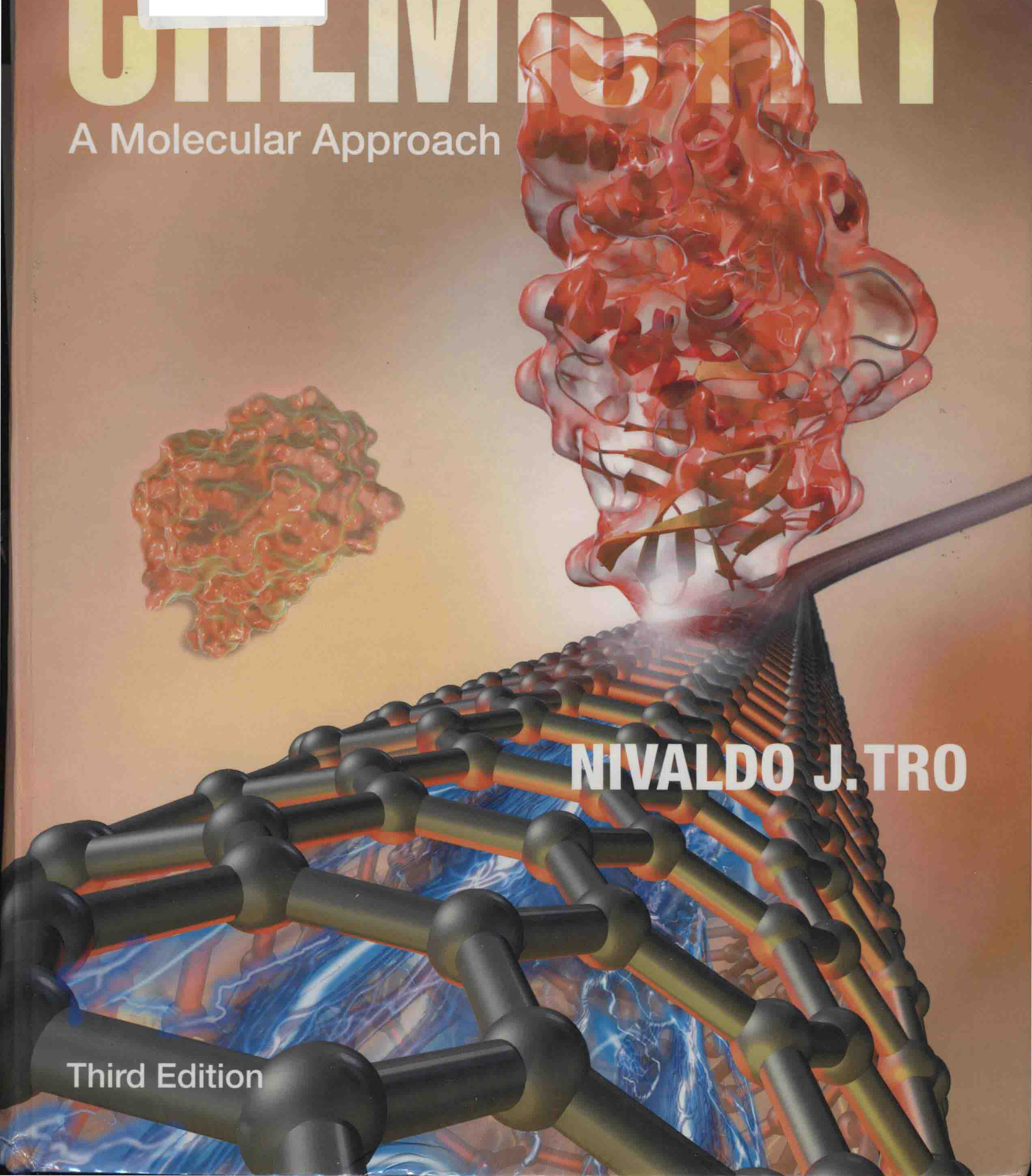
CHEMISTRY

A Molecular Approach



NIVALDO J. TRO

Third Edition

