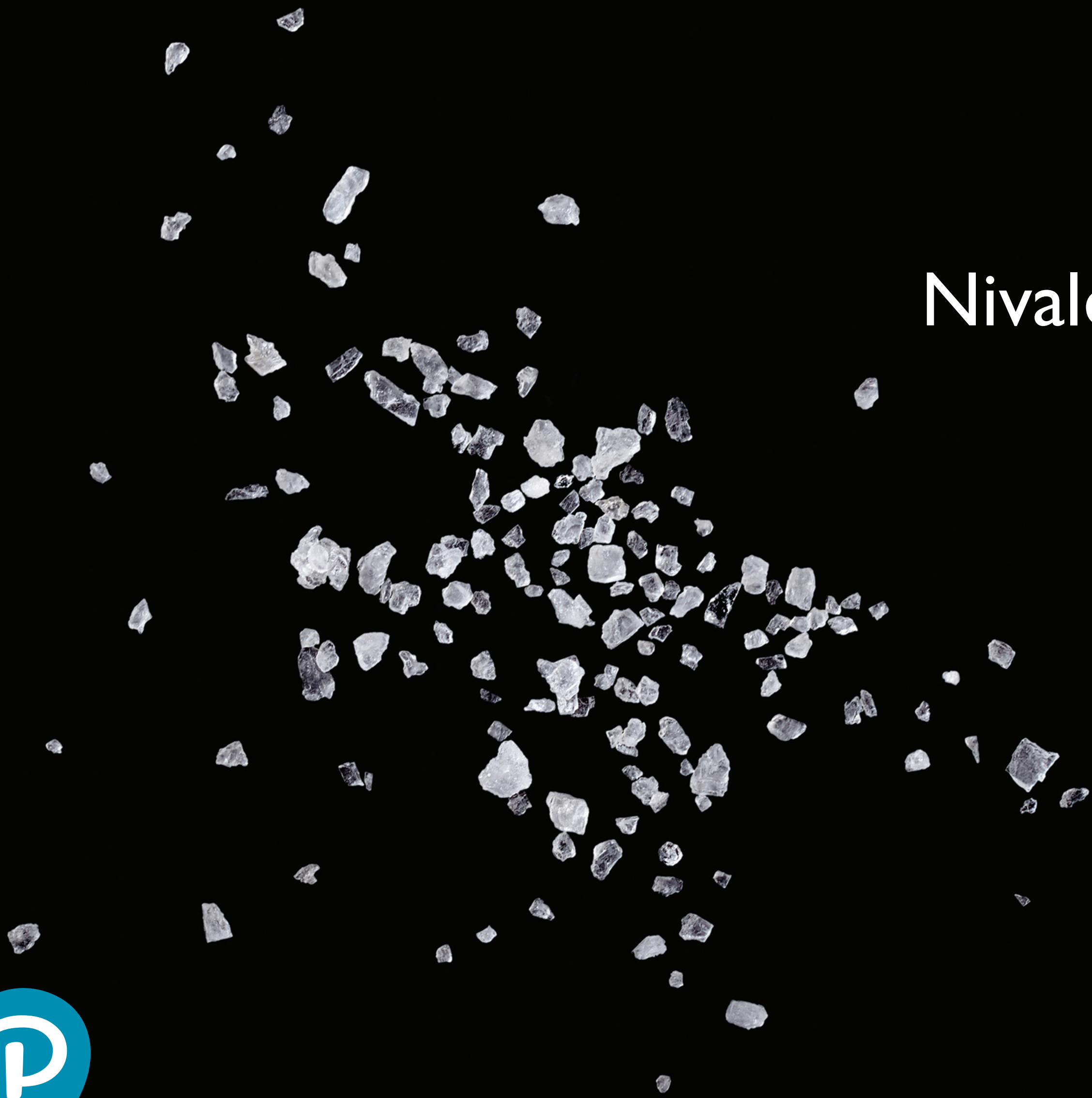
GLOBAL EDITION

Principles of Chemistry

A Molecular Approach

FOURTH EDITION



Nivaldo J. Tro

List of Elements with Their Symbols and Atomic Masses

Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	227.03[a]
Aluminum	Al	13	26.98
Americium	Am	95	243.06[a]
Antimony	Sb	51	121.76
Argon	Ar	18	39.95
Arsenic	As	33	74.92
Astatine	At	85	209.99[a]
Barium	Ba	56	137.33
Berkelium	Bk	97	247.07[a]
Beryllium	Be	4	9.012
Bismuth	Bi	83	208.98
Bohrium	Bh	107	264.12[a]
Boron	B	5	10.81
Bromine	Br	35	79.90
Cadmium	Cd	48	112.41
Calcium	Ca	20	40.08
Californium	Cf	98	251.08[a]
Carbon	C	6	12.01
Cerium	Ce	58	140.12
Cesium	Cs	55	132.91
Chlorine	Cl	17	35.45
Chromium	Cr	24	52.00
Cobalt	Co	27	58.93
Copernicium	Cn	112	285[a]
Copper	Cu	29	63.55
Curium	Cm	96	247.07[a]
Darmstadtium	Ds	110	271[a]
Dubnium	Db	105	262.11[a]
Dysprosium	Dy	66	162.50
Einsteinium	Es	99	252.08[a]
Erbium	Er	68	167.26
Europium	Eu	63	151.96
Fermium	Fm	100	257.10[a]
Flerovium	Fl	114	289[a]
Fluorine	F	9	19.00
Francium	Fr	87	223.02[a]
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.72
Germanium	Ge	32	72.63
Gold	Au	79	196.97
Hafnium	Hf	72	178.49
Hassium	Hs	108	269.13[a]
Helium	He	2	4.003
Holmium	Ho	67	164.93
Hydrogen	H	1	1.008
Indium	In	49	114.82
Iodine	I	53	126.90
Iridium	Ir	77	192.22
Iron	Fe	26	55.85
Krypton	Kr	36	83.80
Lanthanum	La	57	138.91
Lawrencium	Lr	103	262.11[a]
Lead	Pb	82	207.2
Lithium	Li	3	6.94
Livermorium	Lv	116	292[a]
