaterials, and so forth) that are most relevant to students and instructors alike. This section of the book concludes with Chapter 13, which covers the formation and properties of solutions.

The next several chapters examine the factors that determine the speed and extent of chemical reactions: kinetics (Chapter 14), equilibria (Chapters 15–17), thermodynamics (Chapter 19), and electrochemistry (Chapter 20). Also in this section is a chapter on environmental chemistry (Chapter 18), in which the concepts developed in preceding chapters are applied to a discussion of the atmosphere and hydrosphere. This chapter has increasingly come to be focused on green chemistry and the impacts of human activities on Earth's water and atmosphere.

After a discussion of nuclear chemistry (Chapter 21), the book has two survey chapters. Chapter 22 deals with nonmetals, and Chapter 23 with the chemistry of transition metals, including coordination compounds. These last three chapters are developed in an independent, modular fashion and can be covered in any order.

Organic chemistry is central to all living things and Chapters 24–32 lead us on a journey from elementary hydrocarbons to elaborate bio-organic molecules. Much of what we discuss is treated from a fundamental level so students' transition to tertiary studies in organic chemistry is smooth and rapid. We place emphasis on the core reactions observed in organic chemistry and treat many cases mechanistically. This fosters a deep understanding of why organic molecules react in the way they do, thereby giving students an opportunity to understand much more chemistry than is discussed.

Chapter 24 provides a foundation to our examination of organic chemistry by using hydrocarbons to illustrate how we represent and name organic molecules. It goes on to provide an overview of the functional groups—the reactive parts of the molecule—on which we build our understanding of organic chemistry. The shape of a molecule may be pivotal in determining its reactivity, particularly in a biological context, and Chapter 25 leads to an in-depth discussion of stereochemistry. The next six chapters cover the fundamental reactions encountered in organic chemistry, at each step building to the application of these reactions in a modern world (for example, polymerisation in Chapters 26 and 29) and their essential role in the chemistry of life (for example, carbohydrates in Chapter 28, fats in Chapter 29, proteins and nucleic acids in Chapter 31). Chapter 30 investigates aromatic compounds as a separate class. Here, it is important for the student to note the differences in reactivity to the alkenes studied in Chapter 26.

Finally, Chapter 32 stands alone as a reference guide to mass spectrometry, NMR spectroscopy, and IR spectroscopy. Whether these topics are taught with much emphasis on the technology is up to the instructor. What we believe is most important is students' development at complex problem-solving, bringing two or more concepts together to draw a logical conclusion. The approach to solving molecular structure also confirms their knowledge of the basic principles of organic chemistry, bonding, functional groups and drawing structural formulas. Our coverage of organic chemistry gives students a unique perspective and challenges the very 'standard format' often seen in a first-year text.

Our chapter sequence provides a fairly standard organization, but we recognize that not everyone teaches all the topics in the order we have chosen. We have, therefore, made sure that instructors can make common changes in teaching sequence with no loss in student comprehension. In particular, many instructors prefer to introduce gases (Chapter 10) after stoichiometry (Chapter 3) rather than with states of matter. The chapter on gases has been written to permit this change with *no* disruption in the flow of material. It is also possible to treat balancing redox equations (Sections 20.1 and 20.2) earlier, after the introduction of redox reactions in Section 4.4.

We have brought students into greater contact with descriptive organic and inorganic chemistry by integrating examples throughout the text. Students will find pertinent and relevant examples of "real" chemistry woven into all the chapters to illustrate principles and applications. Some chapters, of course, more directly address the "descriptive" properties of elements and their compounds, especially Chapters 4, 7, 11, 18, 22, and 23. We also incorporate descriptive organic and inorganic chemistry in the exercises found throughout each chapter.

New to This Edition

It is perhaps a natural tendency for chemistry textbooks to grow in length with succeeding editions, but it is one that we have resisted. There are, nonetheless, many updates to features to serve students and instructors better in the classroom. *Chemistry: The Central Science* has traditionally been valued for its clarity of writing, its scientific accuracy and currency, its strong end-of-chapter exercises, and its consistency in level of coverage. The book was updated in a way that did not compromise these characteristics, and we have also continued to employ an open, clean design in the layout of the book.

