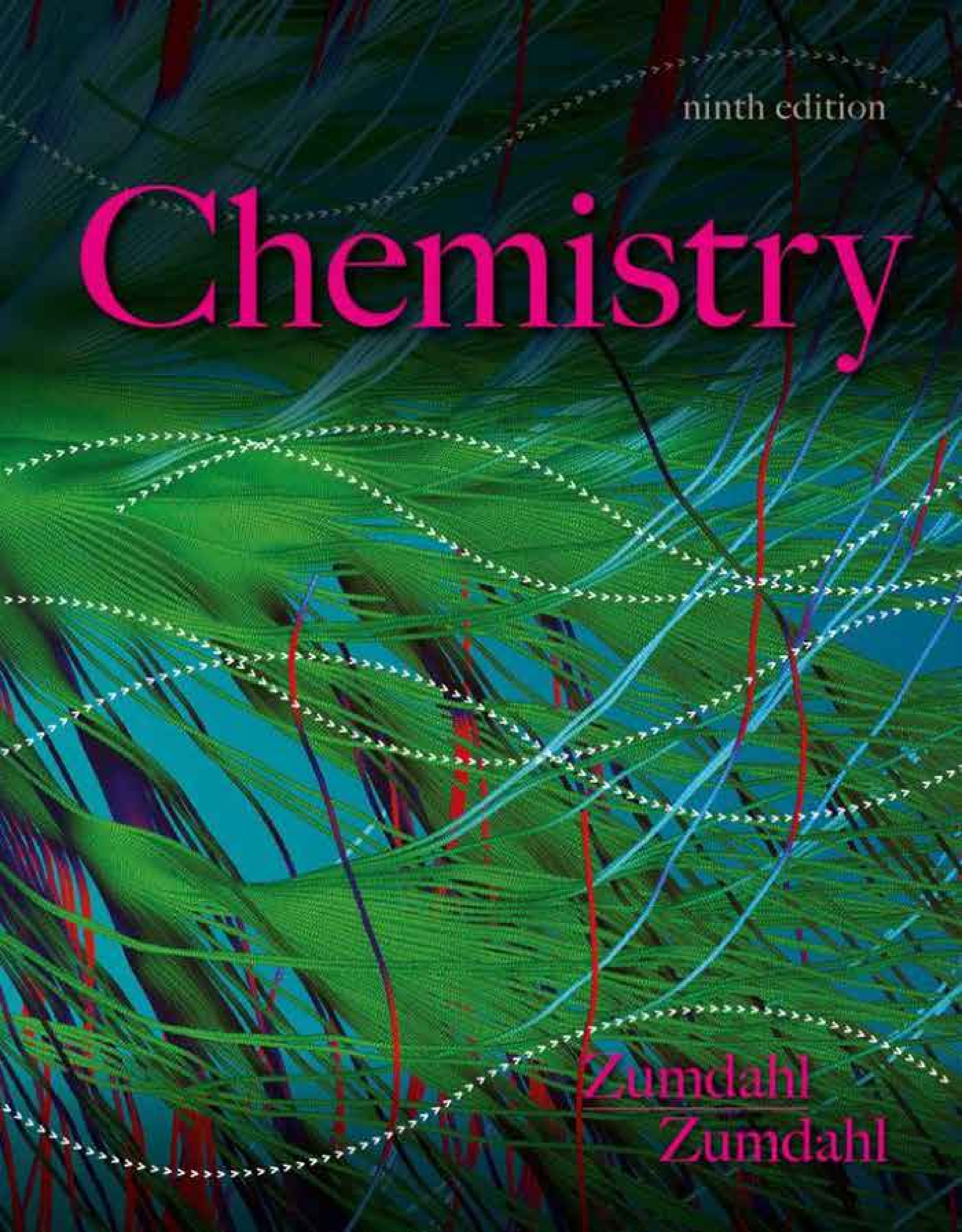

ninth edition
Chemistry
Zumdahl
Zumdahl

Periodic Table of the Elements

Alkali metals (group 1) · Alkaline earth metals (group 2) · Transition metals (groups 3–12) · Halogens (group 17) · Noble gases (group 18) · metals ← → nonmetals

1 1A	2 2A	3	4	5	6	7	8	9	10	11	12	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.008																	**He** 4.003
3 **Li** 6.941	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
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	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** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57 **La*** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226	89 **Ac**† (227)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (264)	108 **Hs** (265)	109 **Mt** (268)	110 **Ds** (271)	111 **Rg** (272)	112 **Cn** (285)	113 **Uut**	114 **Fl** (289)	115 **Uup**	116 **Lv** (293)	117 **Uus**	118 **Uuo**

***Lanthanides**	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
†**Actinides**	90 **Th** 232.0	91 **Pa** (231)	92 **U** 238.0	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

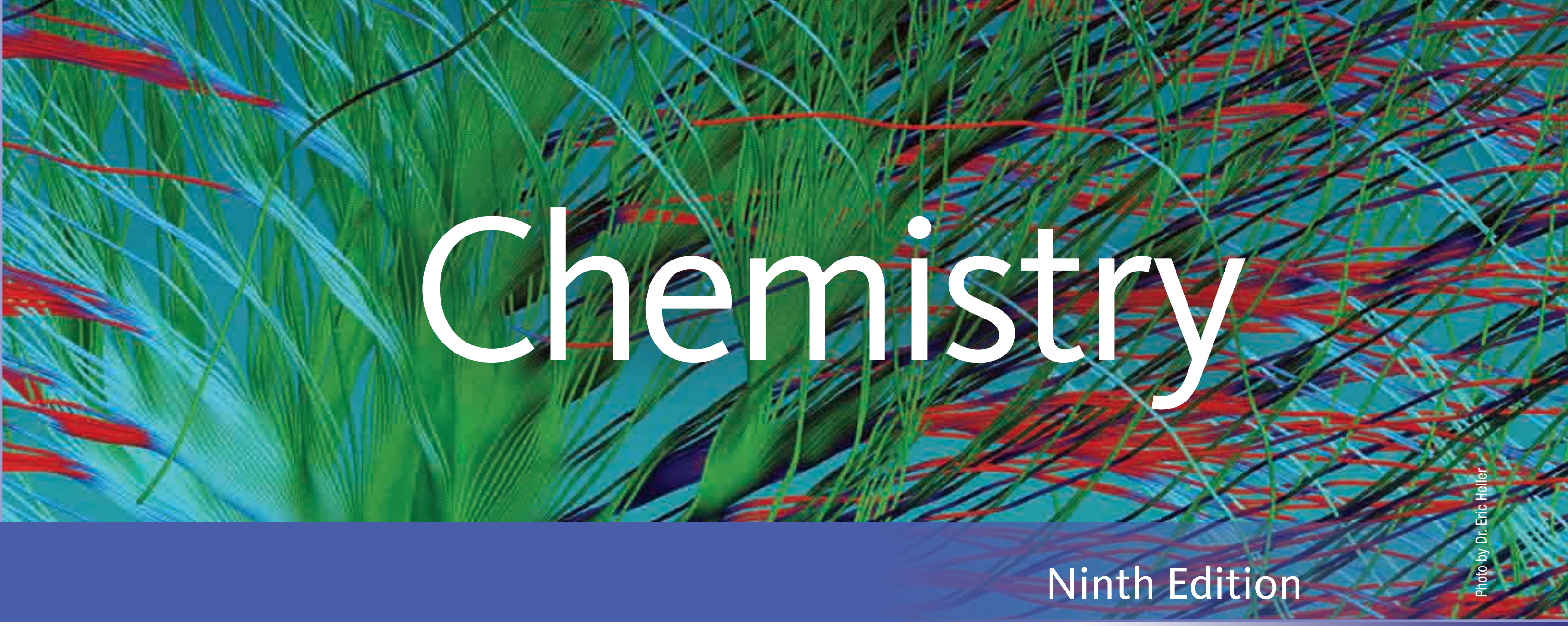
Group numbers 1–18 represent the system recommended by the International Union of Pure and Applied Chemistry.

Table of Atomic Masses*

Element	Symbol	Atomic Number	Atomic Mass	Element	Symbol	Atomic Number	Atomic Mass	Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	[227]§	Germanium	Ge	32	72.59	Potassium	K	19	39.10
Aluminum	Al	13	26.98	Gold	Au	79	197.0	Praseodymium	Pr	59	140.9
Americium	Am	95	[243]	Hafnium	Hf	72	178.5	Promethium	Pm	61	[145]
Antimony	Sb	51	121.8	Hassium	Hs	108	[265]	Protactinium	Pa	91	[231]
Argon	Ar	18	39.95	Helium	He	2	4.003	Radium	Ra	88	226
Arsenic	As	33	74.92	Holmium	Ho	67	164.9	Radon	Rn	86	[222]
Astatine	At	85	[210]	Hydrogen	H	1	1.008	Rhenium	Re	75	186.2
Barium	Ba	56	137.3	Indium	In	49	114.8	Rhodium	Rh	45	102.9
Berkelium	Bk	97	[247]	Iodine	I	53	126.9	Roentgenium	Rg	111	[272]
Beryllium	Be	4	9.012	Iridium	Ir	77	192.2	Rubidium	Rb	37	85.47
Bismuth	Bi	83	209.0	Iron	Fe	26	55.85	Ruthenium	Ru	44	101.1
Bohrium	Bh	107	[264]	Krypton	Kr	36	83.80	Rutherfordium	Rf	104	[261]
Boron	B	5	10.81	Lanthanum	La	57	138.9	Samarium	Sm	62	150.4
Bromine	Br	35	79.90	Lawrencium	Lr	103	[260]	Scandium	Sc	21	44.96
Cadmium	Cd	48	112.4	Lead	Pb	82	207.2	Seaborgium	Sg	106	[263]
Calcium	Ca	20	40.08	Livermorium	Lv	116	[293]	Selenium	Se	34	78.96
Californium	Cf	98	[251]	Lithium	Li	3	6.9419	Silicon	Si	14	28.09
Carbon	C	6	12.01	Lutetium	Lu	71	175.0	Silver	Ag	47	107.9
Cerium	Ce	58	140.1	Magnesium	Mg	12	24.31	Sodium	Na	11	22.99
Cesium	Cs	55	132.90	Manganese	Mn	25	54.94	Strontium	Sr	38	87.62
Chlorine	Cl	17	35.45	Meitnerium	Mt	109	[268]	Sulfur	S	16	32.07
Chromium	Cr	24	52.00	Mendelevium	Md	101	[258]	Tantalum	Ta	73	180.9
Cobalt	Co	27	58.93	Mercury	Hg	80	200.6	Technetium	Tc	43	[98]
Copernicium	CN	112	[285]	Molybdenum	Mo	42	95.94	Tellurium	Te	52	127.6
Copper	Cu	29	63.55	Neodymium	Nd	60	144.2	Terbium	Tb	65	158.9
Curium	Cm	96	[247]	Neon	Ne	10	20.18	Thallium	Tl	81	204.4
Darmstadtium	Ds	110	[271]	Neptunium	Np	93	[237]	Thorium	Th	90	232.0
Dubnium	Db	105	[262]	Nickel	Ni	28	58.69	Thulium	Tm	69	168.9
Dysprosium	Dy	66	162.5	Niobium	Nb	41	92.91	Tin	Sn	50	118.7
Einsteinium	Es	99	[252]	Nitrogen	N	7	14.01	Titanium	Ti	22	47.88
Erbium	Er	68	167.3	Nobelium	No	102	[259]	Tungsten	W	74	183.9
Europium	Eu	63	152.0	Osmium	Os	76	190.2	Uranium	U	92	238.0
Fermium	Fm	100	[257]	Oxygen	O	8	16.00	Vanadium	V	23	50.94
Flerovium	Fl	114	[289]	Palladium	Pd	46	106.4	Xenon	Xe	54	131.3
Fluorine	F	9	19.00	Phosphorus	P	15	30.97	Ytterbium	Yb	70	173.0
Francium	Fr	87	[223]	Platinum	Pt	78	195.1	Yttrium	Y	39	88.91
Gadolinium	Gd	64	157.3	Plutonium	Pu	94	[244]	Zinc	Zn	30	65.38
Gallium	Ga	31	69.72	Polonium	Po	84	[209]	Zirconium	Zr	40	91.22

*The values given here are to four significant figures where possible.

§A value given in parentheses denotes the mass of the longest-lived isotope.



Chemistry

Ninth Edition

Photo by Dr. Eric Heller

Steven S. Zumdahl
University of Illinois

Susan A. Zumdahl
University of Illinois

BROOKS/COLE
CENGAGE Learning

Australia • Brazil • Japan • Korea • Mexico • Singapore • Spain • United Kingdom • United States

BROOKS/COLE
CENGAGE Learning

***Chemistry*, Ninth Edition**
Steven S. Zumdahl and Susan A. Zumdahl

Publisher: Mary Finch
Executive Editor: Lisa Lockwood
Developmental Editor: Thomas Martin
Editorial Assistant: Rebekah Handler
Assistant Editor: Krista Mastroianni
Senior Media Editor: Lisa Weber
Media Editor: Stephanie VanCamp
Marketing Manager: Nicole Hamm
Marketing Assistant: Jing Hu
Marketing Communications Manager: Darlene Macanan
Content Project Manager: Teresa L. Trego
Art Director: Maria Epes
Manufacturing Buyer: Judy Inouye
Rights Acquisitions Specialist: Tom McDonough
Production Service: Graphic World Inc.
Text Designer: Ellen Pettengill
Photo Researcher: Sharon Donahue
Text Permissions: Pablo D'Stair
Copy Editor: Graphic World Inc.
Illustrator: Graphic World Inc.
OWL Producers: Stephen Battisti, Cindy Stein, David Hart (Center for Educational Software Development, University of Massachusetts, Amherst)
Cover Designer: Irene Morris
Cover Image: Dr. Eric J. Heller
Compositor: Graphic World Inc.

Library of Congress Control Number: 2012944465

Student Edition:

ISBN-13: 978-1-133-61109-7

ISBN-10: 1-133-61109-5

Brooks Cole
20 Davis Drive
Belmont, CA 94002-3098
USA

Cengage Learning is a leading provider of customized learning solutions with office locations around the globe, including Singapore, the United Kingdom, Australia, Mexico, Brazil, and Japan. Locate your local office at **www.cengage.com/global**.