Lutetium	Lu	71	174.97
Magnesium	Mg	12	24.31
Manganese	Mn	25	54.94
Meitnerium	Mt	109	268.14[a]
Mendelevium	Md	101	258.10[a]
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.95
Moscovium	Mc	115	289[a]
Neodymium	Nd	60	144.24
Neon	Ne	10	20.18
Neptunium	Np	93	237.05[a]
Nickel	Ni	28	58.69
Nihonium	Nh	113	284[a]
Niobium	Nb	41	92.91
Nitrogen	N	7	14.01
Nobelium	No	102	259.10[a]
Oganesson	Og	118	294[a]
Osmium	Os	76	190.23
Oxygen	O	8	16.00
Palladium	Pd	46	106.42
Phosphorus	P	15	30.97
Platinum	Pt	78	195.08
Plutonium	Pu	94	244.06[a]
Polonium	Po	84	208.98[a]
Potassium	K	19	39.10
Praseodymium	Pr	59	140.91
Promethium	Pm	61	145[a]
Protactinium	Pa	91	231.04
Radium	Ra	88	226.03[a]
Radon	Rn	86	222.02[a]
Rhenium	Re	75	186.21
Rhodium	Rh	45	102.91
Roentgenium	Rg	111	272[a]
Rubidium	Rb	37	85.47
Ruthenium	Ru	44	101.07
Rutherfordium	Rf	104	261.11[a]
Samarium	Sm	62	150.36
Scandium	Sc	21	44.96
Seaborgium	Sg	106	266.12[a]
Selenium	Se	34	78.97
Silicon	Si	14	28.09
Silver	Ag	47	107.87
Sodium	Na	11	22.99
Strontium	Sr	38	87.62
Sulfur	S	16	32.06
Tantalum	Ta	73	180.95
Technetium	Tc	43	98[a]
Tellurium	Te	52	127.60
Tennessine	Ts	117	294[a]
Terbium	Tb	65	158.93
Thallium	Tl	81	204.38
Thorium	Th	90	232.04
Thulium	Tm	69	168.93
Tin	Sn	50	118.71
Titanium	Ti	22	47.87
Tungsten	W	74	183.84
Uranium	U	92	238.03
Vanadium	V	23	50.94
Xenon	Xe	54	131.293
Ytterbium	Yb	70	173.05
Yttrium	Y	39	88.91
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.22