The art program for the fifteenth edition continues the trajectory set in the previous two editions: to make greater and more effective use of the figures as learning tools, by drawing the reader more directly into the figure. The style of the art enhances clarity with a clean and modern look. This includes white-background annotation boxes with crisp, thin leaders; rich and saturated colors in the art, and use of 3D renderings. Using statistics from Pearson Mastering Chemistry, we have shifted some Exercises to the ends of sections, where students are more likely to attempt them before moving on to more complex questions. Also in the ends of sections are new Self-Assessment Exercises that provide immediate assessment and feedback content in the form of multiple-choice questions meant to test the concepts learnt in the section. In the Pearson eText, these exercises provide specific wrong-answer feedback.

Updates to subject matter in chapter text, Sample Exercises, and assessment content reflect current trends in teaching chemistry.

Each section now opens with new section-opening text and images that enhance students' understanding of the concepts introduced in that section as well as explicate the historical contexts around key inventions and discoveries in chemistry.

This edition features eight detailed chapters on organic chemistry for instructors and students who have more in-depth course discussions on organic chemistry than those covered in the shorter, 24-chapter variant of this book. An additional chapter on spectrometry is also available. All these additional chapters come with the wealth of Sample Exercises, essay features, assessment content, and updated art that has made the title a favorite with students and instructors the world over.

- The essays titled *Strategies in Chemistry,* which provide advice to students on problem solving and "thinking like a chemist," have been renamed *Strategies for Success* to better convey their usefulness to the student.

Key Features in This Edition

Chemistry: The Central Science, continues to provide relevant, up-to-date content—be it art or assessment material—that enhances the clarity and effectiveness of the text. Key features for this edition include the following:

- The treatment of energy and thermochemistry draws on significant revisions to previous editions. The introduction of the concept of energy in Chapter 1 allows instructors greater freedom in the order in which they cover the material. For example, this arrangement facilitates coverage of Chapters 6 and 7 immediately following Chapter 2, a sequence that is in line with an atoms-first approach to teaching general chemistry. The discussion of bond enthalpies in Chapter 5 emphasizes the connection between macroscopic quantities, like reaction enthalpies, and the submicroscopic world of atoms and bonds. We feel this leads to a better integration of thermochemical concepts with the surrounding chapters. Bond enthalpies are revisited in Chapter 8 after students have developed a more sophisticated view of chemical bonding.
- The text continues to provide students with a clear discussion, superior problem sets, and better real-time feedback on students' understanding of the material. This is based on the authors' insight into student usage of the interactive e-book platform, such as the most frequently highlighted passages and the accompanying notes and questions.
- Extensive effort has gone into creating enhanced content for the Pearson eText for the book. These features make the eText so much more than just an electronic copy of the physical textbook. Self-Assessment Exercises at the end of each section are enhanced with specific wrong-answer feedback in the Pearson eText. New Smart Figures take key figures from the text and bring them to life through animation and narration. Smart Sample Exercises animate key sample exercises from the text, offering students a more in-depth and detailed discussion than can be provided in the printed text. These interactive features also include follow-up questions, which can be assigned in Pearson Mastering Chemistry.
- Finally, Subtle but important changes have been made to allow students to quickly reference important concepts and assess their knowledge of the material. Key points are set in italic with line spaces above and below for greater emphasis. The skills-based *How To . . .* features offer step-by-step guidance for solving specific types of problems such as Drawing Lewis Structures, Balancing Redox Equations, and Naming Acids. These features, with numbered steps encased by a thin rule, are integrated into the main discussion and are easy to find. Finally, each Learning Objective is now correlated to specific end-of-chapter exercises. This allows students to test their mastery of each learning objective when preparing for quizzes and exams.

We have continued to emphasize conceptual exercises in the end-of-chapter, problems. In each chapter, we begin the exercises with the well-received *Visualizing Concepts* category. These exercises are designed to facilitate conceptual understanding through use of models, graphs, photographs, and other visual materials. They precede the regular end-of-chapter exercises and are identified in each case with the relevant chapter section number. A generous selection of *Integrative Exercises,* which give students the opportunity to solve problems that integrate concepts from the present chapter with those of previous chapters, is included at the end of each chapter. The importance of integrative problem solving is highlighted by the *Sample Integrative Exercise,* which ends each chapter beginning with Chapter 4. In general, we have included more conceptual end-of-chapter exercises and have made sure that there is a good representation of somewhat more difficult exercises to provide a better mix in terms of topic and level of difficulty. Many of the exercises are structured in a way that makes it easy to use them in Pearson Mastering Chemistry. We have made extensive use of the metadata from student use of Pearson Mastering Chemistry to analyze end-of-chapter exercises and make appropriate changes, as well as to develop *Learning Outcomes* for each chapter.

