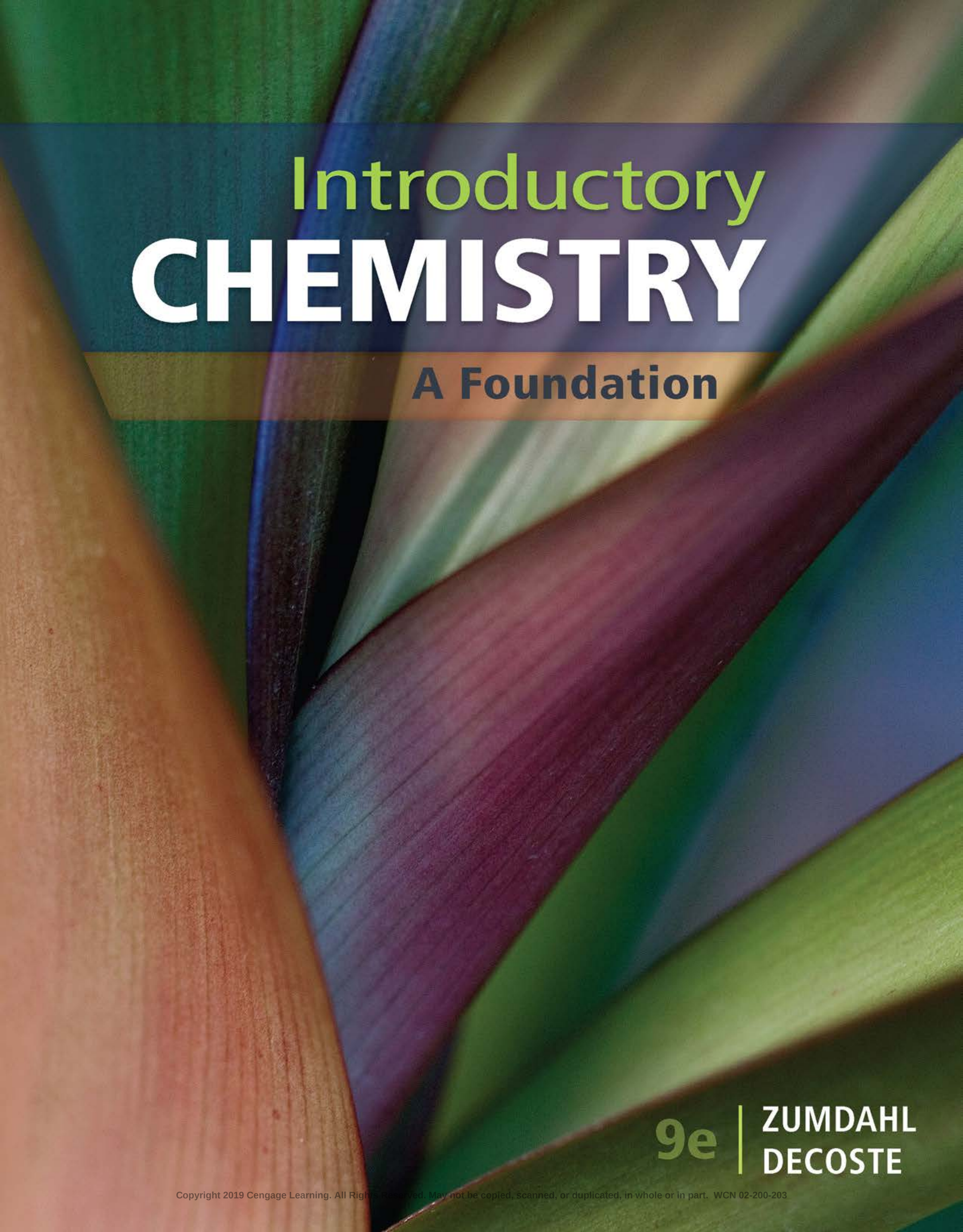


Introductory CHEMISTRY

A Foundation

9e

ZUMDAHL
DECOSTE

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][§]	Hafnium	Hf	72	178.5	Potassium	K	19	39.10
Aluminum	Al	13	26.98	Hassium	Hs	108	[265]	Praseodymium	Pr	59	140.9
Americium	Am	95	[243]	Helium	He	2	4.003	Promethium	Pm	61	[145]
Antimony	Sb	51	121.8	Holmium	Ho	67	164.9	Protactinium	Pa	91	[231]
Argon	Ar	18	39.95	Hydrogen	H	1	1.008	Radium	Ra	88	226
Arsenic	As	33	74.92	Indium	In	49	114.8	Radon	Rn	86	[222]
Astatine	At	85	[210]	Iodine	I	53	126.9	Rhenium	Re	75	186.2
Barium	Ba	56	137.3	Iridium	Ir	77	192.2	Rhodium	Rh	45	102.9
Berkelium	Bk	97	[247]	Iron	Fe	26	55.85	Roentgenium	Rg	111	[272]
Beryllium	Be	4	9.012	Krypton	Kr	36	83.80	Rubidium	Rb	37	85.47
Bismuth	Bi	83	209.0	Lanthanum	La	57	138.9	Ruthenium	Ru	44	101.1
Bohrium	Bh	107	[264]	Lawrencium	Lr	103	[260]	Rutherfordium	Rf	104	[261]
Boron	B	5	10.81	Lead	Pb	82	207.2	Samarium	Sm	62	150.4
Bromine	Br	35	79.90	Livermorium	Lv	116	[293]	Scandium	Sc	21	44.96
Cadmium	Cd	48	112.4	Lithium	Li	3	6.9419	Seaborgium	Sg	106	[263]
Calcium	Ca	20	40.08	Lutetium	Lu	71	175.0	Selenium	Se	34	78.96
Californium	Cf	98	[251]	Magnesium	Mg	12	24.31	Silicon	Si	14	28.09
Carbon	C	6	12.01	Manganese	Mn	25	54.94	Silver	Ag	47	107.9
Cerium	Ce	58	140.1	Meitnerium	Mt	109	[268]	Sodium	Na	11	22.99
Cesium	Cs	55	132.90	Mendelevium	Md	101	[258]	Strontium	Sr	38	87.62
