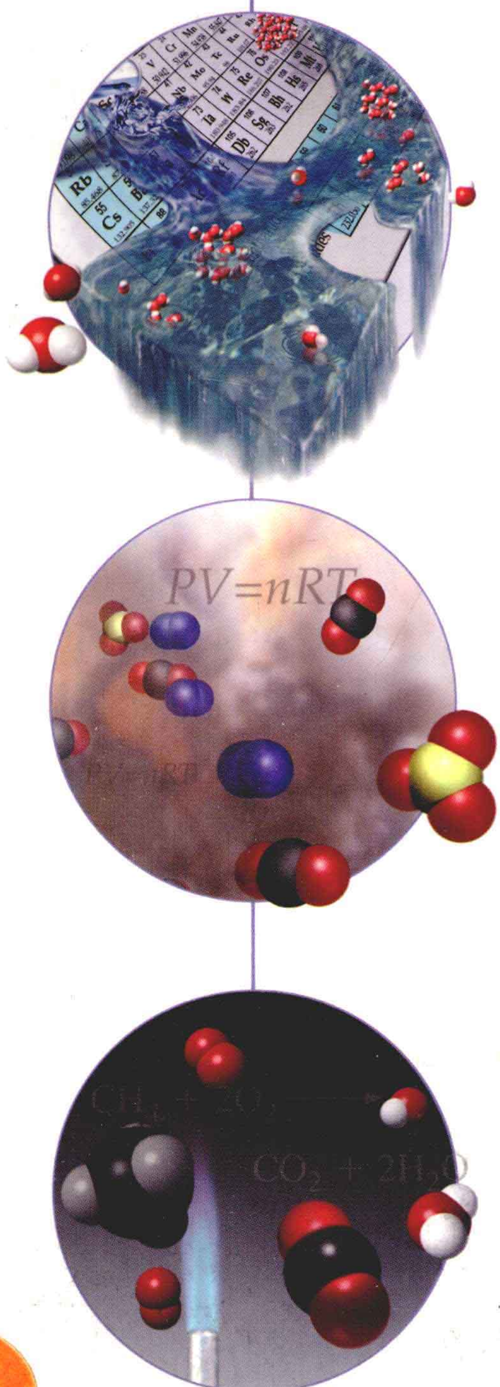
Introductory

CHEMISTRY ESSENTIALS

Second Edition



Steve Russo
Mike Silver

INTRODUCTORY CHEMISTRY

Essentials

Second Edition

STEVE RUSSO
Cornell University

MIKE SILVER
Hope College

Benjamin Cummings

San Francisco • Boston • New York
Cape Town • Hong Kong • London • Madrid • Mexico City
Montreal • Munich • Paris • Singapore • Syndey • Tokyo • Toronto

Editor: Ben Roberts
Senior Developmental Editor: Margot Otway
Developmental Editors: Irene Nunes, Becky Strehlow, Susan Weisberg, John Murdzek
Marketing Manager: Christy Lawrence
Director of Marketing: Stacy Treco
Media Producer: Claire Masson
Production Coordination: Joan Marsh, Tony Asaro
Production Management: Dovetail Publishing Services
Composition: Dovetail Publishing Services
Art Director: Blakeley Kim
Cover Image & Chapter Openers: Emi Koike and Quade Paul, fiVth.com
Text Designer: Mark Ong, Side-by-Side Studios
Artists: Emi Koike, Bert Dodson, Blakeley Kim, Ken Probst
Photographer & Photo Research: Cary Groner, Myrna Engler
Manufacturing: Vivian McDougal
Prepress House: H&S Graphics
Cover Printer: Phoenix Color
Printer and Binder: Von Hoffmann Press

About the Artists: Bert Dodson has illustrated over sixty books. He is the author of *Keys to Drawing*, published in eight languages. His distinctive, whimsical cartoons can also be found in *The Way Life Works*, of which he is co-author. Bert lives in Bradford, Vermont. **Emi Koike and Quade Paul** are scientific and medical illustrators. Quade combined digital illustration and 3-D modeling techniques to create the stunning cover images and chapter openers in this book. All of the molecular imagery in the artwork is based on actual data. Quade and Emi's work also includes editorial illustration, scientific animation, and multimedia projects. They can be contacted at fiVth.com.

Photos courtesy of: 1 (right/top) Courtesy of the National Library of Medicine; **1** (right/bottom) © Tony Stone Imaging; **2** (left to right) © 2001 PhotoDisc, Inc.; **2** © Antonio M. Rosario/Image Bank; **2** © Jessica Ehler/Bruce Coleman; **2** © 2001 PhotoDisc, Inc.; **3** NASA; **6** (gold & diamond) © 2001 PhotoDisc, Inc.; **6** (others) Prentice Hall; **7** (top) Prentice Hall; **7** (gold & marble) © 2001 PhotoDisc, Inc.; **25** NASA; **84** Courtesy of the Houston Astrodome; **92–93** (top) Prentice Hall; **99** © Corel; **107** © 2001 PhotoDisc, Inc.; **108** (top) © David Parker/SPL/Photo Researchers, Inc.; **108** (bottom-both) © Rich Treptow/Photo Researchers, Inc.; **119** © Rich Treptow/Photo Researchers, Inc.; **120** (top) NASA; © David Parker/SPL/Photo Researchers, Inc.; **182** (bottom) © SCIMAT/Photo Researchers, Inc.; **195** © 2001 PhotoDisc, Inc.; **208** (coffee cup) Courtesy of Direct Imagination; **241** © AT&T Bell Labs/SPL/Photo Researchers, Inc.; **242** © Marcello Bertinetti/ Photo Researchers, Inc.; **350** © Corel; **352** © 2001 PhotoDisc, Inc.; **381** (left) © 2001 PhotoDisc, Inc.; **381** (right) Prentice Hall; **382** (bottom/left) © 2001 PhotoDisc, Inc.; **383** (center/right) Prentice Hall; **383** (right) © 2001 PhotoDisc, Inc.; **490** Lysozyme based on file 1/mq.pdb; **493** Mary Evan Picture Library/ Photo Researchers, Inc.