Cengage Learning products are represented in Canada by Nelson Education, Ltd.

To learn more about Brooks/Cole, visit **www.cengage.com/brookscole**.

Purchase any of our products at your local college store or at our preferred online store **www.cengagebrain.com**.

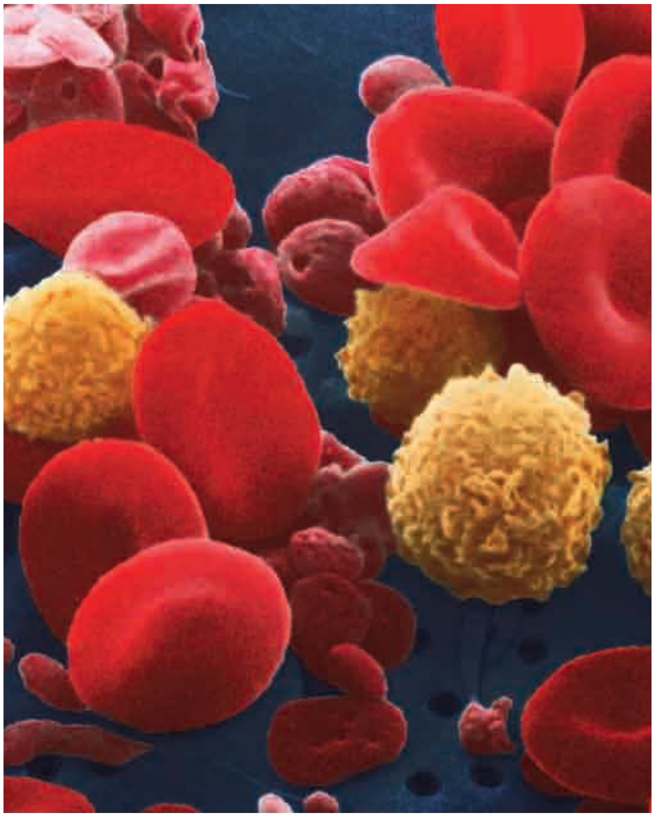
Printed in United States
1 2 3 4 5 6 7 16 15 14 13 12

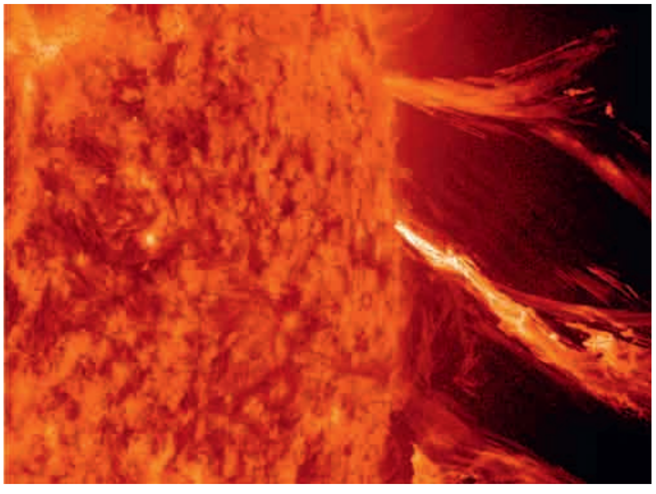
Contents

Daff/Dreamstime.com


© Caren Brinkema/Science Faction/Corbis

Carsten Peter/Speleoresearch Films/National Geographic Stock


National Cancer Institute/Photo Researchers, Inc.



NASA/SDO/AIA

Chip Clark/Smithsonian Institute

Unless otherwise noted, all art on this page is © Cengage Learning 2014.

To the Professor

Features of *Chemistry*, Ninth Edition

Conceptual learning and problem solving are fundamental to the approach of ***Chemistry***. For the ***Ninth Edition,*** we have extended this emphasis by beginning the problem-solving approach in Chapter 1 (rather than Chapter 3 as in the Eighth Edition) to assist students as they learn to use dimensional analysis for unit conversions. Our philosophy is to help students learn to think like chemists so that they can apply the process of problem solving to all aspects of their lives. We give students the tools to become critical thinkers: to ask questions, to apply rules and models, and to evaluate the outcome. It was also our mission to create a media program that embodies this philosophy so that when instructors and students look online for either study aids or online homework, each resource supports the goals of the textbook—a strong emphasis on *models, real-world applications,* and *visual learning*.

What's New

We have made extensive updates to the ***Ninth Edition*** to enhance the learning experience for students. **Here's what's new:**

- A new emphasis has been placed on systematic problem solving in the applications of dimensional analysis.
- *Critical Thinking* questions have been added throughout the text to emphasize the importance of conceptual learning.
- *Interactive Examples* have been added throughout the text. These computer-based examples force students to think through the example step-by-step rather than simply scan the written example in the text as many students do.
- *ChemWork* problems have been added to the end-of-chapter problems throughout the text. These problems test students' understanding of core concepts from each chapter. Students who solve a particular problem with no assistance can proceed directly to the answer. However, students who need help can get assistance through a series of online hints. The online procedure for assisting students is modeled after the way a teacher would help with homework problems in his or her office. The hints are usually in the form of interactive questions that guide students through the problem-solving process. Students cannot receive the correct answer from the computer; rather, it encourages students to continue working though the hints to arrive at the answer. *ChemWork* problems in the text can be worked using the online system or as pencil-and-paper problems.
- New end-of-chapter questions and problems have been added throughout the text.
- The art program has been modified and updated as needed, and new macro/micro illustrations have been added.
- In Chapter 3 the treatment of stoichiometry has been enhanced by the addition of a new section on limiting reactants, which emphasizes calculating the amounts of products that can be obtained from each reactant. Now students are taught how to select a limiting reactant both by comparing the amounts of reactants present and by calculating the amounts of products that can be formed by complete consumption of each reactant.
- A section on photoelectron spectroscopy was added to Chapter 9 (Section 9.6).

Hallmarks of *Chemistry*

- ***Chemistry*** contains numerous discussions, illustrations, and exercises aimed at *overcoming misconceptions*. It has become increasingly clear from our own teaching experience that students often struggle with chemistry because they misunderstand many of the fundamental concepts. In this text, we have gone to great lengths to provide illustrations and explanations aimed at giving students a more accurate picture of the fundamental ideas of chemistry. In particular, we have attempted to represent the microscopic world of chemistry so that students have a picture in their minds of "what the atoms and molecules are doing." The art program along with the animations emphasize this goal. We have also placed a larger emphasis on the qualitative understanding of concepts before quantitative problems are considered. Because using an algorithm to correctly solve a problem often masks misunderstanding—when students assume they understand the material because they got the right "answer"—it is important to probe their understanding in other ways. In this vein, the text includes many *Critical Thinking* questions throughout the text and a number of *Active Learning Questions* at the end of each chapter that are intended for group discussion. It is our experience that students often learn the most when they teach each other. Students are forced to recognize their own lack of understanding when they try and fail to explain a concept to another student.

- With a strong *problem-solving orientation,* this text talks to students about how to approach and solve chemical problems. We emphasize a thoughtful, logical approach rather than simply memorizing procedures. In particular, an innovative method is given for dealing with acid–base equilibria, the material the typical student finds most difficult and frustrating. The key to this approach involves first deciding what species are present in solution, then thinking about the chemical properties of these species. This method provides a general framework for approaching all types of solution equilibria.
- The text contains *almost 300 Examples,* with more given in the text discussions, to illustrate general problem-solving strategies. When a specific strategy is presented, it is summarized in a *Problem-Solving Strategy* box, and the *Example* that follows it reinforces the use of the strategy to solve the problem. In general, we emphasize the use of conceptual understanding to solve problems rather than an algorithm-based approach. This approach is strongly reinforced by the inclusion of many *Interactive Examples,* which encourage students to thoughtfully consider the example step-by-step.
- We have presented a thorough *treatment of reactions* that occur in solution, including acid–base reactions. This material appears in Chapter 4, "Types of Chemical Reactions and Solution Stoichiometry," directly after the chapter on chemical stoichiometry, to emphasize the connection between solution reactions and chemical reactions in general. The early presentation of this material provides an opportunity to cover some interesting descriptive chemistry and also supports the lab, which typically involves a great deal of aqueous chemistry. Chapter 4 also includes oxidation–reduction reactions and balancing by oxidation state, because a large number of interesting and important chemical reactions involve redox processes. However, coverage of oxidation–reduction is optional at this point and depends on the needs of a specific course.
- *Descriptive chemistry* and chemical principles are thoroughly integrated in this text. Chemical models may appear sterile and confusing without the observations that stimulated their invention. On the other hand, facts without organizing principles may seem overwhelming. A combination of observation and models can make chemistry both interesting and understandable. In the chapter on the chemistry of the elements, we have used tables and charts to show how properties and models correlate. Descriptive chemistry is presented in a variety of ways—as applications of principles in separate sections, in photographs, in *Examples* and exercises, in paragraphs, and in *Chemical Connections*.
- Throughout the book a strong *emphasis on models* prevails. Coverage includes how they are constructed, how they are tested, and what we learn when they inevitably fail. Models are developed naturally, with pertinent observation always presented first to show why a particular model was invented.
- *Chemical Connections* boxes present applications of chemistry in various fields and in our daily lives. Margin notes in the *Instructor's Annotated Edition* also highlight many more *Chemical Connections* available on the student website.
- We offer end-of-chapter exercises for every type of student and for every kind of homework assignment: questions that promote group learning, exercises that reinforce student understanding, and problems that present the ultimate challenge with increased rigor and by integrating multiple concepts. We have added biochemistry problems to make the connection for students in the course who are not chemistry majors.
- Judging from the favorable comments of instructors and students who have used the eighth edition, the text seems to work very well in a variety of courses. We were especially pleased that *readability* was cited as a key strength when students were asked to assess the text.

Supporting Materials

Please visit **www.cengage.com/chemistry/zumdahl/chemistry9e** for information about student and instructor resources for this text.

Acknowledgments

This book represents the efforts of many talented and dedicated people. We particularly want to thank Mary Finch, Publisher, for her vision and oversight of the project, and Lisa Lockwood, Executive Editor, whose enthusiasm, powers of organization, and knowledge of the market have contributed immensely to the success of this revision. We also greatly appreciate the work of Teresa Trego, Content Project Manager, who did an outstanding job of managing the production of this complex project.

We especially appreciate the outstanding and untiring work of Tom Martin, Developmental Editor. Tom is always upbeat and has great suggestions. He contributed in many important ways to the successful completion of this edition, keeping the details in order and managing many different people with grace and good humor.

We are especially grateful to Tom Hummel, University of Illinois, Urbana-Champaign, who managed the revision of the end-of-chapter problems and the solutions manuals. Tom's extensive experience teaching general chemistry and his high standards of accuracy and clarity have resulted in great improvements in the quality of the problems and solutions in this edition. Don DeCoste and Gretchen Adams support us in so many ways it is impossible to list all of them. Don wrote all of the *Critical Thinking* questions for this edition. Gretchen constructed all of the online *Interactive Examples,* created the PowerPoint slides, and worked on many of the other media aspects of the program. We are very grateful to Don and Gretchen for their creativity and their incredible work ethic and for being such wonderful colleagues.

Special thanks to Kathy Thrush Saginaw, who contributed excellent suggestions for improving the art in the text, and to Sharon Donahue, who did her usual outstanding job finding just the right photos for this edition. Also we greatly appreciate the advice and support of Nicole Hamm, Senior Marketing Manager.

There are many other people who made important contributions to the success of this edition, including Megan Greiner at Graphic World; Maria Epes, Art Director; Ellen Pettengill, Text Designer; Lisa Weber, Senior Media Editor; and Stephanie VanCamp, Media Editor. Special thanks to Krista Mastroianni, Assistant Editor, who helped in many different ways.

We are especially thankful to all of the reviewers who participated in different aspects of the development process, from reviewing the illustrations and chapters to providing feedback on the development of new features. We sincerely appreciate all of these suggestions.

Reviewers

Ninth Edition Reviewers

Kaveh Azimi, *Tarrant County College–South*

Ron Briggs, *Arizona State University*

Maureen Burkart, *Georgia Perimeter College*

Paula Clark, *Muhlenberg College*

Russell Franks, *Stephen F. Austin State University*

Judy George, *Grossmont College*

Roger LeBlanc, *University of Miami*

Willem Leenstra, *University of Vermont*

Gary Mort, *Lane Community College*

Hitish Nathani, *St. Philip's College*

Shawn Phillips, *Vanderbilt University*

Elizabeth Pulliam, *Tallahassee Community College*

Michael Sommer, *University of Wyoming*

Clarissa Sorensen-Unruh, *Central New Mexico Community College*

William Sweeney, *Hunter College, The City University of New York*

Brooke Taylor, *Lane Community College*

Hongqiu Zhao, *Indiana University-Purdue University Indianapolis*

Lin Zhu, *Indiana University-Purdue University Indianapolis*

AP Reviewers:

Todd Abronowitz, *Parish Episcopal High School*

Kristen Jones, *College Station ISD*

Lisa McGaw, *Laying the Foundation*

Priscilla Tuttle, *Eastport-South Manor Junior/Senior High School*

Eighth Edition Reviewers

Yiyan Bai, *Houston Community College*

David A. Boyajian, *Palomar College San Marcos*

Carrie Brennan, *Austin Peay State University*

Alexander Burin, *Tulane University*

Jerry Burns, *Pellissippi State Technical Community College*

Stuart Cohen, *Horry-Georgetown Technical College*

Philip Davis, *University of Tennessee at Martin*

William M. Davis, *The University of Texas at Brownsville*

Stephanie Dillon, *Florida State University*

David Evans, *Coastal Carolina University*

Leanna Giancarlo, *University of Mary Washington*

Tracy A. Halmi, *Penn State Erie, The Behrend College*

Myung Han, *Columbus State Community College*

Carl Hoeger, *University of California, San Diego*

Richard Jarman, *College of DuPage*

Kirk Kawagoe, *Fresno City College*

Cathie Keenan, *Chaffey College*

Donald P. Land, *University of California, Davis Department of Chemistry*

Craig Martens, *University of California, Irvine*

Chavonda Mills, *Georgia College & State University*

John Pollard, *University of Arizona*

Rene Rodriguez, *Idaho State University*

Tim Royappa, *University of West Florida*

Karl Sienerth, *Elon University*

Brett Simpson, *Coastal Carolina University*

Alan Stolzenberg, *West Virginia University, Morgantown*

Paris Svoronos, *Queensborough Community College, CUNY*

Brooke Taylor, *Lane Community College*

James Terner, *Virgina Commonwealth University*

Jackie Thomas, *Southwestern College*

David W. Thompson, *College of William and Mary*

Edward Walters, *University of New Mexico*

Darrin M. York, *University of Minnesota*

Noel S. Zaugg, *Brigham Young University, Idaho*

AP Reviewers:

Robert W. Ayton, Jr., *Dunnellon High School*

David Hostage, *The Taft School*

Steven Nelson, *Addison Trail High School*

Connie Su, *Adolfo Camarillo High School*

Seventh Edition Reviewers

Dawood Afzal, *Truman State*
Carol Anderson, *University of Connecticut, Avery Point*
Jeffrey R. Appling, *Clemson University*
Dave Blackburn, *University of Minnesota*
Robert S. Boikess, *Rutgers University*
Ken Carter, *Truman State*
Bette Davidowitz, *University of Cape Town*
Natalie Foster, *Lehigh University*
Tracy A. Halmi, *Penn State Erie, The Behrend College*
Carl Hoeger, *University of California, San Diego*
Ahmad Kabbani, *Lebanese American University*
Arthur Mar, *University of Alberta*
Jim McCormick, *Truman State*
Richard Orwell, *Blue Ridge Community College*
Jason S. Overby, *College of Charleston*
Robert D. Pike, *The College of William and Mary*
Daniel Raferty, *Purdue University*
Jimmy Rogers, *University of Texas, Arlington*
Raymond Scott, *Mary Washington College*
Alan Stolzenberg, *West Virginia University, Morgantown*
Rashmi Venkateswaran, *University of Ottawa*

AP Reviewers:

Annis Hapkiewicz, *Okemos High School*
Tina Ohn-Sabatello, *Maine Township HS East*

To the Student

As you jump into the study of chemistry, we hope that you will find our text helpful and interesting. Our job is to present the concepts and ideas of chemistry in a way you can understand. We hope to encourage you in your studies and to help you learn to solve problems in ways you can apply in all areas of your professional and personal lives.

Our main goal is to help you learn to become a truly creative problem solver. Our world badly needs people who can "think outside the box." Our focus is to help you learn to think like a chemist. Why would you want to do that? Chemists are great problem solvers. They use logic, trial and error, and intuition—along with lots of patience—to work through complex problems. Chemists make mistakes, as we all do in our lives. The important thing that a chemist does is to learn from the mistakes and to try again. This "can do" attitude is useful in all careers.

In this book we develop the concepts in a natural way: The observations come first and then we develop models to explain the observed behavior. Models help us to understand and explain our world. They are central to scientific thinking. Models are very useful, but they also have limitations, which we will point out. By understanding the basic concepts in chemistry we lay the foundation for solving problems.

Our main goal is to help you learn a thoughtful method of problem solving. True learning is more than memorizing facts. Truly educated people use their factual knowledge as a starting point—a basis for creative problem solving. Our strategy for solving problems is explained first in Section 1.6 and is covered in more details in Section 3.5. To solve a problem we ask ourselves questions, which help us think through the problem. We let the problem guide us to the solution. This process can be applied to all types of problems in all areas of life.

As you study the text, use the *Examples* and the problem-solving strategies to help you. The strategies are boxed to highlight them for you, and the *Examples* show how these strategies are applied. It is especially important for you to do the computer-based *Interactive Examples* that are found throughout the text. These examples encourage you to think through the examples step-by-step to help you thoroughly understand the concepts involved.

After you have read and studied each chapter of the text, you'll need to practice your problem-solving skills. To do this we have provided plenty of review questions and end-of-chapter exercises. Your instructor may assign these on paper or online; in either case, you'll want to work with your fellow students. One of the most effective ways to learn chemistry is through the exchange of ideas that comes from helping one another. The online homework assignments will give you instant feedback, and in print, we have provided answers to some of the exercises in the back of the text. In all cases, your main goal is not just to get the correct answer but to understand the process for getting the answer. Memorizing solutions for specific problems is not a very good way to prepare for an exam (or to solve problems in the real world!).

To become a great problem solver, you'll need these skills:

1. Look within the problem for the solution. (Let the problem guide you.)
2. Use the concepts you have learned along with a systematic, logical approach to find the solution.
3. Solve the problem by asking questions and learn to trust yourself to think it out.

You will make mistakes, but the important thing is to learn from these errors. The only way to gain confidence is to practice, practice, practice and to use your mistakes to find your weaknesses. Be patient with yourself and work hard to understand rather than simply memorize.

We hope you'll have an interesting and successful year learning to think like a chemist!

Steve and Susan Zumdahl

A GUIDE TO *Chemistry*, NINTH EDITION

Conceptual Understanding Conceptual learning and problem solving are fundamental to the approach of ***Chemistry***. The text gives students the tools to become critical thinkers: to ask questions, to apply rules and models, and to evaluate the outcome.

"Before students are ready to figure out complex problems, they need to master simpler problems in various contortions. This approach works, and the authors' presentation of it should have the students buying in."

—JERRY BURNS, *Pellissippi State Technical Community College*

The authors' **emphasis on modeling** (or chemical theories) throughout the text addresses the problem of rote memorization by helping students better understand and appreciate the process of scientific thinking. By stressing the limitations and uses of scientific models, the authors show students how chemists think and work.

> **8.13 | Molecular Structure: The VSEPR Model**
>
> The structures of molecules play a very important role in determining their chemical properties. As we will see later, this is particularly important for biological molecules; a slight change in the structure of a large biomolecule can completely destroy its usefulness to a cell or may even change the cell from a normal one to a cancerous one.

> **Critical Thinking**
>
> Consider the simple reaction aA $\rightarrow$ products. You run this reaction and wish to determine its order. What if you made a graph of reaction rate versus time? Could you use this to determine the order? Sketch three plots of rate versus time for the reaction if it is zero, first, or second order. Sketch these plots on the same graph and compare them. Defend your answer.

The text includes a number of open-ended **Critical Thinking** questions that emphasize the importance of conceptual learning. These questions are particularly useful for generating group discussion.

> **Let's Review | *Summary of the VSEPR Model***
>
> The rules for using the VSEPR model to predict molecular structure are as follows:
>
> - Determine the Lewis structure(s) for the molecule.
> - For molecules with resonance structures, use any of the structures to predict the molecular structure.
> - Sum the electron pairs around the central atom.
> - In counting pairs, count each multiple bond as a single effective pair.
> - The arrangement of the pairs is determined by minimizing electron-pair repulsions. These arrangements are shown in Table 8.6.
> - Lone pairs require more space than bonding pairs do. Choose an arrangement that gives the lone pairs as much room as possible. Recognize that the lone pairs may produce a slight distortion of the structure at angles less than 120 degrees.

Let's Review boxes help students organize their thinking about the crucial chemical concepts that they encounter.

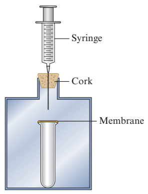
The text includes a number of **Active Learning Questions** at the end of each chapter that are intended for group discussion, since students often learn the most when they teach each other.

A discussion of the Active Learning Questions can be found online in the Instructor's Resource Guide and on PowerLecture. The questions allow students to explore their understanding of concepts through discussion and peer teaching. The real value of these questions is the learning that occurs while students talk to each other about chemical concepts.

Active Learning Questions

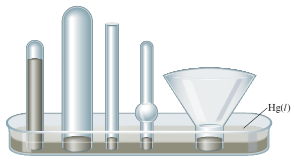
These questions are designed to be used by groups of students in class.

1. Consider the following apparatus: a test tube covered with a nonpermeable elastic membrane inside a container that is closed with a cork. A syringe goes through the cork.

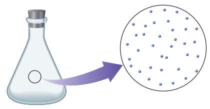


   a. As you push down on the syringe, how does the membrane covering the test tube change?
   b. You stop pushing the syringe but continue to hold it down. In a few seconds, what happens to the membrane?
2. Figure 5.2 shows a picture of a barometer. Which of the following statements is the best explanation of how this barometer works?
   a. Air pressure outside the tube causes the mercury to move in the tube until the air pressure inside and outside the tube is equal.
   b. Air pressure inside the tube causes the mercury to move in the tube until the air pressure inside and outside the tube is equal.
   c. Air pressure outside the tube counterbalances the weight of the mercury in the tube.
   d. Capillary action of the mercury causes the mercury to go up the tube.
   e. The vacuum that is formed at the top of the tube holds up the mercury.

   Justify your choice, and for the choices you did not pick, explain what is wrong with them. Pictures help!
3. The barometer below shows the level of mercury at a given atmospheric pressure. Fill all the other barometers with mercury for that same atmospheric pressure. Explain your answer.



4. As you increase the temperature of a gas in a sealed, rigid container, what happens to the density of the gas? Would the results be the same if you did the same experiment in a container with a piston at constant pressure? (See Fig. 5.17.)
5. A diagram in a chemistry book shows a magnified view of a flask of air as follows:



Problem Solving This text talks to the student about how to approach and solve chemical problems, since one of the main goals of general chemistry is to help students become creative problem solvers. The authors emphasize a thoughtful, logical approach rather than simply memorizing procedures.

"The text gives a meaningful explanation and alternative to memorization. This approach and the explanation [to the student] of the approach will supply the 'secret' of successful problem solving abilities to all students."

—David Boyajian, *Palomar College*

In **Chapter 3**, "Stoichiometry," the authors introduce a new section, **Learning to Solve Problems,** which emphasizes the importance of problem solving. This new section helps students understand that thinking their way through a problem produces more long-term, meaningful learning than simply memorizing steps, which are soon forgotten.

3.5 | Learning to Solve Problems

One of the great rewards of studying chemistry is to become a good problem solver. Being able to solve complex problems is a talent that will serve you well in all walks of life. It is our purpose in this text to help you learn to solve problems in a flexible, creative way based on understanding the fundamental ideas of chemistry. We call this approach **conceptual problem solving**.

The ultimate goal is to be able to solve new problems (that is, problems you have not seen before) on your own. In this text we will provide problems and offer solutions by explaining how to think about the problems. While the answers to these problems are important, it is perhaps even more important to understand the process—the thinking necessary to get the answer. Although at first we will be solving the problem for you, do not take a passive role. While studying the solution, it is crucial that you interactively think through the problem with us. Do not skip the discussion and jump to the answer. Usually, the solution will involve asking a series of questions. Make sure that you understand each step in the process. This active approach should apply to problems outside of chemistry as well. For example, imagine riding with someone in a car to an unfamiliar destination. If your goal is simply to have the other person get you to that destination, you will probably not pay much attention to how to get there (passive), and if you have to find this same place in the future on your own, you probably will not be able to do it. If, however, your goal is to learn how to get there, you would pay attention to distances, signs, and turns (active). This is how you should read the solutions in the text (and the text in general).

While actively studying our solutions to problems is helpful, at some point you will need to know how to think through these problems on your own. If we help you too much as you solve a problem, you won't really learn effectively. If we always "drive," you won't interact as meaningfully with the material. Eventually you need to learn to drive yourself. We will provide more help at the beginning of the text and less as we proceed to later chapters.

John Humble/The Image Bank/Getty Images

Pigeonholes can be used for sorting and classifying objects like mail.

There are two fundamentally different ways you might use to approach a problem. One way emphasizes memorization. We might call this the "pigeonholing method." In this approach, the first step is to label the problem—to decide in which pigeonhole it fits. The pigeonholing method requires that we provide you with a set of steps that you memorize and store in the appropriate slot for each different problem you encounter. The difficulty with this method is that it requires a new pigeonhole each time a problem is changed by even a small amount.

Consider the driving analogy again. Suppose you have memorized how to drive from your house to the grocery store. Do you know how to drive back from the grocery store to your house? Not necessarily. If you have only memorized the directions and do not understand fundamental principles such as "I traveled north to get to the store, so my house is south of the store," you may find yourself stranded. In a more complicated example, suppose you know how to get from your house to the store (and back) and from your house to the library (and back). Can you get from the library to the store without having to go back home? Probably not if you have only memorized directions

Chapters 1–6 introduce a series of questions into the in-chapter **Examples** to engage students in the process of problem solving, such as **Where are we going?** and **How do we get there?** This more active approach helps students think their way through the solution to the problem.

Example 1.12 Temperature Conversions II

One interesting feature of the Celsius and Fahrenheit scales is that −40°C and −40°F represent the same temperature, as shown in Fig. 1.9. Verify that this is true.

Solution

Where are we going?

To show that −40°C = −40°F

What do we know?

› The relationship between the Celsius and Fahrenheit scales

How do we get there?

The difference between 32°F and −40°F is 72°F. The difference between 0°C and −40°C is 40°C. The ratio of these is

$$\frac{72°\text{F}}{40°\text{C}} = \frac{8 \times 9°\text{F}}{8 \times 5°\text{C}} = \frac{9°\text{F}}{5°\text{C}}$$

as required. Thus −40°C is equivalent to −40°F.

See Exercise 1.61

Problem-Solving Strategy boxes focus students' attention on the very important process of problem solving.

Problem-Solving Strategy

Determining Molecular Formula from Empirical Formula

› Obtain the empirical formula.

› Compute the mass corresponding to the empirical formula.

› Calculate the ratio:

$$\frac{\text{Molar mass}}{\text{Empirical formula mass}}$$

› The integer from the previous step represents the number of empirical formula units in one molecule. When the empirical formula subscripts are multiplied by this integer, the molecular formula results. This procedure is summarized by the equation:

$$\text{Molecular formula} = \text{empirical formula} \times \frac{\text{molar mass}}{\text{empirical formula mass}}$$

Interactive Examples engage students in the problem-solving process by requiring them to think through the example step-by-step rather than simply scanning the written example in the text as many students do.

Interactive Example 17.1 Positional Entropy

Sign in at http://login.cengagebrain.com to try this Interactive Example in **OWL**.