CHEMISTRY

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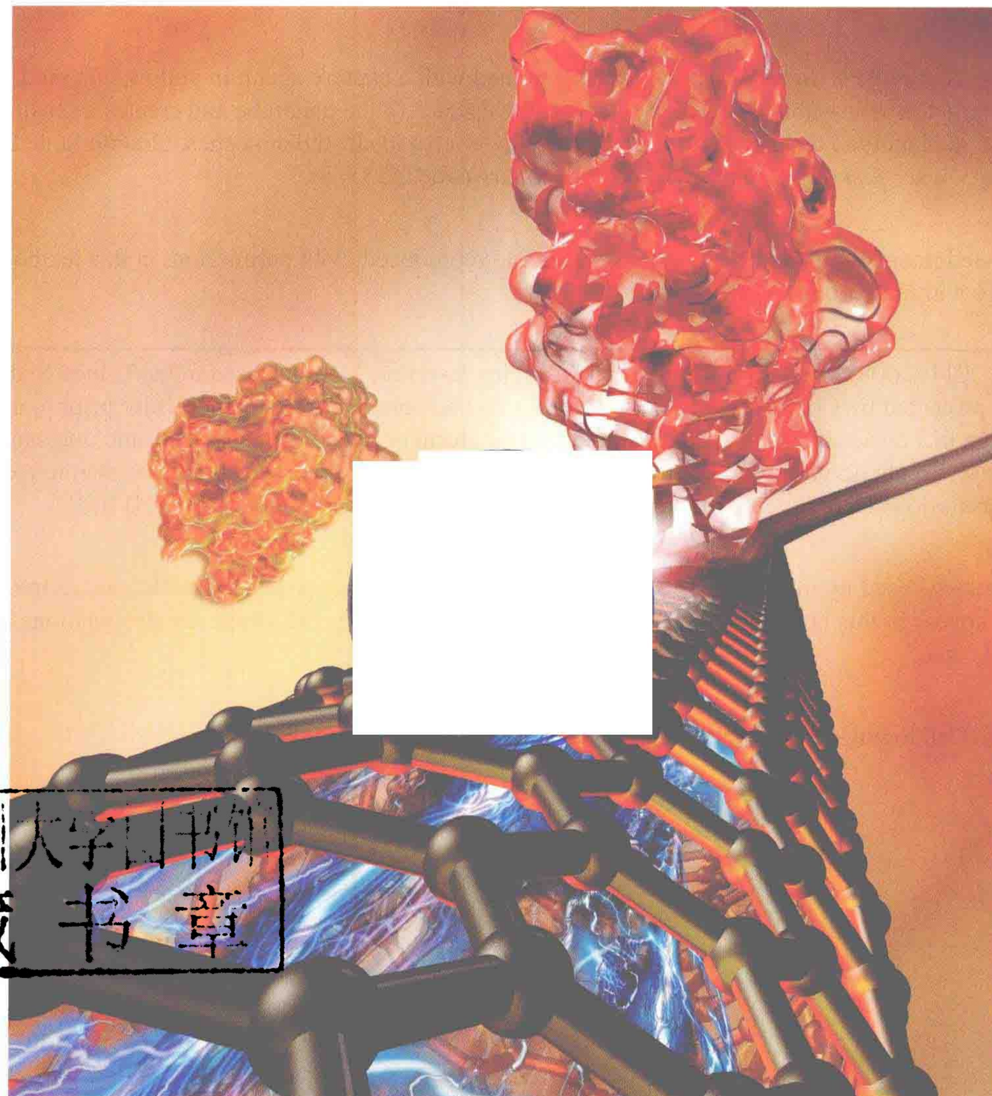