ISBN: 0-321-06867-X

Benjamin Cummings

2 3 4 5 6 7 8 9 10—VHP—04 03 02
www.aw.com/bc

Preface

Many instructors have told us that the first edition of our text was the most readable introductory chemistry textbook their students had ever used. They also told us that their students need more help learning to solve problems—more worked examples, more tools for mastering problem-solving methods, and, simply, more problems. In this edition, we have incorporated new and stronger tools to help students learn the skills they need, while working to make the text even clearer and more memorable than in the first edition.

Our goal with this text has always been to help students make sense of chemistry. As chemists, we know that chemistry is intrinsically interesting, that its principles make sense, and that its problem-solving skills can be mastered by anyone. But, too often, students see the subject as incomprehensible and the course as a frightening labyrinth. All too frequently, they fall back on rote learning—memorizing algorithms, plugging numbers into formulas, and forgetting the course as quickly as they can. As chemistry instructors, we hate to see that. Therefore, we designed this book to promote comprehension and problem solving as complementary skills. A student who understands the principles of chemistry doesn't have to memorize as much and is more likely to enjoy and retain the material. Equally, practice at solving problems will help students to master the principles. We hope that our book will help students to come out of the course with a body of knowledge and skills that will serve them and that they will want to retain.

Promoting Active Learning

How can we, as textbook authors, promote active learning? First, quite simply, we provide a book that makes sense to students. A student who understands the material is less likely to fall back on passive memorization. As one instructor told us, "This book allows me to spend class time doing hands-on learning versus spending time explaining the book."

Second, we incorporate devices to encourage active reading. A flip through the book will show many sets of Practice Problems. These Practice Problems are located so that students can immediately apply the skill the text has presented. They come in sets of three or four; the first problem is solved in place in the text, and the answers to the others are given at the back of the book. Each chapter contains an average of 25 Practice Problems.

However, we are not naive. We know that many students routinely skip in-chapter practice problems. Therefore, we also include conceptual practice problems called WorkPatches. A Workpatch is a "stealth" problem. It follows smoothly from the preceding text and is not boxed off. What is more, a student who tries to read through a WorkPatch without solving it will find that the subsequent text refers to, and often depends on, the answer—but does not say what it is. (The solutions to all WorkPatches are given at the end of the chapter.) In some cases, a WorkPatch serves as the springboard into the next topic. WorkPatches are denoted by a red stop-sign icon in the margin.

Helping Students Master Problem-Solving Skills

An instructor flipping through our text might be inclined to ask, "Where are all the worked examples?" In fact, this edition has an abundance of worked examples and other problem-solving aids, but we have handled them in a way that preserves the text's coherence. As in the first edition, many worked examples are presented in the text itself. We feel strongly that problem-solving techniques should be explained with the same care and continuity we use for concepts.

When students are working problems, however, they also need access to compact summaries and examples. We have augmented these resources in the following ways:

- Important problem-solving methods are summarized in charts in the text.
- The same charts, accompanied by worked examples and additional material, appear in a special Skills to Know section at the end of the chapter immediately preceding the end-of-chapter problems. This section is intended as a "help center" to which students can refer while working problems. (A few of the more purely conceptual chapters do not have a Skills to Know section.)
- An abundance of additional step-by-step methods, worked examples, and practice problems are provided in the *Problem Solving Guide and Workbook* that accompanies the text, authored by our colleague Saundra Yancy McGuire. For a weak or struggling student, nothing is more important than abundant, guided, confidence-building practice. This workbook enables us to offer a truly realistic amount of help while maintaining a clean, readable textbook. The *Workbook* also contains a generous mathematics review. We came to know Dr. McGuire when she directed the Center for Learning and Teaching at Cornell; she now directs the Center for Academic Success at Louisiana State University. We are extremely glad that she chose to join her expertise with ours.
- As noted earlier, each chapter contains internal Practice Problems and WorkPatches in addition to end-of-chapter problems.

Room to Practice: Revised and Expanded Problem Sets

With the generous aid of several colleagues, we have revised and substantially expanded the end-of-chapter problem sets.

- Each problem set now includes a section of Additional Problems that are not categorized by chapter section.
- We more than doubled the number of end-of-chapter problems.
- We have worked to ensure that each problem set contains a sufficient abundance of each of the types of problems an instructor might require.
- As in the first edition, answers to selected problems are provided at the end of the book. (The full solutions for these selected problems, as well as for all the Practice Problems, are available in the *Study Guide and Selected Solutions* manual.)

Making Chemistry Memorable

Instructors have told us that a surprising number of their students actually read our book, rather than using it mainly as a resource while solving problems. In this second edition, we have worked to improve the features that made the first edition so readable. We explain chemistry using everyday, conversational language, and we tie the concepts and calculations to stories and examples that help bring them to life. We use humor in places. We also ensure that the students know which points are fundamental and which represent additional detail. You will notice that most of the illustrations lack legends. That is because the text and the illustrations work hand-in-hand, and each illustration is placed exactly where it belongs.

We Want to Hear from You

One of the pleasures of revising a book is hearing from instructors who use it—learning what works and doesn't work; gathering ideas. If you have any comments or suggestions, please feel free to contact us at the following email addresses: sr19@cornell.edu (Steve Russo); silver@hope.edu (Mike Silver).