Chlorine	Cl	17	35.45	Mercury	Hg	80	200.6	Sulfur	S	16	32.07
Chromium	Cr	24	52.00	Molybdenum	Mo	42	95.94	Tantalum	Ta	73	180.9
Cobalt	Co	27	58.93	Moscovium	Mc	115	[288]	Technetium	Tc	43	[98]
Copernicium	Cn	112	[285]	Neodymium	Nd	60	144.2	Tellurium	Te	52	127.6
Copper	Cu	29	63.55	Neon	Ne	10	20.18	Tennessine	Ts	117	[294]
Curium	Cm	96	[247]	Neptunium	Np	93	[237]	Terbium	Tb	65	158.9
Darmstadtium	Ds	110	[271]	Nickel	Ni	28	58.69	Thallium	Tl	81	204.4
Dubnium	Db	105	[262]	Nihonium	Nh	113	[284]	Thorium	Th	90	232.0
Dysprosium	Dy	66	162.5	Niobium	Nb	41	92.91	Thulium	Tm	69	168.9
Einsteinium	Es	99	[252]	Nitrogen	N	7	14.01	Tin	Sn	50	118.7
Erbium	Er	68	167.3	Nobelium	No	102	[259]	Titanium	Ti	22	47.88
Europium	Eu	63	152.0	Oganesson	Og	118	[294]	Tungsten	W	74	183.9
Fermium	Fm	100	[257]	Osmium	Os	76	190.2	Uranium	U	92	238.0
Flerovium	Fl	114	[289]	Oxygen	O	8	16.00	Vanadium	V	23	50.94
Fluorine	F	9	19.00	Palladium	Pd	46	106.4	Xenon	Xe	54	131.3
Francium	Fr	87	[223]	Phosphorus	P	15	30.97	Ytterbium	Yb	70	173.0
Gadolinium	Gd	64	157.3	Platinum	Pt	78	195.1	Yttrium	Y	39	88.91
Gallium	Ga	31	69.72	Plutonium	Pu	94	[244]	Zinc	Zn	30	65.38
Germanium	Ge	32	72.59	Polonium	Po	84	[209]	Zirconium	Zr	40	91.22
Gold	Au	79	197.0								

*The values given here are to four significant figures where possible. [§]A value given in parentheses denotes the mass of the longest-lived isotope.