NIVALDO J. TRO

Westmont College

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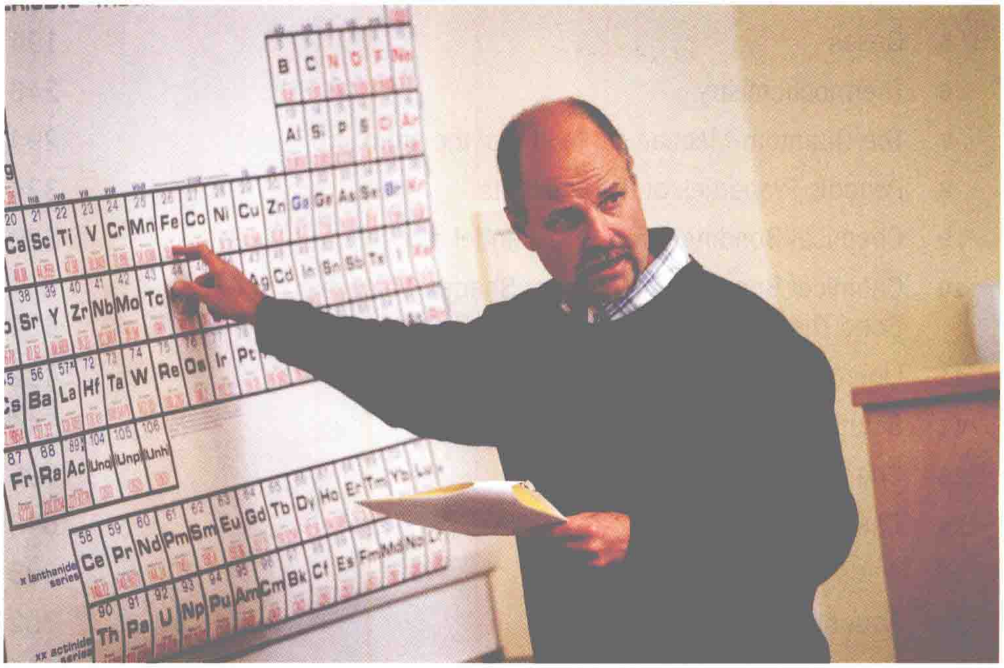
To Michael, Ali, Kyle, and Kaden

About the Author



NIVALDO TRO is a professor of chemistry at Westmont College in Santa Barbara, California, where he has been a faculty member since 1990. 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. Since coming to Westmont, Professor Tro has been awarded grants from the American Chemical Society Petroleum Research Fund, from Research Corporation, and from the National Science Foundation to study the dynamics of various processes occurring in thin adlayer films adsorbed on dielectric surfaces. He has been honored as Westmont's outstanding teacher of the year three times and has also received the college's outstanding researcher of the year award. 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, reading to his children, and being outdoors with his family.

Brief Contents

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. While 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 sensitivity of the world we *can* see to 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, creates 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 hairspray 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 hairspray depleting the ozone layer and thereby leading to global warming, the chlorofluorocarbons that deplete ozone have been banned from hairspray 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 understand 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 first and second 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 acted as a reviewer or have contacted me directly, you will likely see your suggestions reflected in the changes I have made. Thank you.

In spite of the changes I just mentioned, the goal of the book 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. Even though I teach at a relatively selective institution, my courses are populated with students with a range of backgrounds and abilities in chemistry. The challenge of successful teaching, in my opinion, is therefore 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 away 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, yet can be used and understood by any student willing to put in the necessary effort.

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. *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.

Chemistry: A Molecular Approach is secondly 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.*

Chemistry: A Molecular Approach is thirdly a *visual book.* Wherever possible, images are used to deepen the student's insight into chemistry. In developing chemical principles, multipart images help to 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. The resulting images are rich with information but also uncommonly clear and quickly understood.

Chemistry: A Molecular Approach is fourthly 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.

Chemistry: A Molecular Approach is lastly 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 simply have to meet them where they are, challenge them to the highest level of achievement, and then 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 email me with any questions or comments about the book.

Nivaldo J. Tro
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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. I have detailed the most significant changes to the book and its supplements below.