Content Changes in this Edition

- **Chapter 2, "The Numerical Side of Chemistry,"** now includes coverage of specific heat and simple calorimetry.
- In **Chapter 4, "The Modern Model of the Atom,"** we expanded the treatment of orbitals.
- In **Chapter 5, "Chemical Bonding and Nomenclature,"** we now give full basic coverage of inorganic nomenclature.
- **Chapter 7, "Chemical Reactions,"** covers equation balancing more thoroughly than in the first edition. It also now covers reaction types. There is a section on solubility and precipitation reactions (including net ionic equations and the solubility rules), and a simple introduction to acid/base reactions.
- The new **Chapter 8, "Stoichiometry and the Mole,"** represents an expanded treatment of material formerly placed in Chapter 7. Stoichiometric calculations and mole/mass conversions are covered at greater length (and more visually) than in the first edition.
- Limiting-reactant problems are now handled in their own expanded section, followed by a section on percent composition and molecular formulas. We placed these sections at the end of the chapter so that instructors who do not teach these topics can easily skip them.
- **Chapter 11, "What If There Were No Intermolecular Forces? The Ideal Gas,"** represents an expanded treatment of a topic formerly covered in the chapter on intermolecular forces. The ideal gas concept and ideal gas law are presented at more length. In addition, the chapter now shows how the ideal gas law can be used to determine the density and molar mass of a gas.
- In **Chapter 12, "Solutions,"** we expanded the treatment of molarity as the connection between molar amount and volume. The discussion of dilution now also includes the $M_1V_1 = M_2V_2$ relationship. We also added sections on solution stoichiometry (including simple titrations) and colligative properties (including vapor pressure). We placed these sections at the end of the chapter, as some instructors may prefer to skip them.

ACKNOWLEDGMENTS

We wish to extend our warmest thanks to the reviewers whose patient and thoughtful comments helped us to shape both the first and the second editions of this book.

Edward Alexander, *San Diego Mesa College*
Melissa Armstrong, *Gaston College*
Joe Asire, *Cuesta College*
Barbara Balko, *Lewis and Clark College*
David Ball, *Cleveland State University*
Dan Bedgood, *Arizona State University*
Jack Benefield, *Valencia Community College*
Kenneth Bennett, *Kalamazoo Valley Community College*
Bill Bornhorst, *Grossmont College*
Simon Bott, *University of Houston*
Joe Burnett, *University of Iowa*
Jeff Cavalieri, *Dutchess Community College*
Jing-Yi Chin, *Suffolk County Community College*
Connie Churchill, *Oakton Community College*
Ana Ciereszko, *Miami-Dade Community College*
John Cullen, *Ricks College*
William Daniel, *Modesto Junior College*
Patrick Daubenmire, *Loyola Blakefield*
Denisha Dawson, *Diablo Valley College*
Walter Dean, *Lawrence Technological University*
Ron Distefano, *Northampton Community College*
David Dollimore, *University of Toledo*
Jerry Driscoll, *University of Utah*
Mary Ann Durick, *Bismarck State College*
Gary Fisher, *De Anza College*
Perry Forman, *University of Alabama at Birmingham*
Roger Frampton, *Tidewater Community College*
Marc Franco, *South Seattle Community College*
Elizabeth Gaillard, *Northern Illinois University*
John Gelder, *Oklahoma State University*
Galen George, *Santa Rosa Junior College*
Angela Glisan-King, *Wake Forest University*
Wendy Gloffke, *Cedar Crest College*
John Goodwin, *Coastal Carolina University*
George Goth, *Skyline College*
Stanley Grenda, *University of Nevada, Las Vegas*
Elizabeth Griffith, *University of South Carolina*
James Hardcastle, *Texas Woman's University*
Leslie Heasley, *University of Alaska, Anchorage*
Claudia Hein, *Diablo Valley College*
Eileen Hinks, *Virginia Military Institute*
R.A. Hoots, *Davis, CA*
Jeffrey Hurlbut, *Metropolitan State College*
James Jacob, *University of Rhode Island*
Fred Johnson, *Brevard Community College*
Ray Johnson, *Hillsdale College*
Stanley Johnson, *Orange Coast College*
Curtis Keedy, *Lewis and Clark College*
Keith Kennedy, *St. Cloud State University*
Roy Kennedy, *Massachusetts Bay Community College*
Christine Kerr, *Montgomery College*
Leslie Kinsland, *University of Southwestern Louisiana*
John Konitzer, *McHenry County College*
Dave Kort, *Mississippi State University*
Glenn Kuehn, *New Mexico State University*
Alfred Lee, *City College of San Francisco*
Nancy Levinger, *Colorado State University*
Jimmy Li, *College of San Mateo*
Ann Loeb, *College of Lake County*
David Macaulay, *William Rainey Harper College*
Christopher Makaroff, *Miami University*
Joe March, *University of Alabama at Birmingham*
Stanley Marcus, *Cornell University*
Don Marshall, *Sonoma State University*
Carol Martinez, *Albuquerque Technical/Vocational Institute*
Dan McGuire, *Oklahoma State University*
Saundra McGuire, *Louisiana State University*
Valerie Meehan, *City College of San Francisco*
Sara Melford, *DePaul University*
Richard Mitchell, *Arkansas State University*
Wendell Morgan, *Hutchinson Community College*
Karl Mueller, *Pennsylvania State University*
Milica Nedelson, *Oakton Community College*
Tom Neils, *Grand Rapids Community College*
Patricia Perez, *Mt. San Antonio College*
Cortlandt Pierpont, *University of Colorado at Boulder*
Barbara Rainard, *Community College of Allegheny County*
Don Roach, *Miami-Dade Community College*
Mike Rodgers, *Southeast Missouri State University*
Patricia Rogers, *University of California, Irvine*
Rolland Rue, *South Dakota State University*
Ron Rusay, *Diablo Valley College*
Victor Ryzhov, *Northern Illinois University*
Martha Sanner, *Middlesex Community College*
Wesley Smith, *Ricks College*
Dennis Stevens, *University of Nevada, Las Vegas*
Louise Stracener, *Edgewood College*
Laura Stultz, *Birmingham-Southern College*
Christine Sullivan, *Skyline College*
Dave Tanis, *Grand Valley State University*