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

Main groups | Transition metals | Main groups

Metals | Metalloids | Nonmetals

Period	1A[a] 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** 1.008																	2 **He** 4.003
2	3 **Li** 6.94	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.97	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** [98]	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** [208.98]	85 **At** [209.99]	86 **Rn** [222.02]
7	87 **Fr** [223.02]	88 **Ra** [226.03]	89 **Ac** [227.03]	104 **Rf** [261.11]	105 **Db** [262.11]	106 **Sg** [266.12]	107 **Bh** [264.12]	108 **Hs** [269.13]	109 **Mt** [268.14]	110 **Ds** [271]	111 **Rg** [272]	112 **Cn** [285]	113 **Nh** [284]	114 **Fl** [289]	115 **Mc** [289]	116 **Lv** [292]	117 **Ts** [294]	118 **Og** [294]

Lanthanide series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** [145]	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
Actinide series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** [237.05]	94 **Pu** [244.06]	95 **Am** [243.06]	96 **Cm** [247.07]	97 **Bk** [247.07]	98 **Cf** [251.08]	99 **Es** [252.08]	100 **Fm** [257.10]	101 **Md** [258.10]	102 **No** [259.10]	103 **Lr** [262.11]

[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.

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

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GLOBAL EDITION

Nivaldo J. Tro

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About the Author

Nivaldo Tro has been teaching college Chemistry since 1990 and is currently teaching at Santa Barbara City College. He received his Ph.D. in chemistry from Stanford University for work on developing and using optical techniques to study the adsorption and desorption of molecules to and from surfaces in ultrahigh vacuum. He then went on to the University of California at Berkeley, where he did postdoctoral research on ultrafast reaction dynamics in solution. Professor Tro has been awarded grants from the American Chemical Society Petroleum Research Fund, the Research Corporation, and the National Science Foundation to study the dynamics of various processes occurring in thin adlayer films adsorbed on dielectric surfaces. Professor Tro lives in Santa Barbara with his wife, Ann, and their four children, Michael, Ali, Kyle, and Kaden. In his leisure time, Professor Tro enjoys mountain biking, surfing, and being outdoors with his family.

To Michael, Ali, Kyle, and Kaden

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Interactive Media Contents in Mastering Chemistry

KEY CONCEPT VIDEOS (KCVs)

INTERACTIVE WORKED EXAMPLES (IWEs)

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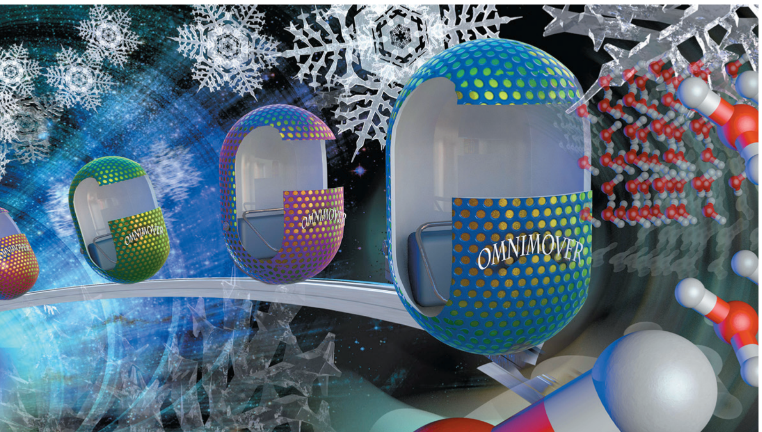