- I have added a 10–15 question multiple-choice end-of-chapter Self Assessment Quiz to each chapter. Since many colleges and universities utilize multiple-choice exams, and because standardized final exams are often multiple choice, these quizzes are meant for students to self test their basic knowledge and skills for each chapter.
- I have added approximately 50 new Conceptual Connection questions throughout the book. I have also moved the answers to all Conceptual Connections from within the chapter to the end-of-chapter material.
- I have updated all data throughout the book to reflect the most recent measurements available. These updates include *Figure 4.2 Carbon Dioxide in the Atmosphere; Figure 4.3 Global Temperatures; Figure 4.25 U.S. Energy Consumption; Table 13.4 Change in Pollutant Levels*; *Figure 13.19 Ozone Depletion in the Antarctic Spring; Figure 15.15 Sources of U.S. Energy; Figure 15.16 Acid Rain;* and *Figure 15.18 U.S. Sulfur Dioxide Pollutant Levels.*
- I have added a new *Chemistry in Your Day: Evolving Atomic Masses* box to Section 2.9 to address the recent changes in IUPAC atomic masses. I have modified the atomic masses of Li, S, and Ge throughout the book to reflect these changes.
- I have added new material in which students must interpret mass spectra to Section 2.8. This material includes a new unnumbered figure and new end-of-chapter problems.
- I have added a new section (Section 3.7 *Summary of Inorganic Nomenclature*) that includes a new in-chapter figure (Figure 3.10) and a new example (Example 3.11). This new material summarizes nomenclature and allows the student to learn how to name a compound without the compound being pre-classified.
- I have added a new example (Example 3.24) on balancing chemical equations containing ionic compounds with polyatomic ions.
- I have replaced Section 7.1 with a new chapter opener entitled *Schrödinger's Cat.* The opener includes new art depicting Erwin Schrödinger's desk.

- I have expanded and clarified the description of the photoelectric effect and the particle nature of light in Section 7.2, including a new figure (Figure 7.9) that depicts a graph of the rate of electron ejection from a metal versus the frequency of light used.
- I have moved the introduction of the fourth quantum number, m_s, the spin quantum number, from Chapter 8 to Section 7.5.
- I have added a new example to Chapter 9 (Example 9.9).
- I have changed the wedge notation used to draw 3D structures (first introduced in Section 10.4) to reflect current trends in this notation.
- I have added electrostatic potential maps for a number of molecules in Chapter 11 to help students better visualize polarity and interactions between polar molecules.
- I have updated all of the energy statistics in Section 15.12.
- I have added information about the Fukushima nuclear accident added to Section 19.7. I have also updated the content about the proposed nuclear waste storage facility in Yucca Mountain, Nevada.
- I have revised the Key Concepts end-of-chapter material so that it is now in a bulleted list format for all chapters for easy student review.
- I have added or modified approximately 60 end-of-chapter problems.
- I have enlarged many key figures throughout text.

Supplements

For the Instructor

MasteringChemistry® is the best adaptive-learning online homework and tutorial system. Instructors can create online assignments for their students by choosing from a wide range of items, including end-of-chapter problems and research-enhanced tutorials. Assignments are automatically graded with up-to-date diagnostic information, helping instructors pinpoint where students struggle either individually or as a class as a whole.

Instructor Resource DVD (0-321-81363-4) This DVD provides an integrated collection of resources designed to help instructors make efficient and effective use of their time. It features four pre-built PowerPoint™ presentations. The first presentation contains all the images/figures/tables from the text embedded within the PowerPoint slides, while the second includes a complete modifiable lecture outline. The final two presentations contain worked "in-chapter" sample exercises and questions to be used with Classroom Response Systems. This DVD also contains movies and animations, as well as the TestGen version of the Test Bank, which allows instructors to create and tailor exams to their needs.

Solutions Manual (0-321-81376-6) Prepared by MaryBeth Kramer of the University of Delaware and Kathleen Thrush Shaginaw, this manual contains step-by-step solutions to all complete, end-of-chapter exercises. The Solutions Manual to accompany the second edition has been extensively revised. All problems have been accuracy checked and the design has been upgraded to improve clarity and ease of use. With instructor permission, this manual may be made available to students.

Instructor Resource Manual (0-321-81354-5) Organized by chapter, this useful guide includes objectives, lecture outlines, references to figures and solved problems, as well as teaching tips.

Printed Test Bank (0-321-81367-7) Prepared by Christine Hermann of Radford University. The printed test bank contains more than 2000 multiple choice, true/false, and short-answer questions. The third edition also contains more than 1400 algorithmic questions.

Blackboard® and WebCT® All test questions are available formatted for either Blackboard or WebCT. These are available for download at www.pearsonhighered.com/chemistry.