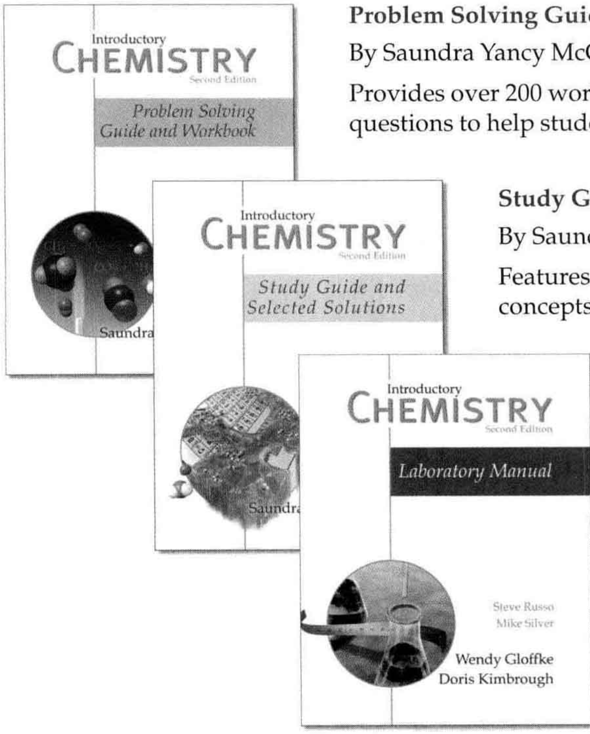
Michael Tessmer, *Southwestern College*
Vernon Theilmann, *Southwest Missouri State University*
Eric Trump, *Emporia State University*
Kenward Vaughn, *Bakersfield College*
Trudie Jo Slapar Wagner, *Vincennes University*
John Weyh, *Western Washington University*
Thomas Willard, *Florida Southern College*
Don Williams, *Hope College*
Joseph Wilson, *University of Kentucky*
Linda Wilson, *Middle Tennessee State University*

Writing a textbook is a humbling experience. The first edition taught us that no author can produce a good book without the extensive help and support of a large number of dedicated and talented people (senior editors, copy editors, developmental editors, publishing assistants, artists, reviewers, colleagues, . . .). Writing the second edition only increased our humility and our respect for this army of talent.

First, we wish to thank Saundra Yancy McGuire for her invaluable contributions, her incisive advice, her patience, and her rash willingness to get more deeply involved with each edition. In addition to reviewing all the chapters and writing the *Problem Solving Guide and Workbook* and the *Study Guide and Selected Solutions* manual, she stepped into the breach and helped us with revising and expanding the end-of-chapter problem sets. We also extend our grateful thanks to the other people who contributed to, reviewed, critiqued, and tested the problem sets—our colleagues Laura Stultz, Denisha Dawson, Jing-Yi Chin, and Victor Ryzhov, and our skilled editor John Murdzek.

To Margot Otway, our senior developmental editor for both editions, what can we say? Without your exquisite attention to every detail, your passionate drive toward excellence, your belief in our philosophy, and your extraordinary ability to do the work of ten people—this book would be a mere shadow of its present form. You may not retire until we do. To Maureen Kennedy, our editor, whose energy and focus were instrumental in shaping this second edition; to Emiko Koike and Blakeley Kim, the talented artists who are so responsible for giving this book its unique look by always insisting that they could do even better and spending many hours fretting over details in the art that neither author could even discern; to Irene Nunes, our fabulously picky, extremely dedicated, and knowledgeable editor who kept us on the right path and in line; to Joan Keyes and Jonathan Peck at Dovetail Publishing Services, for once again taking on the challenge of laying out an unconventional book; to Lisa Leung, publishing assistant and doer of a thousand tasks, for working directly with Maureen and Saundra and keeping them on task; to Tony Asaro, production coordinator (and music composer) for helping Lisa help everybody else—it goes without saying that this book could not exist without your dedication and efforts. And of course, to Joan Marsh, production editor par excellence, the nicest pest you could ever hope to work with, and Ben Roberts, our senior editor, for keeping the faith with this experiment (a readable chemistry text) and its crazed set of authors, mere words could never express our gratitude (the chocolate is in the mail). Margot Otway, Maureen Kennedy, Joan Marsh, and Ben Roberts—the four chambers of the heart of this book. We will always be in your debt.

Supplements for the Student



Problem Solving Guide and Workbook (0-321-06866-1)

By Saundra Yancy McGuire of Louisiana State University

Provides over 200 worked examples and more than 550 practice problems and quiz questions to help students develop and practice their problem-solving skills.

Study Guide and Selected Solutions (0-321-05327-3)

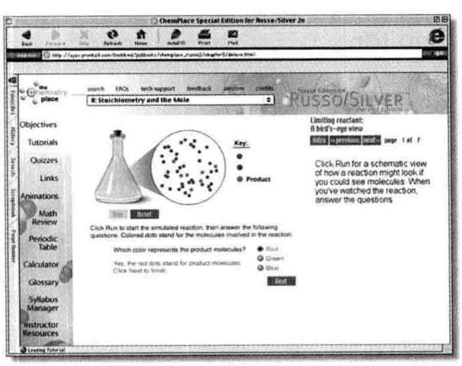
By Saundra Yancy McGuire of Louisiana State University

Features examples from each chapter, learning objectives, review of key concepts from the text, and additional problems for student practice. Also provides comprehensive answers and explanations to selected end-of-chapter problems from the text.