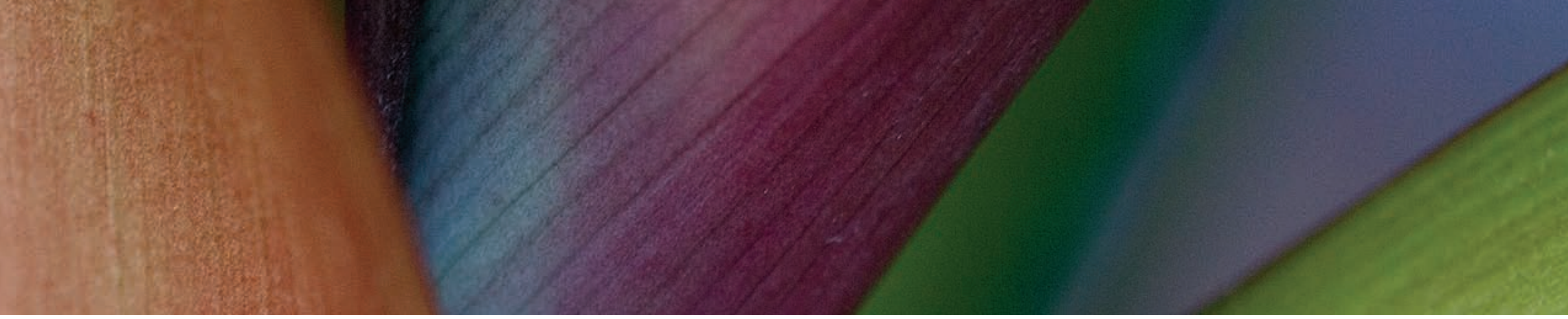
Periodic Table of Elements

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

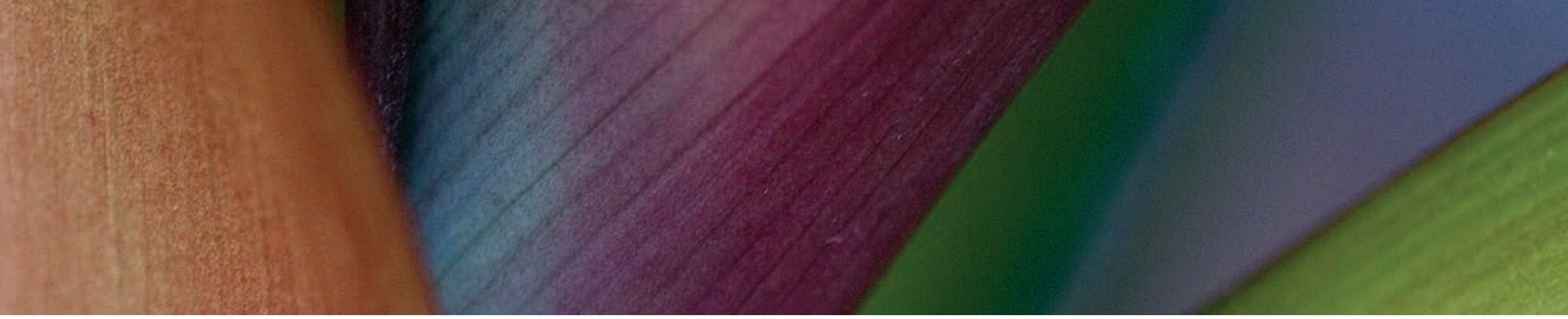
1 (1A)	2 (2A)	3	4	5	6	7	8	9	10	11	12	13 (3A)	14 (4A)	15 (5A)	16 (6A)	17 (7A)	18 (8A)
1 **H** 1.008																	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **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 **Nh** (284)	114 **Fl** (289)	115 **Mc** (288)	116 **Lv** (293)	117 **Ts** (294)	118 **Og** (294)

***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.



Introductory Chemistry



NINTH EDITION

Introductory Chemistry

A Foundation

Steven S. Zumdahl
University of Illinois

Donald J. DeCoste
University of Illinois

CENGAGE Learning®

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Brief Contents

Contents

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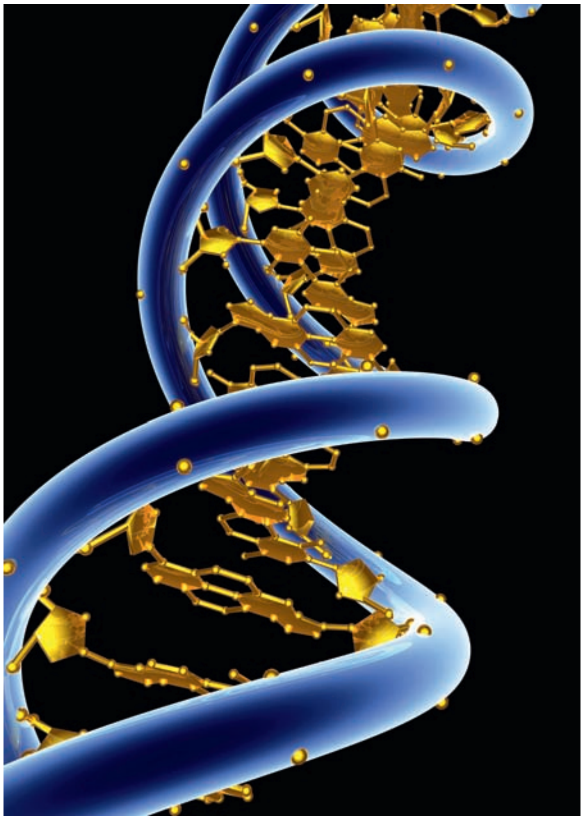
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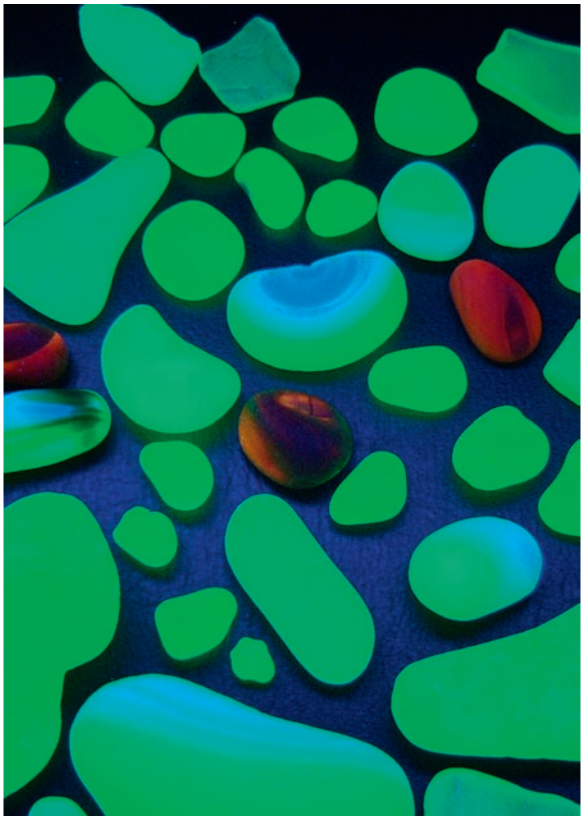

Courtesy, By the Bay Treasures, photo by Charles Peden

Photo by Martin Hunter/Getty Images

Preface

The ninth edition of *Introductory Chemistry* continues toward the goals we have pursued for the first eight editions: to make chemistry interesting, accessible, and understandable to the beginning student. For this edition, we have included additional support for instructors and students to help achieve these goals.