For each of the following pairs, choose the substance with the higher positional entropy (per mole) at a given temperature.

a. Solid CO_2 and gaseous CO_2

b. N_2 gas at 1 atm and N_2 gas at 1.0×10^{-2} atm

Solution

a. Since a mole of gaseous CO_2 has the greater volume by far, the molecules have many more available positions than in a mole of solid CO_2. Thus gaseous CO_2 has the higher positional entropy.

b. A mole of N_2 gas at 1×10^{-2} atm has a volume 100 times that (at a given temperature) of a mole of N_2 gas at 1 atm. Thus N_2 gas at 1×10^{-2} atm has the higher positional entropy.

See Exercise 17.31

Interactive Example 17.2 Predicting Entropy Changes

Sign in at http://login.cengagebrain.com to try this Interactive Example in **OWL**.

Predict the sign of the entropy change for each of the following processes.

a. Solid sugar is added to water to form a solution.

b. Iodine vapor condenses on a cold surface to form crystals.

Solution

a. The sugar molecules become randomly dispersed in the water when the solution forms and thus have access to a larger volume and a larger number of possible positions. The positional disorder is increased, and there will be an increase in entropy. ΔS is positive, since the final state has a larger entropy than the initial state, and $\Delta S = S_{\text{final}} - S_{\text{initial}}$.

b. Gaseous iodine is forming a solid. This process involves a change from a relatively large volume to a much smaller volume, which results in lower positional disorder. For this process ΔS is negative (the entropy decreases).

See Exercise 17.32

Dynamic Art Program Most of the glassware, orbitals, graphs, flowcharts, and molecules have been redrawn to better serve visual learners and enhance the textbook.

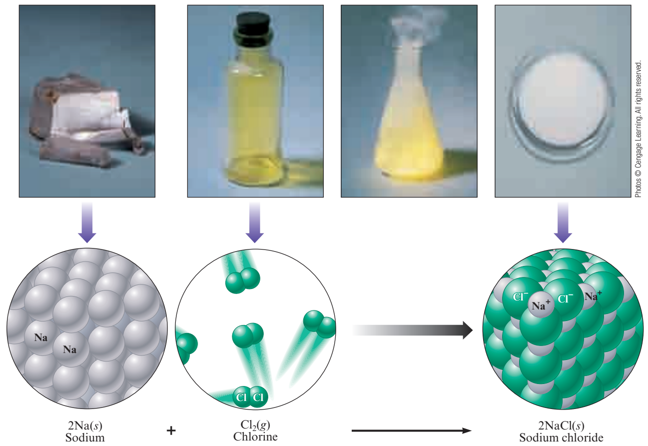


Figure 4.19 | The reaction of solid sodium and gaseous chlorine to form solid sodium chloride.

The art program emphasizes molecular-level interactions that help students visualize the “micro/macro” connection.

Realistic drawings of glassware and instrumentation found in the lab help students make real connections.

Figure 4.10 | Steps involved in the preparation of a standard aqueous solution. (a) Put a weighed amount of a substance (the solute) into the volumetric flask, and add a small quantity of water. (b) Dissolve the solid in the water by gently swirling the flask (*with the stopper in place*). (c) Add more water (with gentle swirling) until the level of the solution just reaches the mark etched on the neck of the flask. Then mix the solution thoroughly by inverting the flask several times.

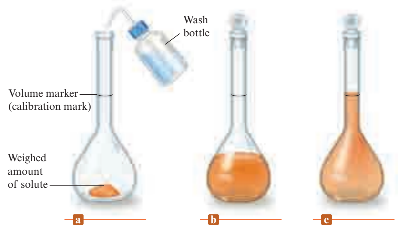


Figure 8.5 | (a) The charge distribution in the water molecule. (b) The water molecule in an electric field. (c) The electrostatic potential diagram of the water molecule.

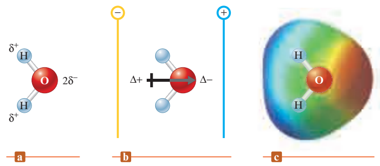
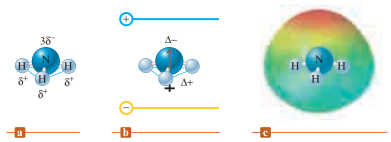
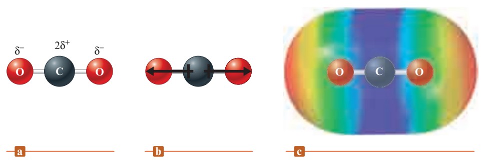


Figure 8.6 | (a) The structure and charge distribution of the ammonia molecule. The polarity of the N—H bonds occurs because nitrogen has a greater electronegativity than hydrogen. (b) The dipole moment of the ammonia molecule oriented in an electric field. (c) The electrostatic potential diagram for ammonia.



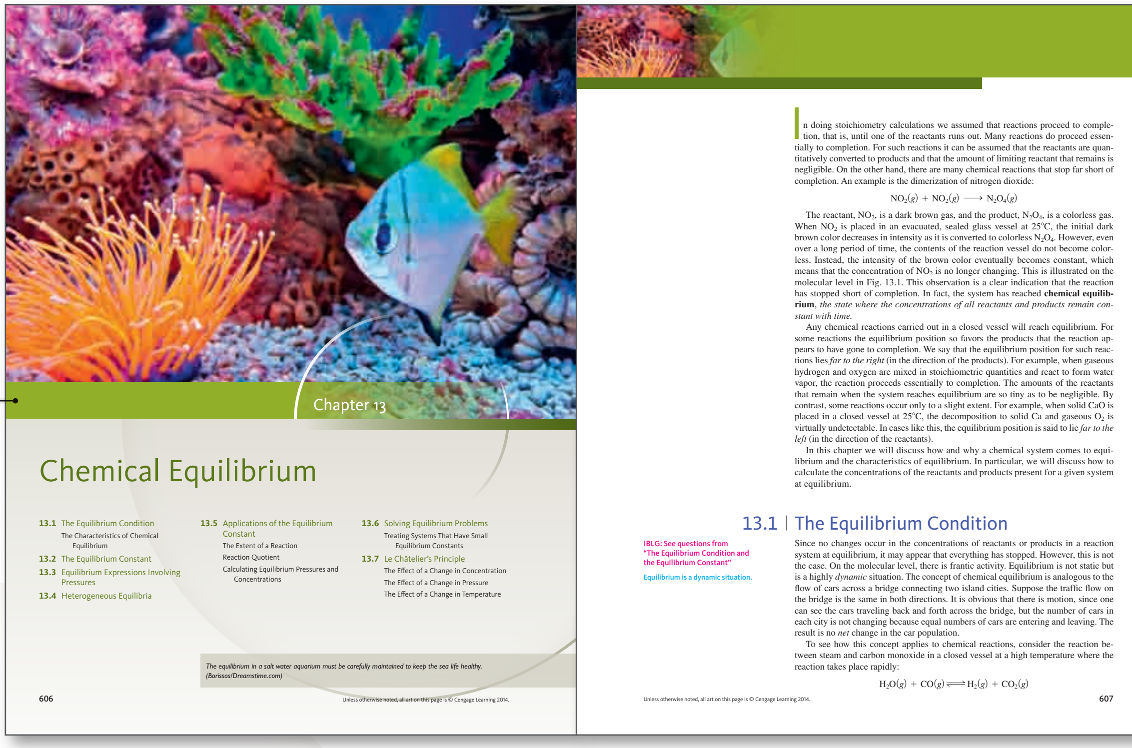
Electrostatic potential maps help students visualize the distribution of charge in molecules.

Figure 8.7 | (a) The carbon dioxide molecule. (b) The opposed bond polarities cancel out, and the carbon dioxide molecule has no dipole moment. (c) The electrostatic potential diagram for carbon dioxide.



Real-World Applications Interesting applications of modern chemistry show students the relevance of chemistry to their world.

Each chapter begins with an engaging introduction that demonstrates how chemistry is related to everyday life.



Chapter 13

Chemical Equilibrium

The equilibrium in a salt water aquarium must be carefully maintained to keep the sea life healthy. (Borissos/Dreamstime.com)

606 Unless otherwise noted, all art on this page is © Cengage Learning 2014.

In doing stoichiometry calculations we assumed that reactions proceed to completion, that is, until one of the reactants runs out. Many reactions do proceed essentially to completion. For such reactions it can be assumed that the reactants are quantitatively converted to products and that the amount of limiting reactant that remains is negligible. On the other hand, there are many chemical reactions that stop far short of completion. An example is the dimerization of nitrogen dioxide:

$$NO_2(g) + NO_2(g) \longrightarrow N_2O_4(g)$$

The reactant, NO_2, is a dark brown gas, and the product, N_2O_4, is a colorless gas. When NO_2 is placed in an evacuated, sealed glass vessel at 25°C, the initial dark brown color decreases in intensity as it is converted to colorless N_2O_4. However, even over a long period of time, the contents of the reaction vessel do not become colorless. Instead, the intensity of the brown color eventually becomes constant, which means that the concentration of NO_2 is no longer changing. This is illustrated on the molecular level in Fig. 13.1. This observation is a clear indication that the reaction has stopped short of completion. In fact, the system has reached **chemical equilibrium**, *the state where the concentrations of all reactants and products remain constant with time.*

Any chemical reactions carried out in a closed vessel will reach equilibrium. For some reactions the equilibrium position so favors the products that the reaction appears to have gone to completion. We say that the equilibrium position for such reactions lies *far to the right* (in the direction of the products). For example, when gaseous hydrogen and oxygen are mixed in stoichiometric quantities and react to form water vapor, the reaction proceeds essentially to completion. The amounts of the reactants that remain when the system reaches equilibrium are so tiny as to be negligible. By contrast, some reactions occur only to a slight extent. For example, when solid CaO is placed in a closed vessel at 25°C, the decomposition to solid Ca and gaseous O_2 is virtually undetectable. In cases like this, the equilibrium position is said to lie *far to the left* (in the direction of the reactants).

In this chapter we will discuss how and why a chemical system comes to equilibrium and the characteristics of equilibrium. In particular, we will discuss how to calculate the concentrations of the reactants and products present for a given system at equilibrium.

13.1 | The Equilibrium Condition

IBLG: See questions from "The Equilibrium Condition and the Equilibrium Constant"

Equilibrium is a dynamic situation.

Since no changes occur in the concentrations of reactants or products in a reaction system at equilibrium, it may appear that everything has stopped. However, this is not the case. On the molecular level, there is frantic activity. Equilibrium is not static but is a highly *dynamic* situation. The concept of chemical equilibrium is analogous to the flow of cars across a bridge connecting two island cities. Suppose the traffic flow on the bridge is the same in both directions. It is obvious that there is motion, since one can see the cars traveling back and forth across the bridge, but the number of cars in each city is not changing because equal numbers of cars are entering and leaving. The result is no *net* change in the car population.

To see how this concept applies to chemical reactions, consider the reaction between steam and carbon monoxide in a closed vessel at a high temperature where the reaction takes place rapidly:

$$H_2O(g) + CO(g) \rightleftharpoons H_2(g) + CO_2(g)$$

Unless otherwise noted, all art on this page is © Cengage Learning 2014. 607

Chemical Connections describe current applications of chemistry. These special-interest boxes cover such topics as the invention of Post-it Notes, farming the wind, and the use of iron metal to clean up contaminated groundwater. Additional *Chemical Connections* are available on the student website.

Chemical connections
A Note-able Achievement

Post-it Notes, a product of the 3M Corporation, revolutionized casual written communications and personal reminders. Introduced in the United States in 1980, these sticky-but-not-too-sticky notes have now found countless uses in offices, cars, and homes throughout the world.

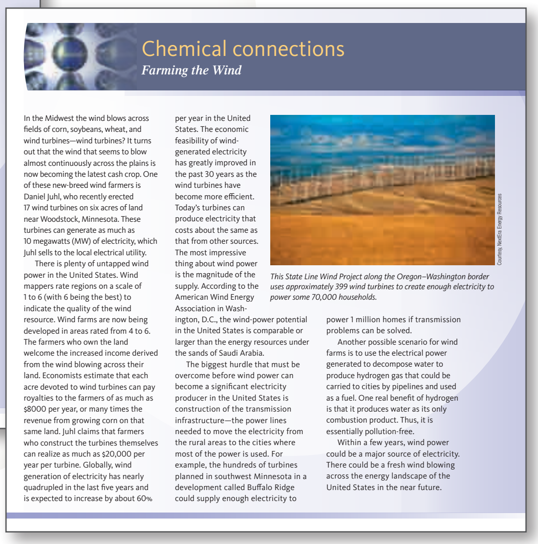
The invention of sticky notes occurred over a period of about 10 years and involved a great deal of serendipity. The adhesive for Post-it Notes was discovered by Dr. Spencer F. Silver of 3M in 1968. Silver found that when an acrylate polymer material was made in a particular way, it formed cross-linked microspheres. When suspended in a solvent and sprayed on a sheet of paper, this substance formed a "sparse monolayer" of adhesive after the solvent evaporated. Scanning electron microscope images of the adhesive show that it has an irregular surface, a little like the surface of a gravel road. In contrast, the adhesive on cellophane tape looks smooth and uniform, like a superhighway. The bumpy surface of Silver's adhesive caused it to be sticky but not so sticky to produce permanent adhesion, because the number of contact points between the binding surfaces was limited.

When he invented this adhesive, Silver had no specific ideas for its use, so he spread the word of his discovery to his fellow employees at 3M to see if anyone had an application for it. In addition, over the next several years development was carried out to improve the adhesive's properties. It was not until 1974 that the idea for Post-it Notes popped up. One Sunday Art Fry, a chemical engineer for 3M, was singing in his church choir when he became annoyed that the bookmark in his hymnal kept falling out. He thought to himself that it would be nice if the bookmark were sticky enough to stay in place but not so sticky that it couldn't be moved. Luckily, he remembered Silver's glue—and the Post-it Note was born.

For the next three years, Fry worked to overcome the manufacturing obstacles associated with the product. By 1977 enough Post-it Notes were being produced to supply 3M's corporate headquarters, where the employees quickly became addicted to their many uses. Post-it Notes are now available in 62 colors and 25 shapes.