Introductory Chemistry Laboratory Manual (0-321-04639-0)

By Wendy Gloffke of Cedar Crest College and Doris Kimbrough of the University of Colorado at Denver

Helps students develop data acquisition, organization, and analysis skills while teaching basic techniques. Written to accompany the Russo/Silver text, this manual offers 25 experiments.



Special Edition of The Chemistry Place

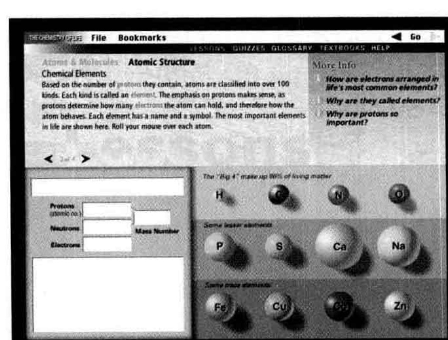
www.chemplace.com/college

This special edition of **The Chemistry Place** engages students in interactive exploration of chemistry concepts and provides a wealth of tutorial support. Tailored to Russo/Silver Second Edition, the site includes detailed objectives for each chapter of the text, interactive tutorials featuring simulations, animations, and 3-D visualization tools, multiple-choice and short-answer quizzes, an extensive set of Web links, and a mathematics review. For instructors, a **Syllabus Manager** makes it easy to create an online syllabus complete with weekly assignments, projects, and test dates that students may access on the ChemPlace site.

The Chemistry of Life for Introductory Chemistry CD-ROM (0-8053-3109-3)

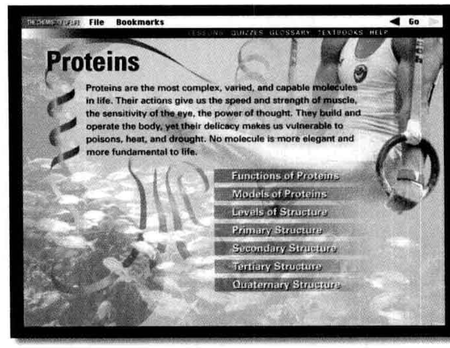
By Robert M. Thornton of the University of California, Davis

This lively tutorial teaches chemistry concepts through animations and interactive activities. The CD-ROM helps students master crucial concepts such as Atoms and Molecules, Reactions and Equilibrium, Water, Acids and Bases, Organic Molecules, Carbohydrates, Lipids, Proteins, Nucleic Acids, and Enzymes and Pathways. Includes diagnostic quizzes, an illustrated glossary, and topics correlated to the Russo/Silver text.



The Chemistry Tutor Center
www.aw.com/tutorcenter

Provides one-to-one tutoring four ways—phone, fax, email, and the Internet—during evening hours and on weekends. Qualified college instructors tutor students by answering questions and providing instruction regarding examples, exercises, and other content found in the text.



Supplements for the Instructor

Instructor's Teaching Guide (0-321-05332-X)

By Saundra Yancy McGuire of Louisiana State University

Includes chapter summaries, complete descriptions of appropriate chemical demonstrations for lecture, suggestions for addressing common student misconceptions, and examples of everyday applications of selected topics for lecture use.

Printed Test Bank (0-321-05326-5)

By Paris Svoronos and Soraya Svoronos of Queensborough Community College of the City University of New York

This printed test bank includes over 1700 questions that correspond to the major topics in the text.

Computerized Test Bank (0-321-05328-1)

By Paris Svoronos and Soraya Svoronos of Queensborough Community College of the City University of New York

This dual-platform CD-ROM includes over 1700 questions that correspond to the major topics in the text.

Complete Solutions Manual (0-321-05331-1)

By Saundra Yancy McGuire of Louisiana State University

Instructor's Manual for the Lab Manual, Second Edition (0-321-05330-3)

By Wendy Gloffke of Cedar Crest College and Doris Kimbrough of the University of Colorado at Denver

Benjamin Cummings Digital Library for *Introductory Chemistry* **CD-ROM** (0-321-04637-4)

This cross-platform CD-ROM features all of the visuals from the Russo/Silver text. The CD-ROM provides instructors with a complete set of illustrations for incorporation into lecture presentations, study materials, and tests.

Transparency Acetates (0-321-05329-X)

Includes 125 full-color acetate transparencies.

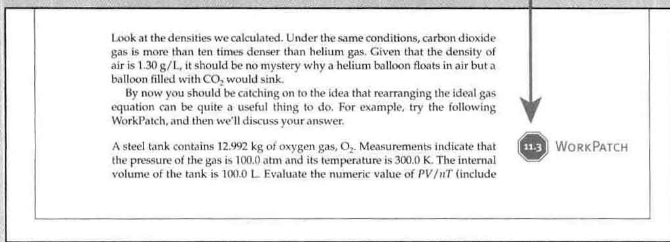
CourseCompass™

CourseCompass™ combines the strength of Benjamin Cummings content with state-of-the-art eLearning tools! **CourseCompass™** is a nationally hosted, dynamic, interactive online course management system powered by BlackBoard, leaders in the development of Internet-based learning tools. This easy-to-use and customizable program enables professors to tailor content and functionality to meet individual course needs! Every CourseCompass™ course includes a range of preloaded content such as testing and assessment question pools, chapter-level objectives, chapter summaries, photos, illustrations, videos, animations, and Web activities—all designed to help students master core course objectives. Visit www.coursecompass.com for more information.

A Suite of Tools for Learning Problem-Solving Skills

Different students need different tools. Using the example of initial-condition, final-condition gas law problems, these pages illustrate the integrated tools offered by *Introductory Chemistry* to help students master problem-solving skills.

The story begins on page 409 with WorkPatch 11.3, which asks the student to solve *PV/nT* to obtain a value for *R*. Besides emphasizing the importance of using correct units, this WorkPatch sets the stage for initial-condition, final-condition problems.