For the Student

MasteringChemistry® provides students with two learning systems: an extensive self-study area with an interactive eBook and the most widely used chemistry homework and tutorial system (if an instructor chooses to make online assignments part of the course).

Pearson eText The integration of Pearson eText within MasteringChemistry® gives students, with new books, easy access to the electronic text when they are logged into MasteringChemistry. Pearson eText pages look exactly like the printed text, offering powerful new functionality for students and instructors. Users can create notes, highlight text in different colors, create bookmarks, zoom, view in single-page or two-page view, etc.

Selected Solutions Manual (0-321-81364-2) Prepared by MaryBeth Kramer of the University of Delaware and Kathleen Thrush Shaginaw, this manual for students contains complete, step-by-step solutions to selected odd-numbered end-of-chapter problems. The Selected Solutions Manual to accompany the third edition has been extensively revised. All problems have been accuracy checked and the design has been upgraded to improve clarity and ease of use.

Study Guide (0-321-81362-6) Prepared by Jennifer Shanoski of Merritt College. This Study Guide was written specifically to assist students using the third edition of *Chemistry: A Molecular Approach*. It presents the major concept, theories, and applications discussed in the text in a comprehensive and accessible manner for students. It contains learning objectives, chapter summaries, and outlines, as well as examples, self test, and concept questions.

Laboratory Manual (0-321-81377-4) Prepared by John B. Vincent and Erica Livingston, both of the University of Alabama. This manual contains 29 experiments with a focus on real-world applications. Each experiment contains a set of pre-laboratory questions, an introduction, a step-by-step procedure (including safety information), and a report section featuring post-laboratory questions. Additional features include a section on laboratory safety rules, an overview on general techniques and equipment, and a detailed tutorial on graphing data in Excel.

Acknowledgments

The book you hold in your hands bears my name on the cover, but I am really only one member of a large team that carefully crafted the first edition, the second edition, and now the third edition of this book. Most importantly, I thank my new editor on this edition, Terry Haugen. Terry is a great editor and friend. He gives me the right balance of freedom and direction and always supports me in my endeavors. Thanks Terry for all you have done for me and for general chemistry courses throughout the world. I am just as grateful for my project editor, Jennifer Hart, who has now worked with me on multiple editions of several books. Jennifer, your guidance, organizational skills, and wisdom are central to the success of my projects, and I am eternally grateful. New to this edition is Jessica Moro. Although we have only worked together a short while, I am already indebted to her helpfulness. I am also grateful to Erin Kneuer, who helped with organizing reviews, as well as numerous other tasks associated with keeping the team running smoothly. I also thank Erin Mulligan, who has now worked with me on several projects. Erin is an outstanding developmental editor who not only worked with me on crafting and thinking through every word, but also became a friend and fellow foodie in the process. I am also grateful to Adam Jaworski. His skills and competence have led the chemistry team since he took over as editor-in-chief. And of course, I am continually grateful for Paul Corey, with whom I have now worked for over 12 years and 9 projects. Paul is a man of incredible energy and vision, and it is my great privilege to work with him. Paul told me many years ago (when he first signed me on to the Pearson team) to dream big, and then he provided the resources I needed to make those dreams come true. *Thanks, Paul.* I would also like to thank my first editor at Pearson, Kent Porter-Hamann. Kent and I spent many good years together writing books, and I continue to miss her presence in my work.

New to the team is my marketing manager, Jonathan Cottrell, and although we have worked together for only a short while, I am already impressed by his energy in marketing this book. I continue to owe a special word of thanks to Glenn and Meg Turner of Burrston House, ideal collaborators whose contributions to the first edition of the book were extremely important and much appreciated. Quade and Emiko Paul, who make my ideas come alive with their art, have been with us from the beginning, and I owe a special debt of gratitude to them. I am also grateful to Mark Ong and Emily Friel for their creativity and hard work in crafting the design of this text; to Michelle Durgerian, Shari Toron, and Gina Cheselka, whose skill and diligence gave this book its physical existence; and to Connie Long who managed the extensive art program. Finally, I would like to thank my copyeditor and proofreader from the GEX Publishing Services editorial team for their dedication and professionalism, and Erin Schrader for his exemplary photo research. The team at Pearson is a first-class operation—this text has benefited immeasurably from their talents and hard work.