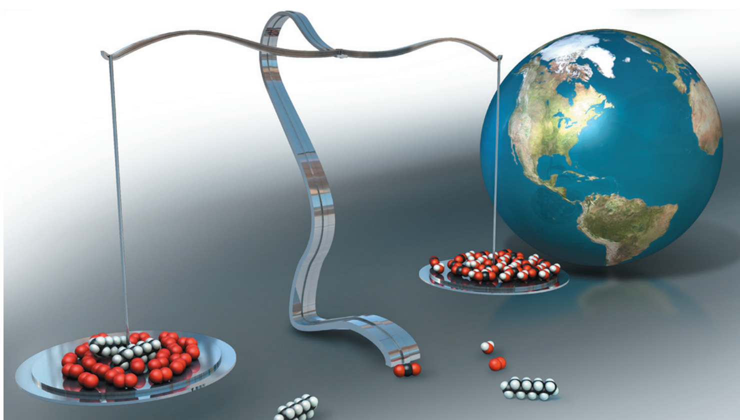

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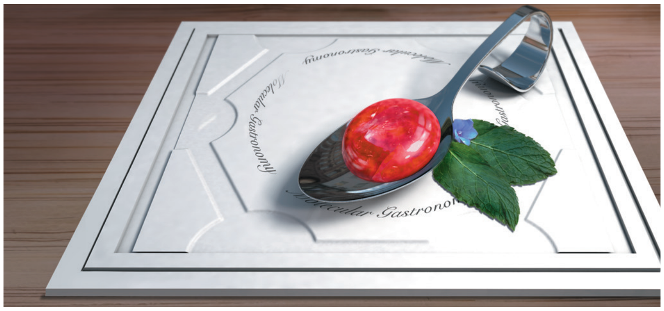

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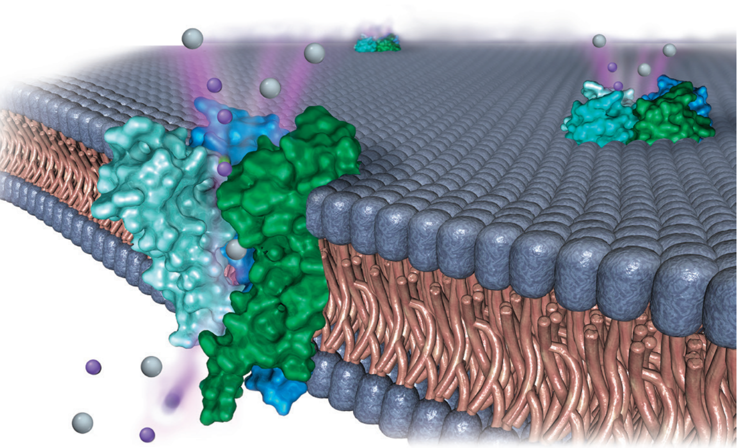
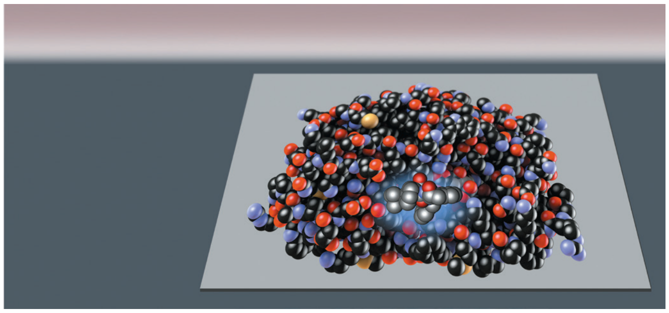
4 Fe(s) + 3 O2(g) → 2 Fe2O3(s)
159.7


Schrödinger's Cat





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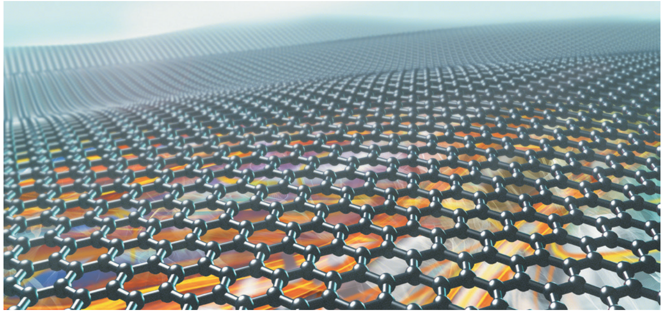

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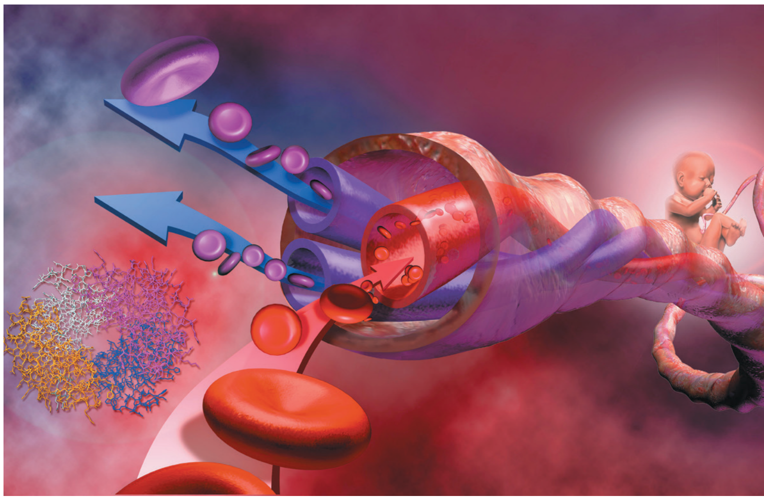