The essays in our well-received *Chemistry Put To Work* and *Chemistry and Life* series emphasize world events, scientific discoveries, and medical breakthroughs relevant to topics developed in each chapter. We maintain our focus on the positive aspects of chemistry without neglecting the problems that can arise in an increasingly technological world. Our goal is to help students appreciate the real-world perspective of chemistry and the ways in which chemistry affects their lives.

To the Student

Chemistry: The Central Science, Fifteenth Edition, has been written to introduce you to modern chemistry. As authors, we have, in effect, been engaged by your instructor to help you learn chemistry. Based on the comments of students and instructors who have used this book in its previous editions, we believe that we have done that job well. Of course, we expect the text to continue to evolve through future editions. We invite you to write to tell us what you like about the book so that we will know where we have helped you most. Also, we would like to learn of any shortcomings so we may further improve the book in subsequent editions. Our addresses are given at the end of the Preface.

Advice for Learning and Studying Chemistry

Learning chemistry requires both the assimilation of many concepts and the development of analytical skills. In this text, we have provided you with numerous tools to help you succeed in both tasks. If you are going to succeed in your chemistry course, you will have to develop good study habits. Science courses, and chemistry in particular, make different demands on your learning skills than do other types of courses. We offer the following tips for success in your study of chemistry:

Don't fall behind! As the course moves along, new topics will build on material already presented. If you don't keep up in your reading and problem solving, you will find it much harder to follow the lectures and discussions on current topics. Experienced teachers know that students who read the relevant sections of the text *before* coming to a class learn more from the class and retain greater recall. "Cramming" just before an exam has been shown to be an ineffective way to study any subject, chemistry included. So now you know. How important to you, in this competitive world, is a good grade in chemistry?

Focus your study. The amount of information you will be expected to learn may seem overwhelming. It is essential to recognize those concepts and skills that are particularly important. Pay attention to what your instructor is emphasizing. As you work through the *Sample Exercises* and homework assignments, try to see what general principles and skills they employ. A single reading of a chapter will generally not be enough for successful learning of chapter concepts and problem-solving skills. You will often need to go over assigned materials more than once. Don't skip the *Go Figure* features, *Sample Exercises,* and *Practice Exercises.* These are your guides to whether you are learning the material. They are also good preparation for test-taking. The *Learning Outcomes* and *Key Equations* at the end of the chapter will also help you focus your study.

Keep good lecture notes. Your lecture notes will provide you with a clear and concise record of what your instructor regards as the most important material to learn. Using your lecture notes in conjunction with this text is the best way to determine which material to study.

Skim topics in the text before they are covered in lecture. Reviewing a topic before lecture will make it easier for you to take good notes. First read the end-of-chapter *Summary;* then quickly read through the chapter, skipping Sample Exercises and supplemental sections. Paying attention to the titles of sections and subsections gives you a feeling for the scope of topics. Try to avoid thinking that you must learn and understand everything right away.

You need to do a certain amount of preparation before lecture. More than ever, instructors are using the lecture period not simply as a one-way channel of communication from teacher to student. Rather, they expect students to come to class ready to work on problem solving and critical thinking. Coming to class unprepared is not a good idea for any lecture environment, but it certainly is not an option for an active learning classroom if you aim to do well in the course.

After lecture, carefully read the topics covered in class. As you read, pay attention to the concepts presented and to the application of these concepts in the *Sample Exercises.* Once you think you understand a *Sample Exercise,* test your understanding by working the accompanying *Practice Exercise.*

Learn the language of chemistry. As you study chemistry, you will encounter many new words. It is important to pay attention to these words and to know their meanings or the entities to which they refer. Knowing how to identify chemical substances from their names is an important skill; it can help you avoid painful mistakes on examinations. For example, "chlorine" and "chloride" refer to very different things.