I acknowledge the great work of my colleague Mary Beth Kramer from the Chemistry Department at University of Delaware, who has been a co-author on the solutions manual for this book. Mary Beth Kramer worked tirelessly to ensure that the solutions manual was accurate and useful to students. Sadly, Professor Kramer passed away shortly before this book went to press. We will all miss her and her excellent work. A special thank you to Kathleen Thrush Shaginaw for all her hard work in order to complete the Solutions Manual on time.

I acknowledge the help of my colleagues Allan Nishimura, Kristi Lazar, David Marten, Stephen Contakes, Michael Everest, and Carrie Hill who have supported me in my department while I worked on this book. I am also grateful to Gayle Beebe, the president of Westmont College, who has allowed me the time and space to work on my books. Thank you, Gayle, for allowing me to pursue my gifts and my vision. I am also grateful to those who have supported me personally. First on that list is my wife, Ann. Her patience and love for me are beyond description, and without her, this book would never have been written. I am also indebted to my children, Michael, Ali, Kyle, and Kaden, whose smiling faces and love of life always inspire me. I come from a large Cuban family whose closeness and support most people would envy. Thanks to my parents, Nivaldo and Sara; my siblings, Sarita, Mary, and Jorge; my siblings-in-law, Jeff, Nachy, Karen, and John; my nephews and nieces, Germain, Danny, Lisette, Sara, and Kenny. These are the people with whom I celebrate life.

I would like to thank all of the general chemistry students who have been in my classes throughout my 22 years as a professor at Westmont College. You have taught me much about teaching that is now in this book. I am especially grateful to Michael Tro who put in many hours proofreading my manuscript, working problems and quiz questions, and organizing art codes and appendices. Michael, you are an amazing kid—it is my privilege to have you work with me on this project. I would also like to express my appreciation to Josh Alamillo, Catherine Olson, Hannah Sievers, and Rose Corcoran, who were a tremendous help with the new self assessment quizzes.

I would like to thank Brian Woodfield from Brigham Young University, the students at the University of Kentucky, and the Pearson Student Advisory Board for helping me create the interactive worked examples.

Lastly, I am indebted to the many reviewers, listed on the following pages, whose ideas are imbedded throughout this book. They have corrected me, inspired me, and sharpened my thinking on how best to teach this subject we call chemistry. I deeply appreciate their commitment to this project. I am particularly grateful to Bob Boikess for his important contributions to the book. Thanks also to Frank Lambert for his review of the entropy sections in the first edition of the book, and to Diane K. Smith for her review of and input on the electrochemistry chapter. Last but by no means least, I would like to thank Nancy Lee for her suggestions on the origin of elements box, and Alyse Dilts, Tracey Knowles, Gary Mines, and Alison Soult for their help in reviewing page proofs.

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> —Matthew Joshua Buhr, Student, *University of South Dakota*

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Icons appear next to examples indicating that a digital version is available. See the ways to access listed on the facing page.

Many problems are solved with a **conceptual plan** that provides a visual outline of the steps leading from the given information to the solution.

The **right column** shows the implementation of the steps explained in the left column.

Two-Column Example

EXAMPLE 6.5 Measuring ΔE_{rxn} in a Bomb Calorimeter

When 1.010 g of sucrose ($C_{12}H_{22}O_{11}$) undergoes combustion in a bomb calorimeter, the temperature rises from 24.92 °C to 28.33 °C. Find ΔE_{rxn} for the combustion of sucrose in kJ/mol sucrose. The heat capacity of the bomb calorimeter, determined in a separate experiment, is 4.90 kJ/°C. (You can ignore the heat capacity of the small sample of sucrose because it is negligible compared to the heat capacity of the calorimeter.)

SORT You are given the mass of sucrose, the heat capacity of the calorimeter, and the initial and final temperatures. You are asked to find the change in internal energy for the reaction.