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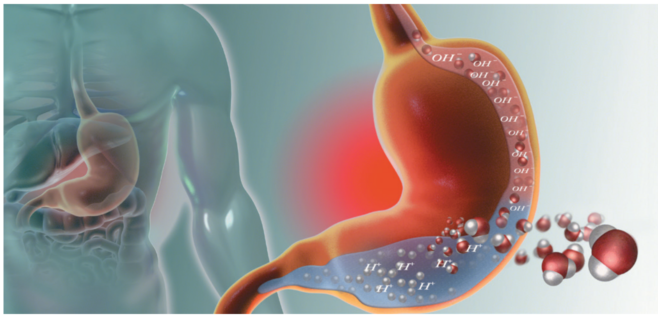

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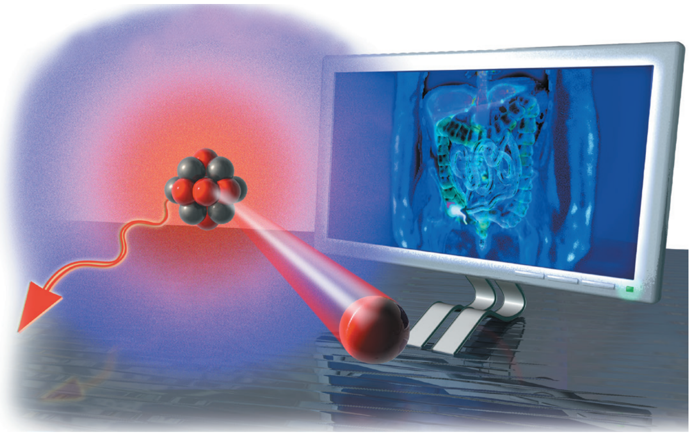

Preface

To the Student

As you begin this course, I invite you to think about your reasons for enrolling in it. Why are you taking general chemistry? More generally, why are you pursuing a college education? If you are like most college students taking general chemistry, part of your answer is probably that this course is required for your major and that you are pursuing a college education so you can get a good job some day. Although these are good reasons, I would like to suggest a better one. I think the primary reason for your education is to prepare you to *live a good life*. You should understand chemistry—not for what it can *get* you—but for what it can *do* to you. Understanding chemistry, I believe, is an important source of happiness and fulfillment. Let me explain.

Understanding chemistry helps you to live life to its fullest for two basic reasons. The first is *intrinsic*: through an understanding of chemistry, you gain a powerful appreciation for just how rich and extraordinary the world really is. The second reason is *extrinsic*: understanding chemistry makes you a more informed citizen—it allows you to engage with many of the issues of our day. In other words, understanding chemistry makes *you* a deeper and richer person and makes your country and the world a better place to live. These reasons have been the foundation of education from the very beginnings of civilization.

How does chemistry help prepare you for a rich life and conscientious citizenship? Let me explain with two examples. My first one comes from the very first page of Chapter 1 of this book. There, I ask the following question: What is the most important idea in all of scientific knowledge? My answer to that question is this: **the behavior of matter is determined by the properties of molecules and atoms**. That simple statement is the reason I love chemistry. We humans have been able to study the substances that compose the world around us and explain their behavior by reference to particles so small that they can hardly be imagined. If you have never realized the remarkable dependence of the world we *can* see on the world we *cannot*, you have missed out on a fundamental truth about our universe. To have never encountered this truth is like never having read a play by Shakespeare or seen a sculpture by Michelangelo—or, for that matter, like never having discovered that the world is round. It robs you of an amazing and unforgettable experience of the world and the human ability to understand it.