In the years since the introduction of Post-it Notes, 3M has heard some remarkable stories connected to the use of these notes. For example, a Post-it Note was applied to the nose of a corporate jet, where it was intended to be read by the plane's Las Vegas ground crew. Someone forgot to remove it, however. The note was still on the nose of the plane when it landed in Minneapolis, having survived a takeoff, a landing, and speeds of 500 miles per hour at temperatures as low as −56°F. Stories on the 3M Web site describe how a Post-it Note on the front door of a home survived the 140-mile-per-hour winds of Hurricane Hugo and how a foreign official accepted Post-it Notes in lieu of cash when a small bribe was needed to cut through bureaucratic hassles.

Post-it Notes have definitely changed the way we communicate and remember things.



Chemical connections
Farming the Wind

In the Midwest the wind blows across fields of corn, soybeans, wheat, and wind turbines—wind turbines? It turns out that the wind that seems to blow almost continuously across the plains is now becoming the latest cash crop. One of these new-breed wind farmers is Daniel Juhl, who recently erected 17 wind turbines on six acres of land near Woodstock, Minnesota. These turbines can generate as much as 10 megawatts (MW) of electricity, which Juhl sells to the local electrical utility.

There is plenty of untapped wind power in the United States. Wind mappers rate regions on a scale of 1 to 6 (with 6 being the best) to indicate the quality of the wind resource. Wind farms are now being developed in areas rated from 4 to 6. The farmers who own the land welcome the increased income derived from the wind blowing across their land. Economists estimate that each acre devoted to wind turbines can pay royalties to the farmers of as much as $8000 per year, or many times the revenue from growing corn on that same land. Juhl claims that farmers who construct the turbines themselves can realize as much as $20,000 per year per turbine. Globally, wind generation of electricity has nearly quadrupled in the last five years and is expected to increase by about 60% per year in the United States. The economic feasibility of wind-generated electricity has greatly improved in the past 30 years as the wind turbines have become more efficient. Today's turbines can produce electricity that costs about the same as that from other sources. The most impressive thing about wind power is the magnitude of the supply. According to the American Wind Energy Association in Washington, D.C., the wind-power potential in the United States is comparable or larger than the energy resources under the sands of Saudi Arabia.

The biggest hurdle that must be overcome before wind power can become a significant electricity producer in the United States is construction of the transmission infrastructure—the power lines needed to move the electricity from the rural areas to the cities where most of the power is used. For example, the hundreds of turbines planned in southwest Minnesota in a development called Buffalo Ridge could supply enough electricity to power 1 million homes if transmission problems can be solved.

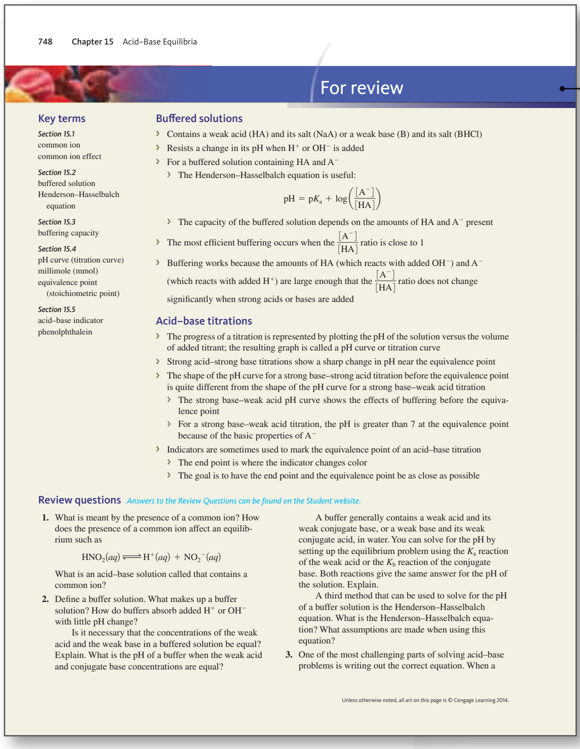
Another possible scenario for wind farms is to use the electrical power generated to decompose water to produce hydrogen gas that could be carried to cities by pipelines and used as a fuel. One real benefit of hydrogen is that it produces water as its only combustion product. Thus, it is essentially pollution-free.

Within a few years, wind power could be a major source of electricity. There could be a fresh wind blowing across the energy landscape of the United States in the near future.

This State Line Wind Project along the Oregon–Washington border uses approximately 399 wind turbines to create enough electricity to power some 70,000 households.

Comprehensive End-of-Chapter Practice and Review We offer end-of-chapter exercises for every type of student and for every kind of homework assignment.

Each chapter has a **For Review** section to reinforce key concepts and includes review questions for students to practice independently.



748 Chapter 15 Acid–Base Equilibria

For review

Key terms

Section 15.1
common ion
common ion effect

Section 15.2
buffered solution
Henderson–Hasselbalch equation

Section 15.3
buffering capacity

Section 15.4
pH curve (titration curve)
millimole (mmol)
equivalence point (stoichiometric point)

Section 15.5
acid–base indicator
phenolphthalein

Buffered solutions

- Contains a weak acid (HA) and its salt (NaA) or a weak base (B) and its salt (BHCl)
- Resists a change in its pH when H^+ or OH^- is added
- For a buffered solution containing HA and A^-
  - The Henderson–Hasselbalch equation is useful:

$$pH = pK_a + \log\left(\frac{[A^-]}{[HA]}\right)$$

  - The capacity of the buffered solution depends on the amounts of HA and A^- present
- The most efficient buffering occurs when the $\frac{[A^-]}{[HA]}$ ratio is close to 1
- Buffering works because the amounts of HA (which reacts with added OH^-) and A^- (which reacts with added H^+) are large enough that the $\frac{[A^-]}{[HA]}$ ratio does not change significantly when strong acids or bases are added

Acid–base titrations

- The progress of a titration is represented by plotting the pH of the solution versus the volume of added titrant; the resulting graph is called a pH curve or titration curve
- Strong acid–strong base titrations show a sharp change in pH near the equivalence point
- The shape of the pH curve for a strong base–strong acid titration before the equivalence point is quite different from the shape of the pH curve for a strong base–weak acid titration
  - The strong base–weak acid pH curve shows the effects of buffering before the equivalence point
  - For a strong base–weak acid titration, the pH is greater than 7 at the equivalence point because of the basic properties of A^-
- Indicators are sometimes used to mark the equivalence point of an acid–base titration
  - The end point is where the indicator changes color
  - The goal is to have the end point and the equivalence point be as close as possible

Review questions *Answers to the Review Questions can be found on the Student website.*

1. What is meant by the presence of a common ion? How does the presence of a common ion affect an equilibrium such as

$$HNO_2(aq) \rightleftharpoons H^+(aq) + NO_2^-(aq)$$

What is an acid–base solution called that contains a common ion?

2. Define a buffer solution. What makes up a buffer solution? How do buffers absorb added H^+ or OH^- with little pH change?

Is it necessary that the concentrations of the weak acid and the weak base in a buffered solution be equal? Explain. What is the pH of a buffer when the weak acid and conjugate base concentrations are equal?

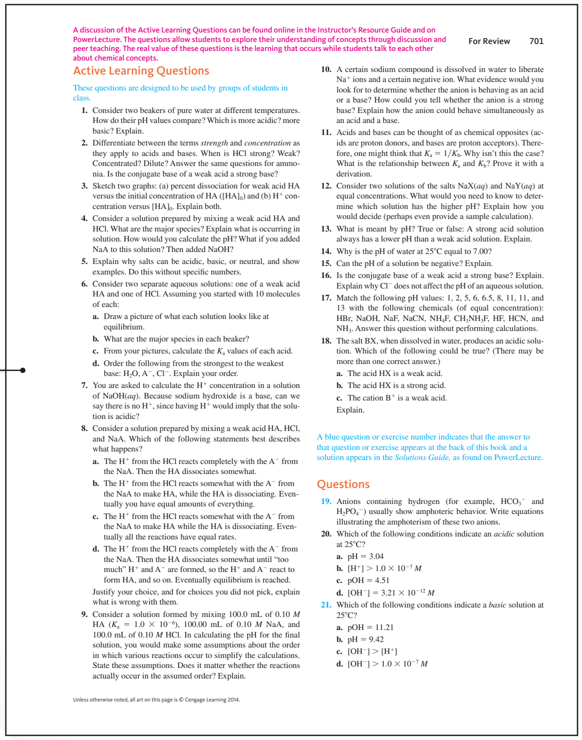
A buffer generally contains a weak acid and its weak conjugate base, or a weak base and its weak conjugate acid, in water. You can solve for the pH by setting up the equilibrium problem using the K_a reaction of the weak acid or the K_b reaction of the conjugate base. Both reactions give the same answer for the pH of the solution. Explain.

A third method that can be used to solve for the pH of a buffer solution is the Henderson–Hasselbalch equation. What is the Henderson–Hasselbalch equation? What assumptions are made when using this equation?

3. One of the most challenging parts of solving acid–base problems is writing out the correct equation. When a

Unless otherwise noted, all art on this page is © Cengage Learning 2014.

Active Learning Questions are designed to promote discussion among groups of students in class.



A discussion of the Active Learning Questions can be found online in the Instructor's Resource Guide and on PowerLecture. The questions allow students to explore their understanding of concepts through discussion and peer teaching. The real value of these questions is the learning that occurs while students talk to each other about chemical concepts.

For Review 701

Active Learning Questions

These questions are designed to be used by groups of students in class.

1. Consider two beakers of pure water at different temperatures. How do their pH values compare? Which is more acidic? more basic? Explain.
2. Differentiate between the terms *strength* and *concentration* as they apply to acids and bases. When is HCl strong? Weak? Concentrated? Dilute? Answer the same questions for ammonia. Is the conjugate base of a weak acid a strong base?
3. Sketch two graphs: (a) percent dissociation for weak acid HA versus the initial concentration of HA ($[HA]_0$) and (b) H^+ concentration versus $[HA]_0$. Explain both.
4. Consider a solution prepared by mixing a weak acid HA and HCl. What are the major species? Explain what is occurring in solution. How would you calculate the pH? What if you added NaA to this solution? Then added NaOH?
5. Explain why salts can be acidic, basic, or neutral, and show examples. Do this without specific numbers.
6. Consider two separate aqueous solutions: one of a weak acid HA and one of HCl. Assuming you started with 10 molecules of each:
   a. Draw a picture of what each solution looks like at equilibrium.
   b. What are the major species in each beaker?
   c. From your pictures, calculate the K_a values of each acid.
   d. Order the following from the strongest to the weakest base: H_2O, A^-, Cl^-. Explain your order.
7. You are asked to calculate the H^+ concentration in a solution of NaOH(*aq*). Because sodium hydroxide is a base, can we say there is no H^+, since having H^+ would imply that the solution is acidic?
8. Consider a solution prepared by mixing a weak acid HA, HCl, and NaA. Which of the following statements best describes what happens?
   a. The H^+ from the HCl reacts completely with the A^- from the NaA. Then the HA dissociates somewhat.
   b. The H^+ from the HCl reacts somewhat with the A^- from the NaA to make HA, while the HA is dissociating. Eventually you have equal amounts of everything.
   c. The H^+ from the HCl reacts somewhat with the A^- from the NaA to make HA while the HA is dissociating. Eventually all the reactions have equal rates.
   d. The H^+ from the HCl reacts completely with the A^- from the NaA. Then the HA dissociates somewhat until "too much" H^+ and A^- are formed, so the H^+ and A^- react to form HA, and so on. Eventually equilibrium is reached.

   Justify your choice, and for choices you did not pick, explain what is wrong with them.
9. Consider a solution formed by mixing 100.0 mL of 0.10 *M* HA ($K_a = 1.0 \times 10^{-6}$), 100.00 mL of 0.10 *M* NaA, and 100.0 mL of 0.10 *M* HCl. In calculating the pH for the final solution, you would make some assumptions about the order in which various reactions occur to simplify the calculations. State these assumptions. Does it matter whether the reactions actually occur in the assumed order? Explain.
10. A certain sodium compound is dissolved in water to liberate Na^+ ions and a certain negative ion. What evidence would you look for to determine whether the anion is behaving as an acid or a base? How could you tell whether the anion is a strong base? Explain how the anion could behave simultaneously as an acid and a base.
11. Acids and bases can be thought of as chemical opposites (acids are proton donors, and bases are proton acceptors). Therefore, one might think that $K_a = 1/K_b$. Why isn't this the case? What is the relationship between K_a and K_b? Prove it with a derivation.
12. Consider two solutions of the salts NaX(*aq*) and NaY(*aq*) at equal concentrations. What would you need to know to determine which solution has the higher pH? Explain how you would decide (perhaps even provide a sample calculation).
13. What is meant by pH? True or false: A strong acid solution always has a lower pH than a weak acid solution. Explain.
14. Why is the pH of water at 25°C equal to 7.00?
15. Can the pH of a solution be negative? Explain.
16. Is the conjugate base of a weak acid a strong base? Explain. Explain why Cl^- does not affect the pH of an aqueous solution.
17. Match the following pH values: 1, 2, 5, 6, 6.5, 8, 11, 11, and 13 with the following chemicals (of equal concentration): HBr, NaOH, NaF, NaCN, NH_4F, CH_3NH_3F, HF, HCN, and NH_3. Answer this question without performing calculations.
18. The salt BX, when dissolved in water, produces an acidic solution. Which of the following could be true? (There may be more than one correct answer.)
   a. The acid HX is a weak acid.
   b. The acid HX is a strong acid.
   c. The cation B^+ is a weak acid.

   Explain.

A blue question or exercise number indicates that the answer to that question or exercise appears at the back of this book and a solution appears in the *Solutions Guide,* as found on PowerLecture.

Questions

19. Anions containing hydrogen (for example, HCO_3^- and $H_2PO_4^-$) usually show amphoteric behavior. Write equations illustrating the amphoterism of these two anions.
20. Which of the following conditions indicate an *acidic* solution at 25°C?
   a. pH = 3.04
   b. $[H^+] > 1.0 \times 10^{-7}$ *M*
   c. pOH = 4.51
   d. $[OH^-] = 3.21 \times 10^{-12}$ *M*
21. Which of the following conditions indicate a *basic* solution at 25°C?
   a. pOH = 11.21
   b. pH = 9.42
   c. $[OH^-] > [H^+]$
   d. $[OH^-] > 1.0 \times 10^{-7}$ *M*

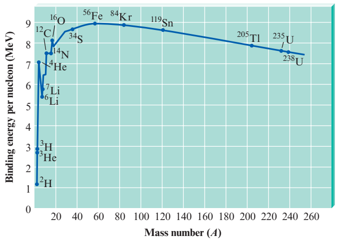
Unless otherwise noted, all art on this page is © Cengage Learning 2014.