GIVEN: 1.010 g $C_{12}H_{22}O_{11}$, $T_i = 24.92$ °C, $T_f = 28.33$ °C, $C_{cal} = 4.90$ kJ/°C

FIND: ΔE_{rxn}

STRATEGIZE The conceptual plan has three parts. In the first part, use the temperature change and the heat capacity of the calorimeter to find q_{cal}.

CONCEPTUAL PLAN

$C_{cal}, \Delta T \rightarrow q_{cal}$

$q_{cal} = C_{cal} \times \Delta T$

In the second part, use q_{cal} to get q_{rxn} (which just involves changing the sign). Since the bomb calorimeter ensures constant volume, q_{rxn} is equivalent to ΔE_{rxn} for the amount of sucrose burned.

$q_{cal} \rightarrow q_{rxn}$

$q_{rxn} = -q_{cal}$

In the third part, divide q_{rxn} by the number of moles of sucrose to get ΔE_{rxn} per mole of sucrose.

$$\Delta E_{rxn} = \frac{q_{rxn}}{\text{mol } C_{12}H_{22}O_{11}}$$

RELATIONSHIPS USED

$q_{cal} = C_{cal} \times \Delta T = -q_{rxn}$

molar mass $C_{12}H_{22}O_{11} = 342.3$ g/mol

SOLVE Gather the necessary quantities in the correct units and substitute these into the equation to calculate q_{cal}.

SOLUTION

$$\Delta T = T_f - T_i = 28.33\ ^\circ C - 24.92\ ^\circ C = 3.41\ ^\circ C$$

$$q_{cal} = C_{cal} \times \Delta T$$

$$q_{cal} = 4.90 \frac{kJ}{^\circ C} \times 3.41\ ^\circ C = 16.7\ kJ$$

Find q_{rxn} by taking the negative of q_{cal}.

$$q_{rxn} = -q_{cal} = -16.7\ kJ$$

Find ΔE_{rxn} per mole of sucrose by dividing q_{rxn} by the number of moles of sucrose (calculated from the given mass of sucrose and its molar mass).

$$\Delta E_{rxn} = \frac{q_{rxn}}{\text{mol } C_{12}H_{22}O_{11}} = \frac{-16.7\ kJ}{1.010\ g\ C_{12}H_{22}O_{11} \times \frac{1\ mol\ C_{12}H_{22}O_{11}}{342.3\ g\ C_{12}H_{22}O_{11}}} = -5.66 \times 10^3\ kJ/mol\ C_{12}H_{22}O_{11}$$

CHECK The units of the answer (kJ) are correct for a change in internal energy. The sign of ΔE_{rxn} is negative, as it should be for a combustion reaction that gives off energy.

FOR PRACTICE 6.5

When 1.550 g of liquid hexane (C_6H_{14}) undergoes combustion in a bomb calorimeter, the temperature rises from 25.87 °C to 38.13 °C. Find ΔE_{rxn} for the reaction in kJ/mol hexane. The heat capacity of the bomb calorimeter, determined in a separate experiment, is 5.73 kJ/°C.

FOR MORE PRACTICE 6.5

The combustion of toluene has a ΔE_{rxn} of -3.91×10^3 kJ/mol. When 1.55 g of toluene (C_7H_8) undergoes combustion in a bomb calorimeter, the temperature rises from 23.12 °C to 37.57 °C. Find the heat capacity of the bomb calorimeter.