Learning chemistry can be very rewarding. And even the novice, we believe, can relate the macroscopic world of chemistry—the observation of color changes and precipitate formation—to the microscopic world of ions and molecules. To achieve that goal, instructors are making a sincere attempt to provide more interesting and more effective ways to learn chemistry, and we hope that *Introductory Chemistry* will be perceived as a part of that effort. In this text we have presented concepts in a clear and sensible manner using language and analogies that students can relate to. We have also written the book in a way that supports active learning. In particular, the Active Learning Questions, found at the end of each chapter, provide excellent material for collaborative work by students. In addition, we have connected chemistry to real-life experience at every opportunity, from chapter-opening discussions of chemical applications to "Chemistry in Focus" features throughout the book. We are convinced that this approach will foster enthusiasm and real understanding as the student uses this text. Highlights of the *Introductory Chemistry* program are described in the following section.

New to This Edition

Building on the success of previous editions of *Introductory Chemistry,* the following changes have been made to further enhance the text:

Updates to the Student Text and Annotated Instructor's Edition

Changes to the student text and the accompanying Annotated Instructor's Edition are outlined as follows:

Limiting Reactant Approach In Chapters 9 and 15 we have enhanced the treatment of stoichiometry by including "BCA" (Before–Change–After) tables. This allows another method by which students can conceptually understand the role coefficients play in a balanced chemical reaction. Students are shown three methods to select a limiting reactant: comparing the amounts of reactant present, calculating the amounts of products that can be formed by complete consumption of each reactant, and using a BCA table.

Art Program We have revised, modified, and updated the figures in the textbook as needed to better serve visual learners.

End-of-Chapter Exercises We replaced over 10% of the end-of-chapter questions and problems. As before, the margin of the Annotated Instructor's Edition includes answers to all of the Self-Check and end-of-chapter exercises, along with additional examples for all Example problems. In the student edition, answers to Self-Checks and to even-numbered exercises are provided at the back of the book.

Emphasis on Reaction Chemistry

We continue to emphasize chemical reactions early in the book, leaving the more abstract material on orbitals for later chapters. In a course in which many students encounter chemistry for the first time, it seems especially important that we present the chemical nature of matter before we discuss the theoretical intricacies of atoms and orbitals. Reactions are inherently interesting to students and can help us draw them to chemistry. In particular, reactions can form the basis for fascinating classroom demonstrations and laboratory experiments.

We have therefore chosen to emphasize reactions before going on to the details of atomic structure. Relying only on very simple ideas about the atom, Chapters 6 and 7 represent a thorough treatment of chemical reactions, including how to recognize a chemical change and what a chemical equation means. The properties of aqueous solutions are discussed in detail, and careful attention is given to precipitation and acid–base reactions. In addition, a simple treatment of oxidation–reduction reactions is given. These chapters should provide a solid foundation, relatively early in the course, for reaction-based laboratory experiments.

For instructors who feel that it is desirable to introduce orbitals early in the course, prior to chemical reactions, the chapters on atomic theory and bonding (Chapters 11 and 12) can be covered directly after Chapter 4. Chapter 5 deals solely with nomenclature and can be used wherever it is needed in a particular course.

Development of Problem-Solving Skills

Problem solving is a high priority in chemical education. We all want our students to acquire problem-solving skills. Fostering the development of such skills has been a central focus of the earlier editions of this text, and we have maintained this approach in this edition.

In the first chapters we spend considerable time guiding students to an understanding of the importance of learning chemistry. At the same time, we explain that the complexities that can make chemistry frustrating at times can also provide the opportunity to develop the problem-solving skills that are beneficial in any profession. Learning to think like a chemist is useful to everyone. To emphasize this idea, we apply scientific thinking to some real-life problems in Chapter 1.

One reason chemistry can be challenging for beginning students is that they often do not possess the required mathematical skills. Thus we have paid careful attention to such fundamental mathematical skills as using scientific notation, rounding off to the correct number of significant figures, and rearranging equations to solve for a particular quantity. And we have meticulously followed the rules we have set down so as not to confuse students.

Attitude plays a crucial role in achieving success in problem solving. Students must learn that a systematic, thoughtful approach to problems is better than brute-force memorization. We foster this attitude early in the book, using temperature conversions as a vehicle in Chapter 2. Throughout the book we encourage an approach that starts with trying to represent the essence of the problem using symbols and/or diagrams and ends with thinking about whether the answer makes sense. We approach new concepts by carefully working through the material before we give mathematical formulas or overall strategies. We encourage a thoughtful, step-by-step approach rather than the premature use of algorithms. Once we have provided the necessary foundation, we highlight important rules and processes in skill development boxes so that students can locate them easily.

Section 8.4: Learning to Solve Problems is written specifically to help students better understand how to think their way through a problem. We discuss how to solve problems in a flexible, creative way based on understanding the fundamental ideas of chemistry and asking and answering key questions. We model this approach in the in-text Examples throughout the text.

Many of the worked examples are followed by Self-Check Exercises, which provide additional practice. The Self-Check Exercises are keyed to end-of-chapter exercises to offer another opportunity for students to practice a particular problem-solving skill or understand a particular concept.