Comprehensive End-of-Chapter Practice and Review

A blue question or exercise number indicates that the answer to that question or exercise appears at the back of this book and a solution appears in the *Solutions Guide*, as found on PowerLecture.

Questions

1. When nuclei undergo nuclear transformations, γ rays of characteristic frequencies are observed. How does this fact, along with other information in the chapter on nuclear stability, suggest that a quantum mechanical model may apply to the nucleus?
2. There is a trend in the United States toward using coal-fired power plants to generate electricity rather than building new nuclear fission power plants. Is the use of coal-fired power plants without risk? Make a list of the risks to society from the use of each type of power plant.
3. Which type of radioactive decay has the net effect of changing a neutron into a proton? Which type of decay has the net effect of turning a proton into a neutron?
4. Consider the following graph of binding energy per nucleon as a function of mass number.



a. What does this graph tell us about the relative half-lives of the nuclides? Explain your answer.
b. Which nuclide shown is the most thermodynamically stable? Which is the least thermodynamically stable?
c. What does this graph tell us about which nuclides undergo fusion and which undergo fission to become more stable? Support your answer.

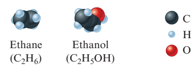
Questions are homework problems directed at concepts within the chapter and in general don't require calculation.

Exercises

In this section similar exercises are paired.

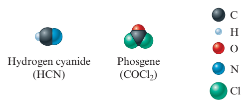
The Localized Electron Model and Hybrid Orbitals

17. Use the localized electron model to describe the bonding in H_2O.
18. Use the localized electron model to describe the bonding in CCl_4.
19. Use the localized electron model to describe the bonding in H_2CO (carbon is the central atom).
20. Use the localized electron model to describe the bonding in C_2H_2 (exists as HCCH).
21. The space-filling models of ethane and ethanol are shown below.



Use the localized electron model to describe the bonding in ethane and ethanol.

22. The space-filling models of hydrogen cyanide and phosgene are shown below.

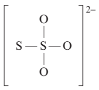


Use the localized electron model to describe the bonding in hydrogen cyanide and phosgene.

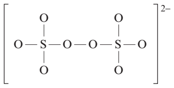
23. Give the expected hybridization of the central atom for the molecules or ions in Exercises 83 and 89 from Chapter 8.
24. Give the expected hybridization of the central atom for the molecules or ions in Exercises 84 and 90 from Chapter 8.
25. Give the expected hybridization of the central atom for the molecules or ions in Exercise 87 from Chapter 8.
26. Give the expected hybridization of the central atom for the molecules in Exercise 88 from Chapter 8.
27. Give the expected hybridization of the central atom for the molecules in Exercises 113 and 114 from Chapter 8.
28. Give the expected hybridization of the central atom for the molecules in Exercises 115 and 116 from Chapter 8.
29. For each of the following molecules, write the Lewis structure(s), predict the molecular structure (including bond angles), give the expected hybrid orbitals on the central atom, and predict the overall polarity.

a. CF_4	e. BeH_2	i. KrF_4
b. NF_3	f. TeF_4	j. SeF_6
c. OF_2	g. AsF_5	k. IF_5
d. BF_3	h. KrF_2	l. IF_3

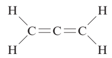
30. For each of the following molecules or ions that contain sulfur, write the Lewis structure(s), predict the molecular structure (including bond angles), and give the expected hybrid orbitals for sulfur.
 a. SO_2
 b. SO_3
 c. $S_2O_3^{2-}$



 d. $S_2O_8^{2-}$

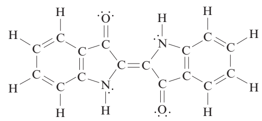


 e. SO_3^{2-}
 f. SO_4^{2-}
 g. SF_2
 h. SF_4
 i. SF_6
 j. $F_3S{-}SF$
 k. SF_5^+
31. Why must all six atoms in C_2H_4 lie in the same plane?
32. The allene molecule has the following Lewis structure:

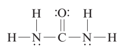


Must all hydrogen atoms lie the same plane? If not, what is their spatial relationship? Explain.

33. Indigo is the dye used in coloring blue jeans. The term *navy blue* is derived from the use of indigo to dye British naval uniforms in the eighteenth century. The structure of the indigo molecule is



 a. How many σ bonds and π bonds exist in the molecule?
 b. What hybrid orbitals are used by the carbon atoms in the indigo molecule?
34. Urea, a compound formed in the liver, is one of the ways humans excrete nitrogen. The Lewis structure for urea is



Using hybrid orbitals for carbon, nitrogen, and oxygen, determine which orbitals overlap to form the various bonds in urea.

There are numerous **Exercises** to reinforce students' understanding of each section. These problems are paired and organized by topic so that instructors can review them in class and assign them for homework.

ChemWork Problems

These multiconcept problems (and additional ones) are found interactively online with the same type of assistance a student would get from an instructor.

95. Which of the following reactions (or processes) are expected to have a negative value for $\Delta S°$?
 a. $SiF_6(aq) + H_2(g) \longrightarrow 2HF(g) + SiF_4(g)$
 b. $4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$
 c. $CO(g) + Cl_2(g) \longrightarrow COCl_2(g)$
 d. $C_2H_4(g) + H_2O(l) \longrightarrow C_2H_5OH(l)$
 e. $H_2O(s) \longrightarrow H_2O(l)$
96. For rubidium $\Delta H°_{vap} = 69.0$ kJ/mol at 686°C, its boiling point. Calculate $\Delta S°$, q, w, and ΔE for the vaporization of 1.00 mole of rubidium at 686°C and 1.00 atm pressure.
97. Given the thermodynamic data below, calculate ΔS and ΔS_{surr} for the following reaction at 25°C and 1 atm:

$$XeF_6(g) \longrightarrow XeF_4(s) + F_2(g)$$

	$\Delta H_f°$ (kJ/mol)	$S°$ (J/K · mol)
$XeF_6(g)$	−294	300.
$XeF_4(s)$	−251	146
$F_2(g)$	0	203

New **ChemWork** end-of-chapter problems are now included, with many additional problems available to assign online for more practice.

Wealth of End-of-Chapter Problems The text offers an unparalleled variety of end-of-chapter content with problems that increase in rigor and integrate multiple concepts.

Challenge Problems

99. The copper(I) ion forms a complex ion with CN^- according to the following equation:

$$Cu^+(aq) + 3CN^-(aq) \rightleftharpoons Cu(CN)_3^{2-}(aq) \qquad K = 1.0 \times 10^{11}$$

a. Calculate the solubility of $CuBr(s)$ ($K_{sp} = 1.0 \times 10^{-5}$) in 1.0 L of 1.0 M NaCN.

b. Calculate the concentration of Br^- at equilibrium.

c. Calculate the concentration of CN^- at equilibrium.

100. Consider a solution made by mixing 500.0 mL of 4.0 M NH_3 and 500.0 mL of 0.40 M $AgNO_3$. Ag^+ reacts with NH_3 to form $AgNH_3^+$ and $Ag(NH_3)_2^+$:

$$Ag^+(aq) + NH_3(aq) \rightleftharpoons AgNH_3^+(aq) \qquad K_1 = 2.1 \times 10^3$$

$$AgNH_3^+(aq) + NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq) \qquad K_2 = 8.2 \times 10^3$$

Determine the concentration of all species in solution.

101. a. Calculate the molar solubility of AgBr in pure water. K_{sp} for AgBr is 5.0×10^{-13}.

b. Calculate the molar solubility of AgBr in 3.0 M NH_3. The overall formation constant for $Ag(NH_3)_2^+$ is 1.7×10^7, that is,

$$Ag^+(aq) + 2NH_3(aq) \longrightarrow Ag(NH_3)_2^+(aq) \qquad K = 1.7 \times 10^7.$$

c. Compare the calculated solubilities from parts a and b. Explain any differences.

d. What mass of AgBr will dissolve in 250.0 mL of 3.0 M NH_3?

e. What effect does adding HNO_3 have on the solubilities calculated in parts a and b?

102. Calculate the equilibrium concentrations of NH_3, Cu^{2+}, $Cu(NH_3)^{2+}$, $Cu(NH_3)_2^{2+}$, $Cu(NH_3)_3^{2+}$, and $Cu(NH_3)_4^{2+}$ in a solution prepared by mixing 500.0 mL of 3.00 M NH_3 with 500.0 mL of 2.00×10^{-3} M $Cu(NO_3)_2$. The stepwise equilibria are

$$Cu^{2+}(aq) + NH_3(aq) \rightleftharpoons CuNH_3^{2+}(aq) \qquad K_1 = 1.86 \times 10^4$$

$$CuNH_3^{2+}(aq) + NH_3(aq) \rightleftharpoons Cu(NH_3)_2^{2+}(aq) \qquad K_2 = 3.88 \times 10^3$$

$$Cu(NH_3)_2^{2+}(aq) + NH_3(aq) \rightleftharpoons Cu(NH_3)_3^{2+}(aq) \qquad K_3 = 1.00 \times 10^3$$

$$Cu(NH_3)_3^{2+}(aq) + NH_3(aq) \rightleftharpoons Cu(NH_3)_4^{2+}(aq) \qquad K_4 = 1.55 \times 10^2$$

Challenge Problems take students one step further and challenge them more rigorously than the Additional Exercises.

Integrative Problems

These problems require the integration of multiple concepts to find the solutions.

130. Creatinine, $C_4H_7N_3O$, is a by-product of muscle metabolism, and creatinine levels in the body are known to be a fairly reliable indicator of kidney function. The normal level of creatinine in the blood for adults is approximately 1.0 mg per deciliter (dL) of blood. If the density of blood is 1.025 g/mL, calculate the molality of a normal creatinine level in a 10.0-mL blood sample. What is the osmotic pressure of this solution at 25.0°C?

131. An aqueous solution containing 0.250 mole of Q, a strong electrolyte, in 5.00×10^2 g water freezes at −2.79°C. What is the van't Hoff factor for Q? The molal freezing-point depression constant for water is 1.86°C · kg/mol. What is the formula of Q if it is 38.68% chlorine by mass and there are twice as many anions as cations in one formula unit of Q?

132. Anthraquinone contains only carbon, hydrogen, and oxygen. When 4.80 mg anthraquinone is burned, 14.2 mg CO_2 and 1.65 mg H_2O are produced. The freezing point of camphor is lowered by 22.3°C when 1.32 g anthraquinone is dissolved in 11.4 g camphor. Determine the empirical and molecular formulas of anthraquinone.

Integrative Problems combine concepts from multiple chapters.

Marathon Problems

These problems are designed to incorporate several concepts and techniques into one situation.

144. Three students were asked to find the identity of the metal in a particular sulfate salt. They dissolved a 0.1472-g sample of the salt in water and treated it with excess barium chloride, resulting in the precipitation of barium sulfate. After the precipitate had been filtered and dried, it weighed 0.2327 g.

Each student analyzed the data independently and came to different conclusions. Pat decided that the metal was titanium. Chris thought it was sodium. Randy reported that it was gallium. What formula did each student assign to the sulfate salt?

Look for information on the sulfates of gallium, sodium, and titanium in this text and reference books such as the *CRC Handbook of Chemistry and Physics.* What further tests would you suggest to determine which student is most likely correct?

145. You have two 500.0-mL aqueous solutions. Solution A is a solution of a metal nitrate that is 8.246% nitrogen by mass. The ionic compound in solution B consists of potassium, chromium, and oxygen; chromium has an oxidation state of +6 and there are 2 potassiums and 1 chromium in the formula. The masses of the solutes in each of the solutions are the same. When the solutions are added together, a blood-red precipitate forms. After the reaction has gone to completion, you dry the solid and find that it has a mass of 331.8 g.

a. Identify the ionic compounds in solution A and solution B.

b. Identify the blood-red precipitate.

c. Calculate the concentration (molarity) of all ions in the original solutions.

d. Calculate the concentration (molarity) of all ions in the final solution.

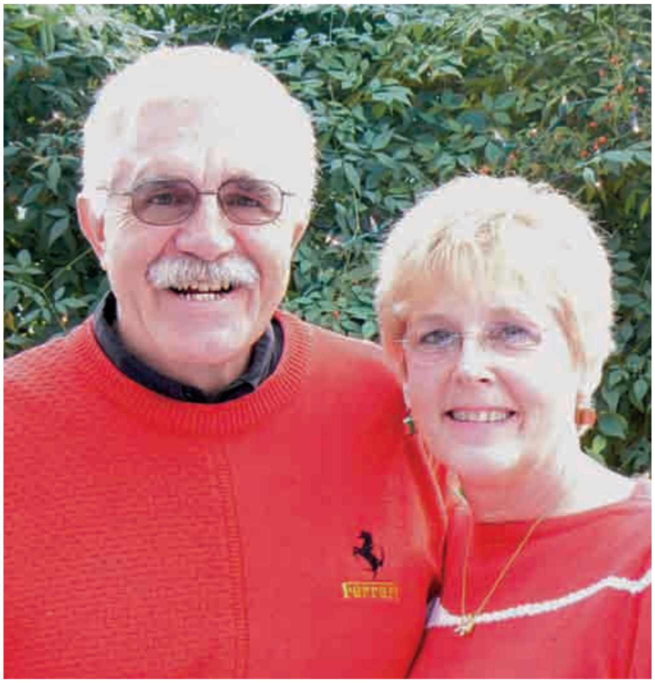
Marathon Problems can be used in class by groups of students to help facilitate problem-solving skills.

Marathon Problems also combine concepts from multiple chapters; they are the most challenging problems in the end-of-chapter material.

"The end-of-chapter content helps students identify and review the central concepts. There is an impressive range of problems that are well graded by difficulty."