My second example demonstrates how science literacy helps you to be a better citizen. Although I am largely sympathetic to the environmental movement, a lack of science literacy within some sectors of that movement and the resulting anti-environmental backlash create confusion that impedes real progress and opens the door to what could be misinformed policies. For example, I have heard conservative pundits say that volcanoes emit more carbon dioxide—the most significant greenhouse gas—than does petroleum combustion. I have also heard a liberal environmentalist say that we have to stop using hair spray because it is causing holes in the ozone layer that will lead to global warming. Well, the claim about volcanoes emitting more carbon dioxide than petroleum combustion can be refuted by the basic tools you will learn to use in Chapter 4 of this book. We can easily show that volcanoes emit only 1/50th as much carbon dioxide as petroleum combustion. As for hair spray depleting the ozone layer and thereby leading to global warming, the chlorofluorocarbons that deplete ozone have been banned from hair spray since 1978, and ozone depletion has nothing to do with global warming anyway. People with special interests or axes to grind can conveniently distort the truth before an ill-informed public, which is why we all need to be knowledgeable.

So this is why I think you should take this course. Not just to satisfy the requirement for your major and not just to get a good job some day, but to help you to lead a fuller life and to make the world a little better for everyone. I wish you the best as you embark on the journey to understanding the world around you at the molecular level. The rewards are well worth the effort.

To the Professor

First and foremost, thanks to all of you who adopted this book in its previous editions. You helped to make this book one of the most popular general chemistry textbooks in the world. I am grateful beyond words. Second, I have listened carefully to your feedback on the previous edition. The changes you see in this edition are the direct result of your input, as well as my own experience using the book in my general chemistry courses. If you have reviewed content or have contacted me directly, you will likely see your suggestions reflected in the changes I have made. Thank you.

Higher education in science is changing. Foremost among those changes is a shift toward *active learning*. A flood of recent studies has demonstrated that General Chemistry students learn better when they are active in the learning process. However, implementing active learning can be a difficult and time-consuming process. One of my main goals in this revision is to give you, the professor, a range of tools to easily implement active learning in your class. My goal is simple: *I want to make it easy for you to engage your students in active learning before class, during class, and after class.*

- **BEFORE CLASS** Although the term *active learning* has been applied mainly to in-class learning, the main idea—*that we learn better when we are actively engaged*—applies to all of learning. I have developed two main tools to help students prepare for class in an active way. The first tool is a complete library of 3– to 6–minute *Key Concept Videos* (*KCVs*) that, with this edition, span virtually all of the key concepts in a general chemistry course. The videos introduce a key concept and encourage active learning because they stop in the middle and pose a question that must be answered before the video continues playing. Each video also has an associated follow-up question that can be assigned using Mastering Chemistry. You can assign a video before each one of your classes to get your students thinking about the concepts for that day. A second tool for use before class is *active reading.* Each chapter in the book now contains 10–12 *Conceptual Connection* questions. These questions are assignable in Mastering Chemistry, and contain wrong answer feedback. Instead of passively reading the assigned material with no accountability, you can now encourage your students to engage in *active reading*, in which they read a bit and then answer a question that probes their comprehension and gives them immediate feedback.
- **DURING CLASS** By delivering some content through key concept videos and active reading before class, you can make room in your lecture to pose questions to your students that make the class experience active as well. This book features two main tools for in-class use. The first tool is *Learning Catalytics*, which allows you to pose many different types of questions to your students during class. Instead of passively listening to your lecture, students interact with the concepts you present through questions you pose. Your students can answer the questions individually, or you can pair them with a partner or small group. A second tool for in-class use is the *Questions for Group Work.* These questions appear in the end-of-chapter material and are specifically designed to be answered in small groups.
- **AFTER CLASS** Active learning can continue after class with two additional tools. The first is another library of 3– to 6–minute videos called *Interactive Worked Examples (IWEs).* Each IWE video walks a student through the solution to a chemistry problem. Like the KCVs, the IWE video stops in the middle and poses a question that must be answered before the video continues playing. Each video also has an associated follow-up problem that can be assigned using Mastering Chemistry. The second tool for after (or outside of) class active learning is *Active Exam Preparation*. Research studies suggest that students who take a pretest before an exam do better on the exam, especially if the pretest contains immediate feedback. Each chapter in this book contains a *Self-Assessment Quiz* that you can use to easily make a pretest for any of your exams. The *Self-Assessment Quizzes* are assignable in Mastering Chemistry, and contain wrong answer feedback. Simply choose the questions that you want from each of the quizzes that span the chapters on your exam, and you can create an assignable pretest that students can use to actively prepare for your exams.