We have expanded the number of end-of-chapter exercises. As in the first eight editions, the end-of-chapter exercises are arranged in "matched pairs," meaning that both problems in the pair explore similar topics. An Additional Problems section includes further practice in chapter concepts as well as more challenging problems. Cumulative Reviews, which appear after every few chapters, test concepts from the preceding chapter block. Answers for all even-numbered exercises appear in a special section at the end of the student edition.

Handling the Language of Chemistry and Applications

We have gone to great lengths to make this book "student friendly" and have received enthusiastic feedback from students who have used it.

As in the earlier editions, we present a systematic and thorough treatment of chemical nomenclature. Once this framework is established, students can progress through the book comfortably.

Along with chemical reactions, applications form an important part of descriptive chemistry. Because students are interested in chemistry's impact on their lives, we have included many "Chemistry in Focus" boxes that describe current applications of chemistry. These special-interest boxes cover such topics as hybrid cars, artificial sweeteners, and positron emission tomography (PET).

Visual Impact of Chemistry

In response to instructors' requests to include graphic illustrations of chemical reactions, phenomena, and processes, we use a full-color design that enables color to be used functionally, thoughtfully, and consistently to help students understand chemistry and to make the subject more inviting to them. We have included only those photos that illustrate a chemical reaction or phenomenon or that make a connection between chemistry and the real world. Many new photos enhance the ninth edition.

Choices of Coverage

For the convenience of instructors, three versions of the ninth edition are available: one paperback version and two hardbound versions. *Introductory Chemistry,* Ninth Edition, available in hardcover and paperback, covers the first 19 chapters. *Introductory Chemistry: A Foundation,* Ninth Edition, a hardbound text, has 21 chapters, with the final 2 chapters providing a brief introduction to organic and biological chemistry.

About the Annotated Instructor's Edition

The Annotated Instructor's Edition (AIE) gathers a wealth of teaching support in one convenient package. The AIE contains all 21 chapters (the full contents of *Introductory Chemistry: A Foundation,* Ninth Edition). Annotations in the wraparound margins of the AIE include the following:

- Answers to Self-Check Exercises, at point of use.
- Answers to all end-of-chapter questions and exercises, at point of use.
- Additional Examples with answers to supplemental worked-out Examples in the text.
- Teaching Support: Suggestions for specific lecture/instruction methods, activities, and in-class demonstrations to help convey concepts.
- An overview of the chapter's learning objectives.
- Teaching Tips: Guidelines for highlighting critical information in the chapter.
- Misconceptions: Tips on where students may have trouble with or be confused by a topic.
- Demonstrations: Detailed instructions for in-class demonstrations and activities. (These are similar to material in Teaching Support and may be referenced in Teaching Support annotations.)
- Laboratory Experiments: Information on which labs in the Laboratory Manual are relevant to chapter content.
- Background Information: Explanations of conventions used in the text.
- Icons mark material correlations between the main text and the electronic support materials, the Test Bank, and the Laboratory Manual.
- Historical Notes: Biographical or other historical information about science and scientists.

Supporting Materials

Please visit **http://www.cengage.com/chemistry/zumdahl/introchem9e** for information about student and instructor resources for this text.

Acknowledgments

This book represents the efforts of many talented and dedicated people. We wish to thank Dawn Giovanniello, Product Director, for her oversight of the project, and Lisa Lockwood, Senior Product Manager, for her support, vision, and enthusiasm. We also appreciate the efforts of Teresa Trego, Senior Product Manager, who did her usual great job of managing this project. It was also a pleasure to work with Elizabeth Woods, Content Developer, whose good ideas and suggestions were always appreciated.

We are also glad to be working again with Gretchen Adams from the University of Illinois. She managed the revision of the end-of-chapter exercises and problems and the solutions manual. She also worked on the Annotated Instructor's Edition. Her positive attitude, tireless work ethic, and great ideas are always appreciated. Thanks to John Little for his outstanding work on *Introductory Chemistry in the Laboratory*. We also appreciate the work of Sharon Donahue, who continues to enhance the text by finding the perfect photos.

Thanks to others who have provided valuable assistance on this revision: Nellie Mitchell, Product Assistant; Sarah Cole, Senior Designer; Janet del Mundo, Senior Marketing Manager; and Cassie Carey, Senior Project Manager (Graphic World).

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Chemistry: An Introduction

CHAPTER

1

Chemistry deals with the natural world.

somphob/iStockphoto.com

Did you ever see a fireworks display on July Fourth and wonder how it's possible to produce those beautiful, intricate designs in the air? Have you read about dinosaurs—how they ruled the earth for millions of years and then suddenly disappeared? Although the extinction happened 65 million years ago and may seem unimportant, could the same thing happen to us? Have you ever wondered why an ice cube (pure water) floats in a glass of water (also pure water)? Did you know that the "lead" in your pencil is made of the same substance (carbon) as the diamond in an engagement ring? Did you ever wonder how a corn plant or a palm tree grows seemingly by magic, or why leaves turn beautiful colors in autumn? Do you know how the battery works to start your car or run your calculator? Surely some of these things and many others in the world around you have intrigued you. The fact is that we can explain all of these things in convincing ways using the models of chemistry and the related physical and life sciences.