—Alan M. Stolzenberg, *West Virginia University*

About the Authors



Steven S. Zumdahl earned a B.S. in Chemistry from Wheaton College (IL) and a Ph.D. from the University of Illinois, Urbana-Champaign. He has been a faculty member at the University of Colorado–Boulder, Parkland College (IL), and the University of Illinois at Urbana-Champaign (UIUC), where he is Professor Emeritus. He has received numerous awards, including the National Catalyst Award for Excellence in Chemical Education, the University of Illinois Teaching Award, the UIUC Liberal Arts and Sciences Award for Excellence in Teaching, UIUC Liberal Arts and Sciences Advising Award, and the School of Chemical Sciences Teaching award (five times). He is the author of several chemistry textbooks. In his leisure time he enjoys traveling and collecting classic cars.

Susan A. Zumdahl earned a B.S. and M.A. in Chemistry at California State University–Fullerton. She has taught science and mathematics at all levels, including middle school, high school, community college, and university. At the University of Illinois at Urbana-Champaign, she developed a program for increasing the retention of minorities and women in science and engineering. This program focused on using active learning and peer teaching to encourage students to excel in the sciences. She has coordinated and led workshops and programs for science teachers from elementary through college levels. These programs encourage and support active learning and creative techniques for teaching science. For several years she was director of an Institute for Chemical Education (ICE) field center in Southern California, and she has authored several chemistry textbooks. Susan spearheaded the development of a sophisticated web-based electronic homework system for teaching chemistry. She enjoys traveling, classic cars, and gardening in her spare time—when she is not playing with her grandchildren.

Chapter 1

Chemical Foundations

A high-performance race car uses chemistry for its structure, tires, and fuel. (© Maria Green/Alamy)

When you start your car, do you think about chemistry? Probably not, but you should. The power to start your car is furnished by a lead storage battery. How does this battery work, and what does it contain? When a battery goes dead, what does that mean? If you use a friend's car to "jump-start" your car, did you know that your battery could explode? How can you avoid such an unpleasant possibility? What is in the gasoline that you put in your tank, and how does it furnish energy to your car so that you can drive it to school? What is the vapor that comes out of the exhaust pipe, and why does it cause air pollution? Your car's air conditioner might have a substance in it that is leading to the destruction of the ozone layer in the upper atmosphere. What are we doing about that? And why is the ozone layer important anyway?

All of these questions can be answered by understanding some chemistry. In fact, we'll consider the answers to all of these questions in this text.

Chemistry is around you all the time. You are able to read and understand this sentence because chemical reactions are occurring in your brain. The food you ate for breakfast or lunch is now furnishing energy through chemical reactions. Trees and grass grow because of chemical changes.

Chemistry also crops up in some unexpected places. When archaeologist Luis Alvarez was studying in college, he probably didn't realize that the chemical elements iridium and niobium would make him very famous when they helped him solve the problem of the disappearing dinosaurs. For decades scientists had wrestled with the mystery of why the dinosaurs, after ruling the earth for millions of years, suddenly became extinct 65 million years ago. In studying core samples of rocks dating back to that period, Alvarez and his coworkers recognized unusual levels of iridium and niobium in these samples—levels much more characteristic of extraterrestrial bodies than of the earth. Based on these observations, Alvarez hypothesized that a large meteor hit the earth 65 million years ago, changing atmospheric conditions so much that the dinosaurs' food couldn't grow, and they died—almost instantly in the geologic timeframe.

Chemistry is also important to historians. Did you realize that lead poisoning probably was a significant contributing factor to the decline of the Roman Empire? The Romans had high exposure to lead from lead-glazed pottery, lead water pipes, and a sweetening syrup called *sapa* that was prepared by boiling down grape juice in lead-lined vessels. It turns out that one reason for sapa's sweetness was lead acetate ("sugar of lead"), which formed as the juice was cooked down. Lead poisoning, with its symptoms of lethargy and mental malfunctions, certainly could have contributed to the demise of the Roman society.

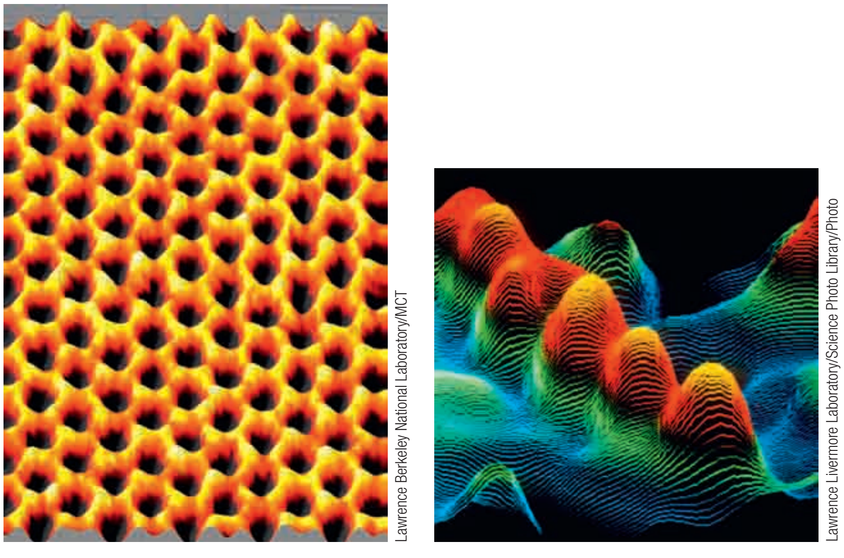
Chemistry is also apparently very important in determining a person's behavior. Various studies have shown that many personality disorders can be linked directly to imbalances of trace elements in the body. For example, studies on the inmates at Stateville Prison in Illinois have linked low cobalt levels with violent behavior. Lithium salts have been shown to be very effective in controlling the effects of manic-depressive disease, and you've probably at some time in your life felt a special "chemistry" for another person. Studies suggest there is literally chemistry going on between two people who are attracted to each other. "Falling in love" apparently causes changes in the chemistry of the brain; chemicals are produced that give that "high" associated with a new relationship. Unfortunately, these chemical effects seem to wear off over time, even if the relationship persists and grows.

The importance of chemistry in the interactions of people should not really surprise us. We know that insects communicate by emitting and receiving chemical signals via molecules called *pheromones*. For example, ants have a very complicated set of chemical signals to signify food sources, danger, and so forth. Also, various female sex attractants have been isolated and used to lure males into traps to control insect populations. It would not be surprising if humans also emitted chemical signals that we were not aware of on a conscious level. Thus chemistry is pretty interesting and pretty important. The main goal of this text is to help you understand the concepts of chemistry so that you can better appreciate the world around you and can be more effective in whatever career you choose.

1.1 | Chemistry: An Overview

Since the time of the ancient Greeks, people have wondered about the answer to the question: What is matter made of? For a long time, humans have believed that matter is composed of atoms, and in the previous three centuries, we have collected much indirect evidence to support this belief. Very recently, something exciting has happened—for the first time we can "see" individual atoms. Of course, we cannot see atoms with the naked eye; we must use a special microscope called a *scanning tunneling microscope* (STM). Although we will not consider the details of its operation here, the STM uses an electron current from a tiny needle to probe the surface of a substance. The STM pictures of several substances are shown in Fig. 1.1. Notice how the atoms are connected to one another by "bridges," which, as we will see, represent the electrons that interconnect atoms.

So, at this point, we are fairly sure that matter consists of individual atoms. The nature of these atoms is quite complex, and the components of atoms don't behave much like the objects we see in the world of our experience. We call this world the *macroscopic world*—the world of cars, tables, baseballs, rocks, oceans, and so forth. One of the main jobs of a scientist is to delve into the macroscopic world and discover its "parts." For example, when you view a beach from a distance, it looks like a continuous solid substance. As you get closer, you see that the beach is really made up of individual grains of sand. As we examine these grains of sand, we find that they are composed of silicon and oxygen atoms connected to each other to form intricate shapes (Fig. 1.2). One of the main challenges of chemistry is to understand the connection between the macroscopic world that we experience and the *microscopic world* of atoms and molecules. To truly understand chemistry, you must learn to think on the atomic level. We will spend much time in this text helping you learn to do that.



Lawrence Berkeley National Laboratory/MCT

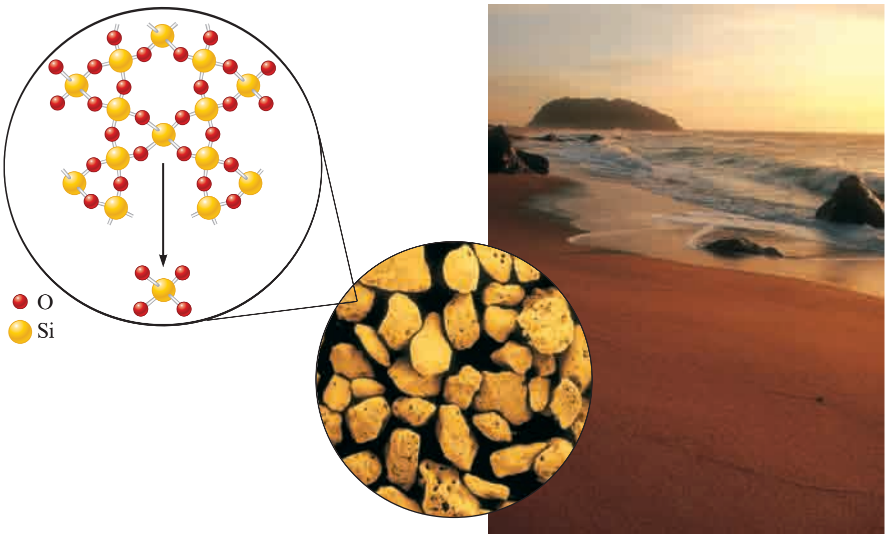
Lawrence Livermore Laboratory/Science Photo Library/Photo Researchers, Inc.

Figure 1.1 | Scanning tunneling microscope images.

An image showing the individual carbon atoms in a sheet of graphene.

Scanning tunneling microscope image of DNA.

Unless otherwise noted, all art on this page is © Cengage Learning 2014.



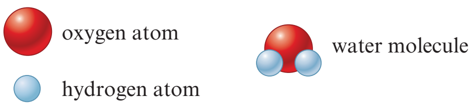
Chuck Place. Inset: Jeremy Burgess/SPL/Photo Researchers, Inc.

Figure 1.2 | Sand on a beach looks uniform from a distance, but up close the irregular sand grains are visible, and each grain is composed of tiny atoms.

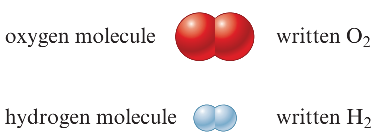
Critical Thinking

The scanning tunneling microscope allows us to "see" atoms. What if you were sent back in time before the invention of the scanning tunneling microscope? What evidence could you give to support the theory that all matter is made of atoms and molecules?

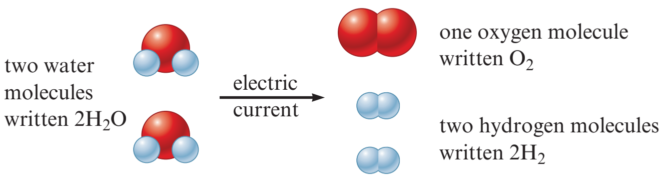
One of the amazing things about our universe is that the tremendous variety of substances we find there results from only about 100 different kinds of atoms. You can think of these approximately 100 atoms as the letters in an alphabet from which all the "words" in the universe are made. It is the way the atoms are organized in a given substance that determines the properties of that substance. For example, water, one of the most common and important substances on the earth, is composed of two types of atoms: hydrogen and oxygen. Two hydrogen atoms and one oxygen atom are bound together to form the water molecule:



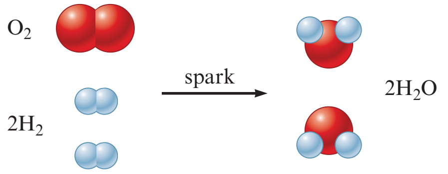
When an electric current passes through it, water is decomposed to hydrogen and oxygen. These *chemical elements* themselves exist naturally as diatomic (two-atom) molecules:



We can represent the decomposition of water to its component elements, hydrogen and oxygen, as follows:



Notice that it takes two molecules of water to furnish the right number of oxygen and hydrogen atoms to allow for the formation of the two-atom molecules. This reaction explains why the battery in your car can explode if you jump-start it improperly. When you hook up the jumper cables, current flows through the dead battery, which contains water (and other things), and causes hydrogen and oxygen to form by decomposition of some of the water. A spark can cause this accumulated hydrogen and oxygen to explode, forming water again.



This example illustrates two of the fundamental concepts of chemistry: (1) Matter is composed of various types of atoms, and (2) one substance changes to another by reorganizing the way the atoms are attached to each other.

These are core ideas of chemistry, and we will have much more to say about them.

Science: A Process for Understanding Nature and Its Changes

How do you tackle the problems that confront you in real life? Think about your trip to school. If you live in a city, traffic is undoubtedly a problem you confront daily. How do you decide the best way to drive to school? If you are new in town, you first get a map and look at the possible ways to make the trip. Then you might collect information about the advantages and disadvantages of various routes from people who know the area. Based on this information, you probably try to predict the best route. However, you can find the best route only by trying several of them and comparing the results. After a few experiments with the various possibilities, you probably will be able to select the best way. What you are doing in solving this everyday problem is applying the same process that scientists use to study nature. The first thing you did was collect relevant data. Then you made a prediction, and then you tested it by trying it out. This process contains the fundamental elements of science.

1. Making observations (collecting data)
2. Suggesting a possible explanation (formulating a hypothesis)
3. Doing experiments to test the possible explanation (testing the hypothesis)

Scientists call this process the *scientific method*. We will discuss it in more detail in the next section. One of life's most important activities is solving problems—not "plug and chug" exercises, but real problems—problems that have new facets to them, that involve things you may have never confronted before. The more creative you are at solving these problems, the more effective you will be in your career and your personal life. Part of the reason for learning chemistry, therefore, is to become a better problem solver. Chemists are usually excellent problem solvers because to master chemistry, you have to master the scientific approach. Chemical problems are frequently very complicated—there is usually no neat and tidy solution. Often it is difficult to know where to begin.