Interactive Worked Examples

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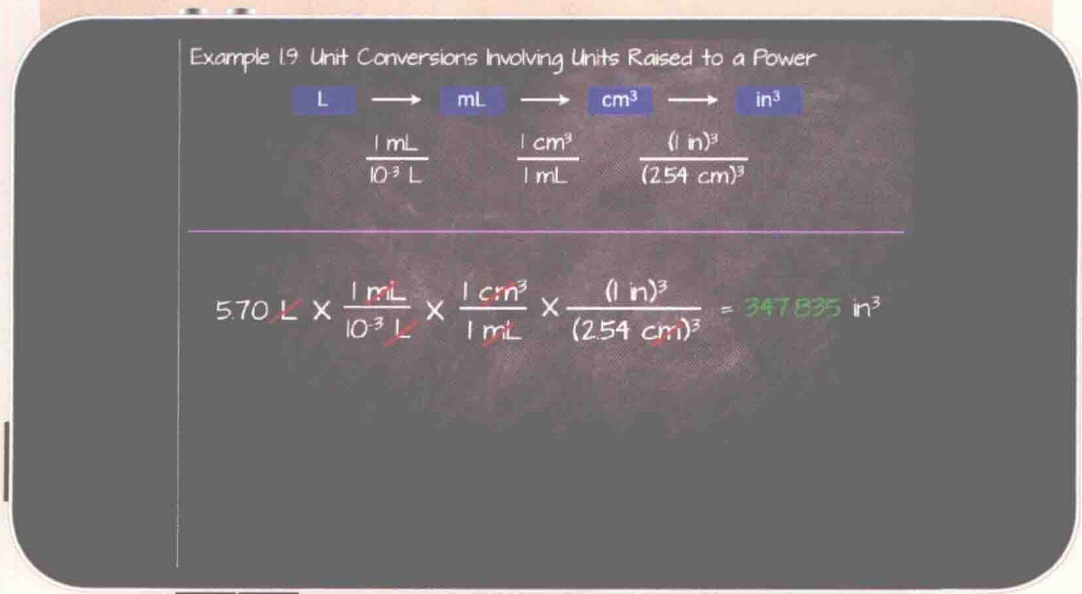


Scan this QR code (located on the back cover of the textbook) with your smartphone to access the Digital Worked Examples.

A Consistent Problem-solving Strategy

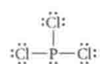
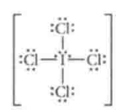
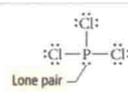
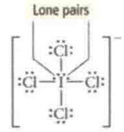
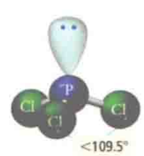
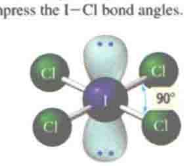
A **consistent approach to problem solving** is used throughout the book and helps students understand the logic and purpose of each step in the problem-solving process.

Problem-solving Procedure Boxes for important categories of problems enable you to see how the same reasoning applies to different problems.

The **general procedure** is shown in the left column.

Two Worked Examples, side by side, make it easy to see how differences are handled.

Three-Column Example

PROCEDURE FOR... Predicting Molecular Geometries	EXAMPLE 10.2 Predicting Molecular Geometries Predict the geometry and bond angles of PCl_3.	EXAMPLE 10.3 Predicting Molecular Geometries Predict the geometry and bond angles of ICl_4^-.
1. **Draw the Lewis structure for the molecule.**	PCl_3 has 26 valence electrons. 	ICl_4^- has 36 valence electrons. 
2. **Determine the total number of electron groups around the central atom.** Lone pairs, single bonds, double bonds, triple bonds, and single electrons each count as one group.	The central atom (P) has four electron groups.	The central atom (I) has six electron groups.
3. **Determine the number of bonding groups and the number of lone pairs around the central atom.** These should sum to your result from step 2. Bonding groups include single bonds, double bonds, and triple bonds.	 Three of the four electron groups around P are bonding groups and one is a lone pair.	 Four of the six electron groups around I are bonding groups and two are lone pairs.
4. **Refer to Table 10.1 to determine the electron geometry and molecular geometry.** If no lone pairs are present around the central atom, the bond angles will be that of the ideal geometry. If lone pairs are present, the bond angles may be smaller than the ideal geometry.	The electron geometry is tetrahedral (four electron groups) and the molecular geometry—the shape of the molecule—is *trigonal pyramidal* (three bonding groups and one lone pair). Because of the presence of a lone pair, the bond angles are less than 109.5°.  Trigonal pyramidal	The electron geometry is octahedral (six electron groups) and the molecular geometry—the shape of the molecule—is *square planar* (four bonding groups and two lone pairs). Even though lone pairs are present, the bond angles are 90° because the lone pairs are symmetrically arranged and do not compress the I—Cl bond angles.  Square planar
	FOR PRACTICE 10.2 Predict the molecular geometry and bond angle of ClNO.	**FOR PRACTICE 10.3** Predict the molecular geometry of I_3^-.