Although we have added many active learning tools to this edition and made other changes as well, the book's goal remains the same: *to present a rigorous and accessible treatment of general chemistry in the context of relevance.* Teaching general chemistry would be much easier if all of our students had exactly the same level of preparation and ability. But alas, that is not the case. My own courses are populated with students with a range of backgrounds and abilities in chemistry. The challenge of successful teaching, in my opinion, is figuring out how to instruct and challenge the best students while not losing those with lesser backgrounds and abilities. My strategy has always been to set the bar relatively high, while at the same time providing the motivation and support necessary to reach the high bar. That is exactly the philosophy of this book. We do not have to compromise rigor in order to make chemistry accessible to our students. In this book, I have worked hard to combine rigor with accessibility—to create a book that does not dilute the content and yet can be used and understood by any student willing to put in the necessary effort.

Principles of Chemistry: A Molecular Approach* is first and foremost a *student-oriented book. My main goal is to motivate students and get them to achieve at the highest possible level. As we all know, many students take general chemistry because it is a requirement; they do not see the connection between chemistry and their lives or their intended careers. *Principles of Chemistry: A Molecular Approach* strives to make those connections consistently and effectively. Unlike other books, which often teach chemistry as something that happens only in the laboratory or in industry, this book teaches chemistry in the context of relevance. It shows students *why* chemistry is important to them, to their future careers, and to their world.

Second, *Principles of Chemistry: A Molecular Approach* is a *pedagogically driven book.* In seeking to develop problem-solving skills, a consistent approach (Sort, Strategize, Solve, and Check) is applied, usually in a two- or three-column format. In the two-column format, the left column shows the student how to analyze the problem and devise a solution strategy. It also lists the steps of the solution, explaining the rationale for each one, while the right column shows the implementation of each step. In the three-column format, the left column outlines the general procedure for solving an important category of problems that is then applied to two side-by-side examples. This strategy allows students to see both the general pattern and the slightly different ways in which the procedure may be applied in differing contexts. The aim is to help students understand both the *concept of the problem* (through the formulation of an explicit conceptual plan for each problem) and the *solution to the problem.*

Third, *Principles of Chemistry: A Molecular Approach* is a *visual book.* Wherever possible, I use images to deepen the student's insight into chemistry. In developing chemical principles, multipart images help show the connection between everyday processes visible to the unaided eye and what atoms and molecules are actually doing. Many of these images have three parts: macroscopic, molecular, and symbolic. This combination helps students to see the relationships between the formulas they write down on paper (symbolic), the world they see around them (macroscopic), and the atoms and molecules that compose that world (molecular). In addition, most figures are designed to teach rather than just to illustrate. They are rich with annotations and labels intended to help the student grasp the most important processes and the principles that underlie them. In this edition, the art program has been thoroughly revised in two major ways. First, navigation of the more complex figures has been reoriented to track from left to right whenever possible. Second, figure captions have been migrated into the image itself as an "author voice" that explains the image and guides the reader through it. The resulting images are rich with information but also clear and quickly understood.

Fourth, *Principles of Chemistry: A Molecular Approach* is a "big-picture" book. At the beginning of each chapter, a short paragraph helps students to see the key relationships between the different topics they are learning. Through a focused and concise narrative, I strive to make the basic ideas of every chapter clear to the student. Interim summaries are provided at selected spots in the narrative, making it easier to grasp (and review) the main points of important discussions. And to make sure that students never lose sight of the forest for the trees, each chapter includes several *Conceptual Connections,* which ask them to think about concepts and solve problems without doing any math. I want students to learn the concepts, not just plug numbers into equations to churn out the right answer. This philosophy is also integral to the *Key Concept Videos*, which concisely reinforce student appreciation of the core concepts in each chapter.

Lastly, *Principles of Chemistry: A Molecular Approach* is a book that delivers the depth of coverage faculty want. We do not have to cut corners and water down the material in order to get our students interested. We have to meet them where they are, challenge them to the highest level of achievement, and support them with enough pedagogy to allow them to succeed.

I hope that this book supports you in your vocation of teaching students chemistry. I am increasingly convinced of the importance of our task. Please feel free to contact me with any questions or comments about the book.

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What's New in This Edition?