Fireworks are a beautiful illustration of chemistry in action.
PhotoDisc/Getty Images

1.1 Chemistry: An Introduction

OBJECTIVE ■ To understand the importance of learning chemistry.

Although chemistry might seem to have little to do with dinosaurs, knowledge of chemistry was the tool that enabled paleontologist Luis W. Alvarez and his coworkers from the University of California at Berkeley to "crack the case" of the disappearing dinosaurs. The key was the relatively high level of iridium found in the sediment that represents the boundary between the earth's Cretaceous (K) and Tertiary (T) periods—the time when the dinosaurs disappeared virtually overnight (on the geologic scale). The Berkeley researchers knew that meteorites also have unusually high iridium content (relative to the earth's composition), which led them to suggest that a large meteorite impacted the earth 65 million years ago, causing the climatic changes that wiped out the dinosaurs.

A knowledge of chemistry is useful to almost everyone—chemistry occurs all around us all of the time, and an understanding of chemistry is useful to doctors, lawyers, mechanics, business-people, firefighters, and poets, among others. Chemistry is important—there is no doubt about that. It lies at the heart of our efforts to produce new materials that make our lives safer and easier, to produce new sources of energy that are abundant and nonpolluting, and to understand and control the many diseases that threaten us and our food supplies. Even if your future career does not require the daily use of chemical principles, your life will be greatly influenced by chemistry.

A strong case can be made that the use of chemistry has greatly enriched all of our lives. However, it is important to understand that the principles of chemistry are inherently neither good nor bad—it's what we do with this knowledge that really matters. Although humans are clever, resourceful, and concerned about others, they also can be greedy, selfish, and ignorant. In addition, we tend to be shortsighted; we concentrate too much on the present and do not think enough about the long-range implications of our actions. This type of thinking has already caused us a great deal of trouble—severe environmental damage has occurred on many fronts. We cannot place all the responsibility on the chemical companies because everyone has contributed to


Courtesy, Bart Eklund

Bart Eklund checking air quality at a hazardous waste site.

these problems. However, it is less important to lay blame than to figure out how to solve these problems. An important part of the answer must rely on chemistry.

One of the "hottest" fields in the chemical sciences is environmental chemistry—an area that involves studying our environmental ills and finding creative ways to address them. For example, meet Bart Eklund, ◀ who works in the atmospheric chemistry field for Radian Corporation in Austin, Texas. Bart's interest in a career in environmental science was fostered by two environmental chemistry courses and two ecology courses he took as an undergraduate. His original plan to gain several years of industrial experience and then to return to school for a graduate degree changed when he discovered that professional advancement with a B.S. degree was possible in the environmental research field. The multidisciplinary nature of environmental problems has allowed Bart to pursue his interest in several fields at the same time. You might say that he specializes in being a generalist.

The environmental consulting field appeals to Bart for a number of reasons: the chance to define and solve a number of research problems; the simultaneous work on a number of diverse projects; the mix of desk, field, and laboratory work; the travel; and the opportunity to perform rewarding work that has a positive effect on people's lives.

Among his career highlights are the following:

- Spending a winter month doing air sampling in the Grand Tetons, where he also met his wife and learned to ski;
- Driving sampling pipes by hand into the rocky ground of Death Valley Monument in California;
- Working regularly with experts in their fields and with people who enjoy what they do;
- Doing vigorous work in 100 °F weather while wearing a rubberized suit, double gloves, and a respirator; and
- Getting to work in and see Alaska, Yosemite Park, Niagara Falls, Hong Kong, the People's Republic of China, Mesa Verde, New York City, and dozens of other interesting places.

Bart Eklund's career demonstrates how chemists are helping to solve our environmental problems. It is how we use our chemical knowledge that makes all the difference.

An example that shows how technical knowledge can be a "double-edged sword" is the case of chlorofluorocarbons (CFCs). When the compound CCl_2F_2 (originally called Freon-12) was first synthesized, it was hailed as a near-miracle substance. Because of its noncorrosive nature and its unusual ability to resist decomposition, Freon-12 was rapidly applied in refrigeration and air-conditioning systems, cleaning applications, the blowing of foams used for insulation and packing materials, and many other ways. For years everything seemed fine—the CFCs actually replaced more dangerous materials, such as the ammonia formerly used in refrigeration systems. The CFCs were definitely viewed as "good guys." But then a problem was discovered—the ozone in the upper atmosphere that protects us from the high-energy radiation of the sun began to decline. What was happening to cause the destruction of the vital ozone?

Much to everyone's amazement, the culprits turned out to be the seemingly beneficial CFCs. Inevitably, large quantities of CFCs had leaked into the atmosphere, but nobody was very worried about this development because these compounds seemed totally benign. In fact, the great stability of the CFCs (a tremendous advantage for their various applications) was in the end a great disadvantage when they were released into the environment. Professor F. S. Rowland and his colleagues at the University of California at Irvine demonstrated that the CFCs eventually drifted to high altitudes in the atmosphere, where the energy of the sun stripped off chlorine atoms. These chlorine atoms in turn promoted the decomposition of the ozone in the upper atmosphere. (We will discuss this in more detail in Chapter 13.) Thus a substance that possessed many advantages in earth-bound applications turned against us in the atmosphere. Who could have guessed it would turn out this way?