1.2 | The Scientific Method

IBLG: See questions from "Chemistry: An Overview and the Scientific Method"

Science is a framework for gaining and organizing knowledge. Science is not simply a set of facts but also a plan of action—a *procedure* for processing and understanding certain types of information. Scientific thinking is useful in all aspects of life, but in this text we will use it to understand how the chemical world operates. As we said in our previous discussion, the process that lies at the center of scientific inquiry is called the **scientific method**. There are actually many scientific methods, depending on the nature of the specific problem under study and the particular investigator involved. However, it is useful to consider the following general framework for a generic scientific method (Fig. 1.3):

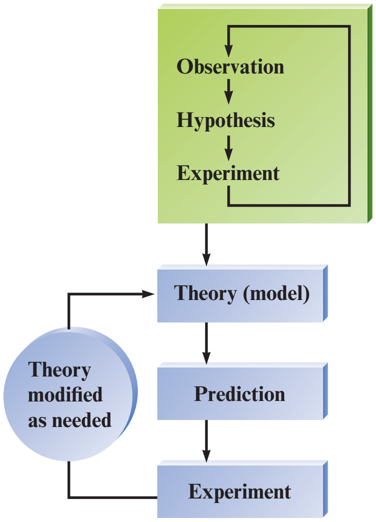


Figure 1.3 | The fundamental steps of the scientific method.

Steps in the Scientific Method

1. *Making observations.* Observations may be *qualitative* (the sky is blue; water is a liquid) or *quantitative* (water boils at 100°C; a certain chemistry book weighs 2 kg). A qualitative observation does not involve a number. A quantitative observation (called a **measurement**) involves both a number and a unit.
2. *Formulating hypotheses.* A **hypothesis** is a *possible* explanation for an observation.
3. *Performing experiments.* An experiment is carried out to test a hypothesis. This involves gathering new information that enables a scientist to decide whether the hypothesis is valid—that is, whether it is supported by the new information learned from the experiment. Experiments always produce new observations, and this brings the process back to the beginning again.

To understand a given phenomenon, these steps are repeated many times, gradually accumulating the knowledge necessary to provide a possible explanation of the phenomenon.

Scientific Models

Once a set of hypotheses that agrees with the various observations is obtained, the hypotheses are assembled into a theory. A **theory**, which is often called a **model**, is a set of tested hypotheses that gives an overall explanation of some natural phenomenon.

It is very important to distinguish between observations and theories. An observation is something that is witnessed and can be recorded. A theory is an *interpretation*—a possible explanation of why nature behaves in a particular way. Theories inevitably change as more information becomes available. For example, the motions of the sun and stars have remained virtually the same over the thousands of years during which humans have been observing them, but our explanations—our theories—for these motions have changed greatly since ancient times.

The point is that scientists do not stop asking questions just because a given theory seems to account satisfactorily for some aspect of natural behavior. They continue doing experiments to refine or replace the existing theories. This is generally done by using the currently accepted theory to make a prediction and then performing an experiment (making a new observation) to see whether the results bear out this prediction.

Always remember that theories (models) are human inventions. They represent attempts to explain observed natural behavior in terms of human experiences. A theory is actually an educated guess. We must continue to do experiments and to refine our theories (making them consistent with new knowledge) if we hope to approach a more complete understanding of nature.

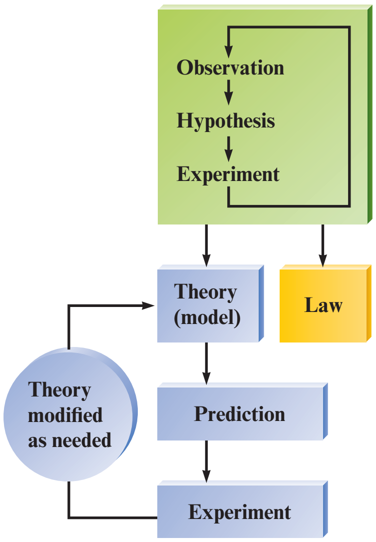


Figure 1.4 | The various parts of the scientific method.

As scientists observe nature, they often see that the same observation applies to many different systems. For example, studies of innumerable chemical changes have shown that the total observed mass of the materials involved is the same before and after the change. Such generally observed behavior is formulated into a statement called a **natural law**. For example, the observation that the total mass of materials is not affected by a chemical change in those materials is called the **law of conservation of mass**.

Note the difference between a natural law and a theory. A natural law is a summary of observed (measurable) behavior, whereas a theory is an explanation of behavior. A law summarizes what happens; a theory (model) is an attempt to explain why it happens.

In this section we have described the scientific method as it might ideally be applied (Fig. 1.4). However, it is important to remember that science does not always progress

Chemical connections

A Note-able Achievement

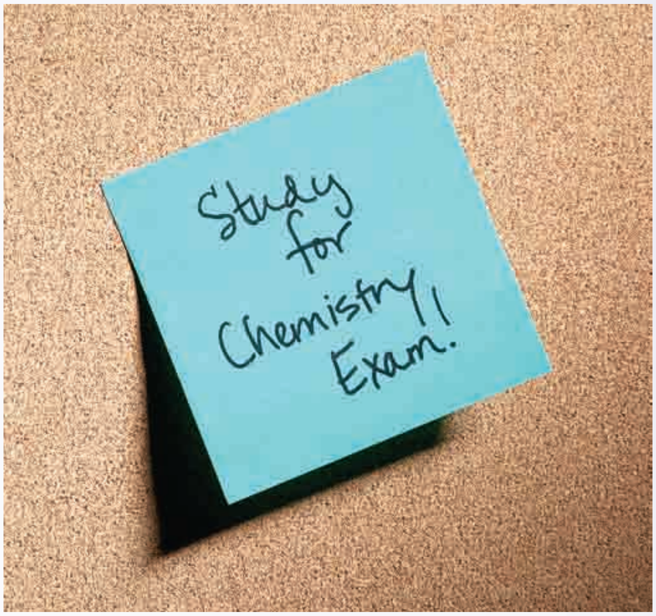


Photo © Cengage Learning. All rights reserved.

Post-it Notes, a product of the 3M Corporation, revolutionized casual written communications and personal reminders. Introduced in the United States in 1980, these sticky-but-not-too-sticky notes have now found countless uses in offices, cars, and homes throughout the world.

The invention of sticky notes occurred over a period of about 10 years and involved a great deal of serendipity. The adhesive for Post-it Notes was discovered by Dr. Spencer F. Silver of 3M in 1968. Silver found that when an acrylate polymer material was made in a particular way, it formed cross-linked microspheres. When suspended in a solvent and sprayed on a sheet of paper, this substance formed a "sparse monolayer" of adhesive after the solvent evaporated. Scanning electron microscope images of the adhesive show that it has an irregular surface, a little like the surface of a gravel road. In contrast, the adhesive on cellophane tape looks smooth and uniform, like a superhighway. The bumpy surface of Silver's adhesive caused it to be sticky but not so sticky to produce permanent adhesion, because the number of contact points between the binding surfaces was limited.

When he invented this adhesive, Silver had no specific ideas for its use, so he spread the word of his discovery to his fellow employees at 3M to see if anyone had an application for it. In addition, over the next several years development was carried out to improve the adhesive's properties. It was not until 1974 that the idea for Post-it Notes popped up. One Sunday Art Fry, a chemical engineer for 3M, was singing in his church choir when he became annoyed that the bookmark in his hymnal kept falling out. He thought to himself that it would be nice if the bookmark were sticky enough to stay in place but not so sticky that it couldn't be moved. Luckily, he remembered Silver's glue—and the Post-it Note was born.

For the next three years, Fry worked to overcome the manufacturing obstacles associated with the product. By 1977 enough Post-it Notes were being produced to supply 3M's corporate headquarters, where the employees quickly became addicted to their many uses. Post-it Notes are now available in 62 colors and 25 shapes.

In the years since the introduction of Post-it Notes, 3M has heard some remarkable stories connected to the use of these notes. For example, a Post-it Note was applied to the nose of a corporate jet, where it was intended to be read by the plane's Las Vegas ground crew. Someone forgot to remove it, however. The note was still on the nose of the plane when it landed in Minneapolis, having survived a takeoff, a landing, and speeds of 500 miles per hour at temperatures as low as −56°F. Stories on the 3M Web site describe how a Post-it Note on the front door of a home survived the 140-mile-per-hour winds of Hurricane Hugo and how a foreign official accepted Post-it Notes in lieu of cash when a small bribe was needed to cut through bureaucratic hassles.

Post-it Notes have definitely changed the way we communicate and remember things.

© Devonshire Collection/Reproduced by permission of Chatsworth Settlement Trustees/The Bridgeman Art Library

Robert Boyle (1627–1691) was born in Ireland. He became especially interested in experiments involving air and developed an air pump with which he produced evacuated cylinders. He used these cylinders to show that a feather and a lump of lead fall at the same rate in the absence of air resistance and that sound cannot be produced in a vacuum. His most famous experiments involved careful measurements of the volume of a gas as a function of pressure. In his book Boyle urged that the ancient view of elements as mystical substances should be abandoned and that an element should instead be defined as anything that cannot be broken down into simpler substances. This concept was an important step in the development of modern chemistry.

smoothly and efficiently. For one thing, hypotheses and observations are not totally independent of each other, as we have assumed in the description of the idealized scientific method. The coupling of observations and hypotheses occurs because once we begin to proceed down a given theoretical path, our hypotheses are unavoidably couched in the language of that theory. In other words, we tend to see what we expect to see and often fail to notice things that we do not expect. Thus the theory we are testing helps us because it focuses our questions. However, at the same time, this focusing process may limit our ability to see other possible explanations.

It is also important to keep in mind that scientists are human. They have prejudices; they misinterpret data; they become emotionally attached to their theories and thus lose objectivity; and they play politics. Science is affected by profit motives, budgets, fads, wars, and religious beliefs. Galileo, for example, was forced to recant his astronomical observations in the face of strong religious resistance. Lavoisier, the father of modern chemistry, was beheaded because of his political affiliations. Great progress in the chemistry of nitrogen fertilizers resulted from the desire to produce explosives to fight wars. The progress of science is often affected more by the frailties of humans and their institutions than by the limitations of scientific measuring devices. The scientific methods are only as effective as the humans using them. They do not automatically lead to progress.

Critical Thinking

What if everyone in the government used the scientific method to analyze and solve society's problems, and politics were never involved in the solutions? How would this be different from the present situation, and would it be better or worse?

1.3 | Units of Measurement

IBLG: See questions from "Uncertainty, Measurement, and Calculations"

Making observations is fundamental to all science. A quantitative observation, or *measurement,* always consists of two parts: a *number* and a scale (called a *unit*). Both parts must be present for the measurement to be meaningful.

In this textbook we will use measurements of mass, length, time, temperature, electric current, and the amount of a substance, among others. Scientists recognized long ago that standard systems of units had to be adopted if measurements were to be useful. If every scientist had a different set of units, complete chaos would result. Unfortunately, different standards were adopted in different parts of the world. The two major systems are the *English system* used in the United States and the *metric system* used by most of the rest of the industrialized world. This duality causes a good deal of trouble; for example, parts as simple as bolts are not interchangeable between machines built using the two systems. As a result, the United States has begun to adopt the metric system.

Most scientists in all countries have used the metric system for many years. In 1960, an international agreement set up a system of units called the *International System* (*le Système International* in French), or the **SI system**. This system is based on the metric system and units derived from the metric system. The fundamental SI units are listed in Table 1.1. We will discuss how to manipulate these units later in this chapter.

Chemical connections

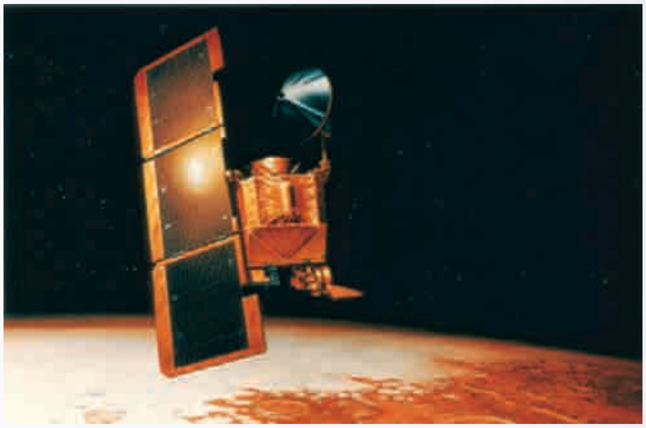
Critical Units!

How important are conversions from one unit to another? If you ask the National Aeronautics and Space Administration (NASA), very important! In 1999, NASA lost a $125 million Mars Climate Orbiter because of a failure to convert from English to metric units.

The problem arose because two teams working on the Mars mission were using different sets of units. NASA's scientists at the Jet Propulsion Laboratory in Pasadena, California, assumed that the thrust data for the rockets on the Orbiter they received from Lockheed Martin Astronautics in Denver, which built the spacecraft, were in metric units. In reality, the units were English. As a result, the Orbiter dipped 100 km lower into the Mars atmosphere than planned, and the friction from the atmosphere caused the craft to burn up.

NASA's mistake refueled the controversy over whether Congress should require the United States to switch to the metric system. About 95% of the world now uses the metric system, and the United States is slowly switching from English to metric. For example, the automobile industry has adopted metric fasteners, and we buy our soda in 2-L bottles.

Units can be very important. In fact, they can mean the difference between life and death on some occasions. In 1983, for example, a Canadian jetliner almost ran out of fuel when someone pumped 22,300 lb of fuel into the aircraft instead of 22,300 kg. Remember to watch your units!



NASA

Artist's conception of the lost Mars Climate Orbiter.

Because the fundamental units are not always convenient (expressing the mass of a pin in kilograms is awkward), prefixes are used to change the size of the unit. These are listed in Table 1.2. Some common objects and their measurements in SI units are listed in Table 1.3.

One physical quantity that is very important in chemistry is *volume,* which is not a fundamental SI unit but is derived from length. A cube that measures 1 meter (m) on

Photo © Cengage Learning. All rights reserved.

Soda is commonly sold in 2-L bottles—an example of the use of SI units in everyday life.

Table 1.1 | Fundamental SI Units

Physical Quantity	Name of Unit	Abbreviation
Mass	kilogram	kg
Length	meter	m
Time	second	s
Temperature	kelvin	K
Electric current	ampere	A
Amount of substance	mole	mol
Luminous intensity	candela	cd