The book has been extensively revised and contains more small changes than can be detailed here. The most significant changes to the book and its supplements are listed below:

- **NEW INTERACTIVE VIDEOS** I have added 16 new *Key Concept Videos (KCVs)* and 24 new *Interactive Worked Examples (IWEs)* to the media package that accompanies the book. *The video library now contains nearly 200 interactive videos.* These tools are designed to help professors engage their students in active learning.
- **NEW IN-CHAPTER QUESTIONS WITH FEEDBACK** I have added approximately 67 new *Conceptual Connection* questions throughout the book and have changed the format to multiple choice (with wrong answer feedback in Mastering Chemistry). Each chapter now has 10–12 of these assignable questions. These questions transform the reading process from passive to active and hold students accountable for reading assignments.
- **NEW *MISSED THIS?* FEATURE** I have added a new feature called *MISSED THIS?* to the *Self-Assessment Quizzes* and to the *Problems by Topic* section of the end-of-chapter problems. This feature lists the resources that students can use to learn how to answer the question or solve the problem. The resources include chapter sections to read, *Key Concept Videos (KCVs)* to watch, and *Interactive Worked Examples (IWEs)* to view. Students often try to solve an assigned question or problem before doing any reading or reviewing; they seek resources only *after* they have missed the question or problem. The *MISSED THIS?* feature guides them to reliable resources that provide just-in-time instruction.
- **NEW FOR PRACTICE FEEDBACK** I have enhanced 64 of the in-chapter *For Practice* problems (which immediately follow an in-chapter worked example) with feedback that can be accessed through Mastering Chemistry.
- **REVISED ART PROGRAM** The art program has been extensively revised. Navigation of the more complex figures has been reoriented to track from left to right, and many figure captions have been broken up and have been moved into the image itself as an "author voice" that explains the image and guides the reader through it.
- **REVISED DATA INTERPRETATION AND ANALYSIS QUESTIONS** The *Data Interpretation and Analysis* questions that accompany each chapter have been extensively revised to make them clearer and more accessible to students.
- **NEW SECTION ON DATA INTERPRETATION AND ANALYSIS** I have added a new section to Chapter 1 (Section 1.9) on the general topic of analyzing and interpreting data. This section introduces the skills required to address many of the revised data interpretation and analysis questions.
- **NEW HOW TO . . . FEATURE** All guidance for essential skills such as problem-solving techniques, drawing Lewis structures, and naming compounds is now presented in a consistent, step-by-step numbered list called *How To...*
- **REVISED CHAPTER 4** Chapter 4 in the previous edition covered both stoichiometry and chemical reactions in solution. In this edition, this content has been

expanded slightly and has been divided into two more focused chapters, so that Chapter 4 is now focused on stoichiometry and Chapter 5 on chemical reactions in solution. This new organization lessens the cognitive load for students and allows each chapter to be more direct and focused. All subsequent chapters have been renumbered accordingly.

- **NEW ACTIVITY SERIES CONTENT** I added a new subsection to Section 5.9 entitled *The Activity Series: Predicting Whether a Redox Reaction Is Spontaneous.* The new section includes new figures, tables, and a new worked example.
- **NEW READY-TO-GO LEARNING MODULES** These online modules offer students easy access to the best Tro content in Mastering Chemistry without needing to have it assigned.
- **NEW TWO-TIER OBJECTIVES** A system of two-tier objectives is being applied to the text and to the Mastering Chemistry assets. The two tiers are Learning Objectives, or LOs, and Enabling Objectives, or EOs. The LOs are broad, high-level objectives that summarize the overall learning goal, while the EOs are the building block skills that enable students to achieve the LO. The learning objectives are given in the Learning Outcomes table at the end of the chapter.
- **REVISED DATA** All the data throughout the book have been updated to reflect the most recent measurements available. These updates include Figure 4.2: *Carbon Dioxide in the Atmosphere*; Figure 4.3: *Global Temperatures*; the unnumbered figure in Section 7.10 of *U.S. Energy Consumption*; Figure 7.12: *Energy Consumption by Source*; Table 7.6: *Changes in National Average Pollutant Levels, 1990–2016*; Figure 15.19: *Ozone Depletion in the Antarctic Spring*; Figure 17.15: *Sources of U.S. Energy*; Figure 17.16: *Acid Rain*; and Figure 17.18: *U.S. Sulfur Dioxide Pollutant Levels*.
- **REVISED CHAPTER OPENERS** Many chapter-opening sections and (or) the corresponding art—including Chapters 1, 3, 4, 5, 6, 7, 10, 11, 18, 19, and 20—have been replaced or modified.

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