Look at the densities we calculated. Under the same conditions, carbon dioxide gas is more than ten times denser than helium gas. Given that the density of air is 1.30 g/L, it should be no mystery why a helium balloon floats in air but a balloon filled with CO_2 would sink.

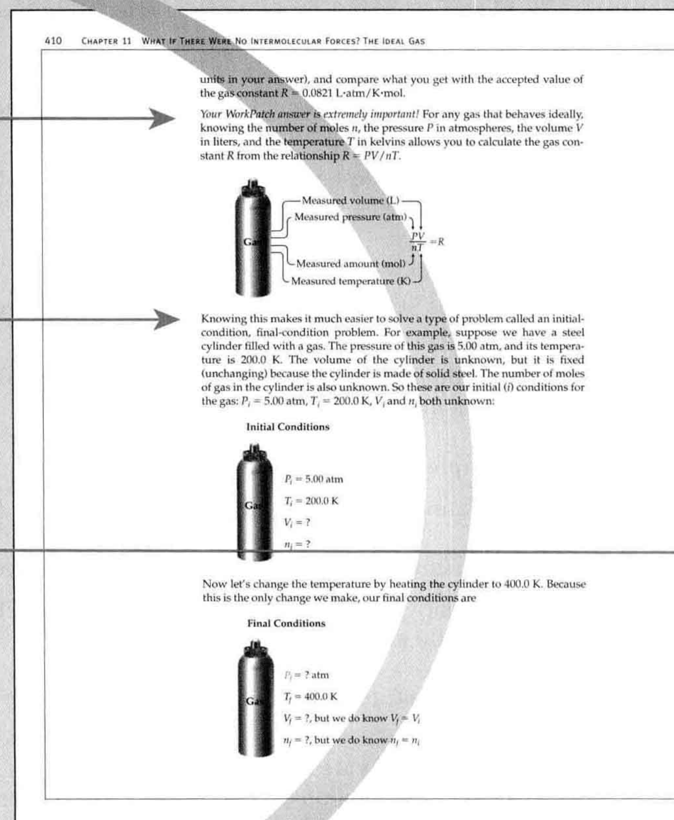
By now you should be catching on to the idea that rearranging the ideal gas equation can be quite a useful thing to do. For example, try the following WorkPatch, and then we'll discuss your answer.

A steel tank contains 12.992 kg of oxygen gas, O_2. Measurements indicate that the pressure of the gas is 100.0 atm and its temperature is 300.0 K. The internal volume of the tank is 100.0 L. Evaluate the numeric value of PV/nT (include

11.3 WorkPatch

The text after the WorkPatch discusses the importance of the answer, but does not reveal it. (All WorkPatches are solved at the end of the chapter.)

Using the context of an example, the text explains initial-condition, final-condition problems. The focus here is on ensuring that the student **understands** this type of problem, how it reflects the underlying chemistry, and how to solve it.



410 Chapter 11 What If There Were No Intermolecular Forces? The Ideal Gas

units in your answer), and compare what you get with the accepted value of the gas constant $R = 0.0821$ L·atm/K·mol.

Your WorkPatch answer is extremely important! For any gas that behaves ideally, knowing the number of moles n, the pressure P in atmospheres, the volume V in liters, and the temperature T in kelvins allows you to calculate the gas constant R from the relationship $R = PV/nT$.

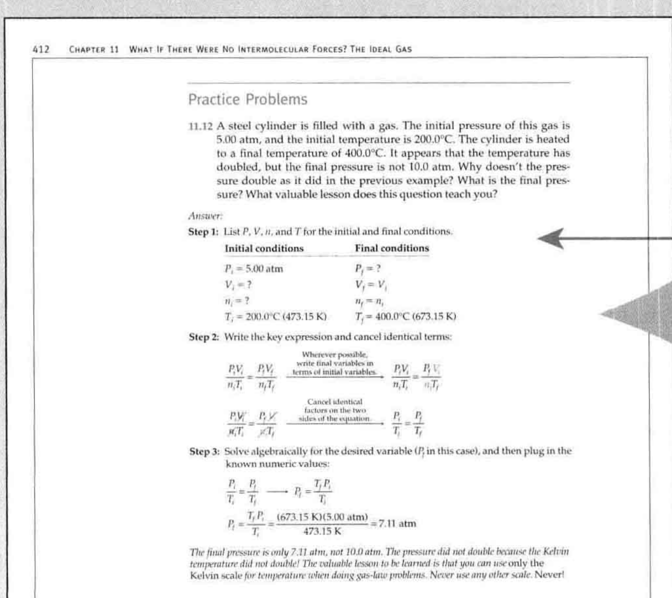
Knowing this makes it much easier to solve a type of problem called an initial-condition, final-condition problem. For example, suppose we have a steel cylinder filled with a gas. The pressure of this gas is 5.00 atm, and its temperature is 200.0 K. The volume of the cylinder is unknown, but it is fixed (unchanging) because the cylinder is made of solid steel. The number of moles of gas in the cylinder is also unknown. So these are our initial (i) conditions for the gas: $P_i = 5.00$ atm, $T_i = 200.0$ K, V_i and n_i both unknown:

Initial Conditions

Now let's change the temperature by heating the cylinder to 400.0 K. Because this is the only change we make, our final conditions are

Final Conditions

At the end of the discussion, the method for solving this type of problem is **summarized in a chart.**



412 Chapter 11 What If There Were No Intermolecular Forces? The Ideal Gas

Practice Problems

11.12 A steel cylinder is filled with a gas. The initial pressure of this gas is 5.00 atm, and the initial temperature is 200.0°C. The cylinder is heated to a final temperature of 400.0°C. It appears that the temperature has doubled, but the final pressure is not 10.0 atm. Why doesn't the pressure double as it did in the previous example? What is the final pressure? What valuable lesson does this question teach you?