CHEMISTRY IN FOCUS

Dr. Ruth—Cotton Hero

Dr. Ruth Rogan Benerito may have saved the cotton industry in the United States. In the 1960s, synthetic fibers posed a serious competitive threat to cotton, primarily because of wrinkling. Synthetic fibers such as polyester can be formulated to be highly resistant to wrinkles both in the laundering process and in wearing. On the other hand, 1960s cotton fabrics wrinkled easily—white cotton shirts had to be ironed to look good. This requirement put cotton at a serious disadvantage and endangered an industry very important to the economic health of the South.


AP Photo/Eric Risberg

Ruth Benerito, the inventor of easy-care cotton.

During the 1960s Ruth Benerito worked as a scientist for the U.S. Department of Agriculture (USDA), where she was instrumental in developing the chemical treatment of cotton to make it wrinkle resistant. In so doing she enabled cotton to remain a preeminent fiber in the market—a place it continues to hold today. She was honored with the Lemelson–MIT Lifetime Achievement Award for Inventions in 2002 when she was 86 years old.

Dr. Benerito began her career when women were not expected to enter scientific fields. However, her mother, who was an artist, adamantly encouraged her to be anything she wanted to be.

Dr. Benerito graduated from high school at age 14 and attended Newcomb College, the women's college associated with Tulane University. She majored in chemistry with minors in physics and math. At that time she was one of only two women allowed to take the physical chemistry course at Tulane. She earned her B.S. degree in 1935 at age 19 and subsequently earned a master's degree at Tulane and a Ph.D. at the University of Chicago.

In 1953 Dr. Benerito began working in the Agriculture Department's Southern Regional Research Center in New Orleans, where she mainly worked on cotton and cotton-related products. She also invented a special method for intravenous feeding in long-term medical patients.

Dr. Benerito retired from the USDA in 1986 but continued to teach and tutor until her death in 2013 at the age of 97. She held 55 patents, including the one for wrinkle-free cotton awarded in 1969. Everyone who knew Dr. Benerito described her as a class act.

See Problem 1.4


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A chemist in the laboratory.

The good news is that the U.S. chemical industry is leading the way to find environmentally safe alternatives to CFCs, and the levels of CFCs in the atmosphere are already dropping.

The saga of the CFCs demonstrates that we can respond relatively quickly to a serious environmental problem if we decide to do so. Also, it is important to understand that chemical manufacturers have a new attitude about the environment—they are now among the leaders in finding ways to address our environmental ills. The industries that apply the chemical sciences are now determined to be part of the solution rather than part of the problem.

As you can see, learning chemistry is both interesting and important. A chemistry course can do more than simply help you learn the principles of chemistry, however. A major by-product of your study of chemistry is that you will become a better problem solver. One reason chemistry has the reputation of being "tough" is that it often deals with rather complicated systems that require some effort to figure out. Although this might at first seem like a disadvantage, you can turn it to your advantage if you have the right attitude. Recruiters for companies of all types maintain that one of the first things they look for in a prospective employee is the ability to solve problems. We will spend a good deal of time solving various types of problems in this book by using a systematic, logical approach that will serve you well in solving any kind of problem in any field. Keep this broader goal in mind as you learn to solve the specific problems connected with chemistry.

Although learning chemistry is often not easy, it's never impossible. In fact, anyone who is interested, patient, and willing to work can learn the fundamentals of chemistry. In this book we will try very hard to help you understand what chemistry is and how it works and to point out how chemistry applies to the things going on in your life.

Our sincere hope is that this text will motivate you to learn chemistry, make its concepts understandable to you, and demonstrate how interesting and vital the study of chemistry is.

1.2 What Is Chemistry?

OBJECTIVE ■ To define chemistry.

Chemical and physical changes will be discussed in Chapter 3.

Chemistry can be defined as *the science that deals with the materials of the universe and the changes that these materials undergo.* ◀ Chemists are involved in activities as diverse as examining the fundamental particles of matter, looking for molecules in space, synthesizing and formulating new materials of all types, using bacteria to produce such chemicals as insulin, and inventing new diagnostic methods for early detection of disease.

The launch of the space shuttle gives clear indications that chemical reactions are occurring. NASA

Chemistry is often called the central science—and with good reason. Most of the phenomena that occur in the world around us involve chemical changes, changes where one or more substances become different substances. Here are some examples of chemical changes:

Wood burns in air, forming water, carbon dioxide, and other substances.

A plant grows by assembling simple substances into more complex substances.

The steel in a car rusts.

Eggs, flour, sugar, and baking powder are mixed and baked to yield a cake.

The definition of the term *chemistry* is learned and stored in the brain.

Emissions from a power plant lead to the formation of acid rain. ◀

As we proceed, you will see how the concepts of chemistry allow us to understand the nature of these and other changes and thus help us manipulate natural materials to our benefit.

1.3 Solving Problems Using a Scientific Approach

OBJECTIVE ■ To understand scientific thinking.

One of the most important things we do in everyday life is solve problems. In fact, most of the decisions you make each day can be described as solving problems.

It's 8:30 a.m. on Friday. Which is the best way to drive to school to avoid traffic congestion?

You have two tests on Monday. Should you divide your study time equally or allot more time to one than to the other?

Your car stalls at a busy intersection, and your little brother is with you. What should you do next?