Answer:

Step 1: List P, V, n, and T for the initial and final conditions.

Initial conditions	Final conditions
$P_i = 5.00$ atm	$P_f = ?$
$V_i = ?$	$V_f = V_i$
$n_i = ?$	$n_f = n_i$
$T_i = 200.0$°C (473.15 K)	$T_f = 400.0$°C (673.15 K)

Step 2: Write the key expression and cancel identical terms:

$$\frac{P_iV_i}{n_iT_i} = \frac{P_fV_f}{n_fT_f} \xrightarrow{\text{Wherever possible, write final variables in terms of initial variables.}} \frac{P_iV_i}{n_iT_i} = \frac{P_fV_i}{n_iT_f}$$

$$\frac{P_i\cancel{V_i}}{\cancel{n_i}T_i} = \frac{P_f\cancel{V_i}}{\cancel{n_i}T_f} \xrightarrow{\text{Cancel identical factors on the two sides of the equation.}} \frac{P_i}{T_i} = \frac{P_f}{T_f}$$

Step 3: Solve algebraically for the desired variable (P_f in this case), and then plug in the known numeric values:

$$\frac{P_i}{T_i} = \frac{P_f}{T_f} \longrightarrow P_f = \frac{T_fP_i}{T_i}$$

$$P_f = \frac{T_fP_i}{T_i} = \frac{(673.15\text{ K})(5.00\text{ atm})}{473.15\text{ K}} = 7.11\text{ atm}$$

The final pressure is only 7.11 atm, not 10.0 atm. The pressure did not double because the Kelvin temperature did not double! The valuable lesson to be learned is that you can use only the Kelvin scale *for temperature when doing gas-law problems. Never use any other scale.* Never!

Starting on the next page, a set of three **Practice Problems** gives the students a chance to try their hand.

The first problem is solved in place using the three-step method summarized in the chart. The answers to unsolved problems are given in the back of the book. (The solutions are available in the *Study Guide and Selected Solutions* manual.)

The **Skills to Know** section at the end of the chapter gathers together the reference information students need while learning to work problems.

In addition, each chart from the chapter is repeated and accompanied by a new worked example.

value to figure out what the gas must be. Make sure you use units compatible with the units of *R*. | $MM = \frac{\quad}{PV}$

Solving initial-condition, final-condition gas problems

Example: An air bubble rises through the ocean from a depth of 1000 feet to the surface. As it rises, its pressure decreases from 31.3 atm to 1.00 atm and its volume increases. Its initial volume is 5.00 mL. The bubble's temperature remains constant, and it gains and loses no gas. What is its final volume?

1. List *P*, *V*, *n*, and *T* for the initial and final conditions. • Write in numerical values for any variables you know. • Where possible, express the final variable in terms of the initial one. For instance, if volume does not change, you can say $V_f = V_i$.	**Initial conditions** $P_i = 31.3$ atm, $V_i = 5.00$mL, $n_i = ?$, $T_i = ?$	**Final conditions** $P_f = 1.00$ atm, $V_f = ?$, $n_f = n_i$, $T_f = T_i$
2. Write the expression $\frac{P_iV_i}{n_iT_i} = \frac{P_fV_f}{n_fT_f}$ • Whenever possible, rewrite this expression to show final variables in terms of initial ones (from step 1). • Cancel quantities that are identical on the two sides of the expression.	$\frac{P_iV_i}{n_iT_i} = \frac{P_fV_f}{n_iT_i}$ Because $n_f = n_i$ and $T_f = T_i$, we can replace variables on the right side of the equation with those from the left side. $\frac{P_iV_i}{n_iT_i} = \frac{P_fV_f}{n_iT_i} \longrightarrow P_fV_f = P_iV_i$	
3. Solve the equation algebraically for the desired variable. Then plug in values for the quantities you know and solve numerically for an answer.	$P_fV_f = P_iV_i \longrightarrow V_f = \frac{P_iV_i}{P_f}$; $V_f = \frac{P_iV_i}{P_f} = \frac{(31.3\text{ atm})(5.00\text{ mL})}{1.00\text{ atm}} = 157$ mL	

Notice that although we still do not know the volume of the gas or the number of moles of gas present, we *can* say that $V_f = V_i$ and $n_f = n_i$ because we did not change these quantities on going from the initial conditions to the final conditions. The pressure, however, has changed (it increased as the temperature increased because the volume could not change). What is the new pressure P_f inside the cylinder? This is an important question. If a storage cylinder of gas gets too hot, the increase in pressure can cause it to explode.

To determine P_f, just remember that PV/nT is always equal to *R*. This means that P_iV_i/n_iT_i is equal to *R*, and P_fV_f/n_fT_f is also equal to *R*. And of course because these expressions both equal *R*, they must be equal to each other:

$$\frac{P_iV_i}{n_iT_i} = \frac{P_fV_f}{n_fT_f}$$

This is an extremely useful result. It is the starting point for solving initial-condition, final-condition problems. The second step is to apply the rule of algebra that allows us to cancel *equal* quantities that appear in the same position on both sides of the equation. In our case, V_i on the left side and V_f on the right side are equal, and both appear in the numerator, which means they cancel each other. Likewise, n_i on the left and n_f on the right are equal and both in the denominator, which means they also cancel. These cancellations simplify our equation to

$$\frac{P_iV_i}{n_iT_i} = \frac{P_fV_f}{n_fT_f} \xrightarrow{\text{simplifies to}} \frac{P_i}{T_i} = \frac{P_f}{T_f}$$

All the variables with unknown values have disappeared! The final step is to rearrange the equation to solve for P_f and then plug in the numeric values for P_i, T_f, and T_i:

$$P_f = \frac{P_iT_f}{T_i} = \frac{(5.00\text{ atm})(400.0\text{ K})}{200.0\text{ K}} = 10.0\text{ atm}$$

This answer tells us that the pressure doubled when we doubled the temperature while holding the volume constant. Make sure you can do this algebraic rearrangement. (Review Chapter 2 if you can't!)

A summary of the method we just described appears at right.

Try the following initial-condition, final-condition practice problems. The first teaches you a valuable lesson about temperature. The second shows you how a seemingly difficult problem is in fact quite solvable.

Solving initial-condition, final-condition gas problems

Step 1: List *P*, *V*, *n*, and *T* for the initial and final conditions.
- Write in numeric values for any variables you know.
- Where possible, express the final variable in terms of the initial one. For instance, if volume does not change, you can say $V_f = V_i$.

Step 2: Write the expression $\frac{P_iV_i}{n_iT_i} = \frac{P_fV_f}{n_fT_f}$
- Whenever possible, rewrite this expression to show final variables in terms of initial ones (from step 1).
- Cancel factors that are identical on the two sides of the expression.

Step 3: Solve the equation algebraically for the desired variable. Then plug in numeric values for the quantities you know and do the calculation to get your answer.

Students having difficulty will find a wealth of carefully structured, confidence-building **guided practice** in the free *Problem Solving Guide and Workbook* that accompanies the text.

The *Workbook* provides explicit methods for solving a great variety of problems, each accompanied by worked examples and practice problems. The *Workbook* also provides chapter quizzes, cumulative quizzes, and answers to all problems.

Example 2

What is the molar mass of an unknown gas if 12.04 g of the gas occupies 7.40 L at 27.0°C and 980 mm Hg?

Solution

Perform step 1:

$$MM = \frac{m_{\text{sample}}RT}{PV}$$

Perform step 2:

T must be converted from °C to K.

$$K = 27.0°C + 273.15 = 300.2\text{ K}$$

P must be converted from mm Hg to atm.

$$P = 980\text{ mm Hg} \times \frac{1\text{ atm}}{760\text{ mm Hg}} = 1.29\text{ atm}$$

Perform step 3:

$$MM = \frac{(12.04\text{ g})(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})(300.2\text{ K})}{(1.29\text{ atm})(7.40\text{ L})} = 31.1\text{ g/mol}$$

Practice Problems

11.4 Calculate the molar mass of a gas if 1.00 L of the gas has a mass of 5.38 g at 15°C and 736 mm Hg.

11.5 What is the molar mass of a gas if 0.985 g of the gas occupies 3.00 L at a pressure of 178 mm Hg and a temperature of 22.5°?

Chart 11.3 Solving initial-condition, final-condition problems

Step 1
- List *P*, *V*, *n*, and *T* for the initial and final conditions.
- Write in numeric values for any known variables.
- Where possible, express the final variable in terms of the initial one (e.g., $V_f = V_i$).

Step 2
- Write the expression

$$\frac{P_iV_i}{n_iT_i} = \frac{P_fV_f}{n_fT_f}$$

- Whenever possible, rewrite this expression to show final variables in terms of initial ones (from step 1).
- Cancel factors that are identical on the two sides of the expression.

Step 3
- Solve the equation algebraically for the desired variable and substitute the numerical values for the known quantities.
- Perform the calculation to get the answer.

Example 1

7.62 moles of gas in a container with a moveable piston are heated from 100.0°C to 175.0°C. If the pressure remains constant, what volume will the gas occupy after the heating if it occupied 2.50 L initially?

Solution

Perform step 1:

Initial conditions	Final conditions
$P_i = P_f$ (unchanged)	$P_f = P_i$ (unchanged)
$V_i = 2.50$ L	$V_f = ?$
$n_i = n_f = 7.62$ mol (unchanged)	$n_f = n_i = 7.62$ mol (unchanged)
$T_i = 373.2$ K	$T_f = 448.2$ K

Perform step 2:

$$\frac{P_iV_i}{n_iT_i} = \frac{P_fV_f}{n_fT_f} \longrightarrow \frac{V_i}{T_i} = \frac{V_f}{T_f}$$

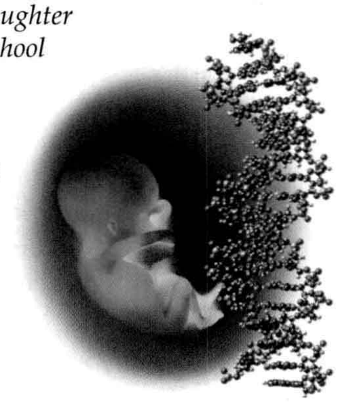
Contents

CHAPTER 1

What Is Chemistry?

It is the latter part of the nineteenth century, 1896 to be exact. I am overcome with grief. My youngest child is burning with fever. The sickness has spread from her ear to her entire body. Her skin has a scarlet look, and she is in great pain. The doctor has applied some tincture of iodine, but he does not know the cause of what ails her. He has told us to make arrangements. My beloved child will not see her fourth birthday.

It is the latter part of the twentieth century, 1996 to be exact. My daughter was ill yesterday with an earache. Our pediatrician diagnosed a streptococcus infection and administered the antibiotic amoxicillin. My daughter thought it tasted good, and she is back in preschool today, completely free of fever and pain.



It is the early part of the twenty-first century, 2026 to be exact. We have chosen to have a daughter. Unlike most of today's parents, we will not pre-select her IQ. However, we do agree with our genetic counselor that her system should be genetically engineered so that she will be immune to all known bacterial and viral infections.

1.1 Science and Technology

The span from 1896 to 1996 was 100 years. The year 2026 is less than 25 years away. The pace at which things are changing is accelerating at an unbelievable rate. One hundred years from now will be as different from today as today is from 500 years ago. Within the past ten years, a significant portion of the genetic code for the human genome has been unraveled. One hundred years ago we had never even