These are everyday problems of the type we all face. What process do we use to solve them? You may not have thought about it before, but there are several steps that almost everyone uses to solve problems:

1. Recognize the problem and state it clearly. Some information becomes known, or something happens that requires action. In science we call this step *making an observation.*
2. Propose *possible* solutions to the problem or *possible* explanations for the observation. In scientific language, suggesting such a possibility is called *formulating a hypothesis.*
3. Decide which of the solutions is the best or decide whether the explanation proposed is reasonable. To do this we search our memories for any pertinent information, or we seek new information. In science we call searching for new information *performing an experiment.*

As we will discover in the next section, scientists use these same procedures to study what happens in the world around us. The important point here is that scientific thinking can help you in all parts of your life. It's worthwhile to learn how to think scientifically—whether you want to be a scientist, an auto mechanic, a doctor, a politician, or a poet!

1.4 The Scientific Method

OBJECTIVE ■ **To describe the method scientists use to study nature.**

In the last section we began to see how the methods of science are used to solve problems. In this section we will further examine this approach.

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. Although scientific thinking is useful in all aspects of life, in this text we will use it to understand how the natural world operates. The process that lies at the center of scientific inquiry is called the **scientific method.** As we saw in the previous section, it consists of the following steps:

Steps in the Scientific Method

1. *State the problem and collect data (make 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 4.5 pounds). A qualitative observation does not involve a number. A quantitative observation is called a **measurement** and does involve a number (and a unit, such as pounds or inches). We will discuss measurements in detail in Chapter 2.
2. *Formulate hypotheses.* A hypothesis is a *possible* explanation for the observation.
3. *Perform experiments.* An experiment is something we do to test the hypothesis. We gather new information that allows us to decide whether the hypothesis is supported by the new information we have learned from the experiment. Experiments always produce new observations, and this brings us back to the beginning of the process again.

CHEMISTRY IN FOCUS

A Mystifying Problem

To illustrate how science helps us solve problems, consider a true story about two people, David and Susan (not their real names). David and Susan were healthy 40-year-olds living in California, where David was serving in the U.S. Air Force. Gradually Susan became quite ill, showing flu-like symptoms including nausea and severe muscle pains. Even her personality changed: she became uncharacteristically grumpy. She seemed like a totally different person from the healthy, happy woman of a few months earlier. Following her doctor's orders, she rested and drank a lot of fluids, including large quantities of coffee and orange juice from her favorite mug, part of a 200-piece set of pottery dishes recently purchased in Italy. However, she just got sicker, developing extreme abdominal cramps and severe anemia.

During this time David also became ill and exhibited symptoms much like Susan's: weight loss, excruciating pain in his back and arms, and uncharacteristic fits of temper. The disease became so debilitating that he retired early from the U.S. Air Force, and the couple moved to Seattle. For a short time their health improved, but after they unpacked all their belongings (including those pottery dishes), their health began to deteriorate again. Susan's body became so sensitive that she could not tolerate the weight of a blanket. She was near death. What was wrong? The doctors didn't know, but one suggested she might have porphyria, a rare blood disease.

Desperate, David began to search the medical literature himself. One day while he was reading about porphyria, a phrase jumped off the page: "Lead poisoning can sometimes be confused with porphyria." Could the problem be lead poisoning?

We have described a very serious problem with life-or-death implications. What should David do next? Overlooking for a moment the obvious response of calling the couple's doctor immediately to discuss the possibility of lead poisoning, could David solve the problem via scientific thinking? Let's use the three steps described in Section 1.3 to attack the problem one part at a time. This is important: usually we solve complex problems by breaking them down into manageable parts. We can then assemble the solution to the overall problem from the answers we have found "piecemeal."

In this case there are many parts to the overall problem:

What is the disease?

Where is it coming from?

Can it be cured?

Let's attack "What is the disease?" first.

Observation: David and Susan are ill with the symptoms described. Is the disease lead poisoning?

Hypothesis: The disease is lead poisoning.

Experiment: If the disease is lead poisoning, the symptoms must match those known to characterize lead poisoning. Look up the symptoms of lead poisoning. David did this and found that they matched the couple's symptoms almost exactly.

This discovery points to lead poisoning as the source of their problem, but David needed more evidence.

Observation: Lead poisoning results from high levels of lead in the bloodstream.

Hypothesis: David and Susan have high levels of lead in their blood.

See Problem 1.7

To explain the behavior of a given part of nature, we repeat these steps many times. Gradually we accumulate the knowledge necessary to understand what is going on.

Once we have a set consisting of hypotheses that agree with our various observations, we assemble the hypotheses into a theory that is often called a *model.* A **theory** (model) is a set of tested hypotheses that gives an overall explanation of some part of nature (Fig. 1.1).

It is 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—have changed greatly since ancient times.

Experiment: Perform a blood analysis. Susan arranged for such an analysis, and the results showed high lead levels for both David and Susan.

This confirms that lead poisoning is probably the cause of the trouble, but the overall problem is still not solved. David and Susan are likely to die unless they find out where the lead is coming from.

Observation: There is lead in the couple's blood.

Hypothesis: The lead is in their food or drink when they buy it.

Experiment: Find out whether anyone else who shopped at the same store was getting sick (no one was). Also note that moving to a new area did not solve the problem.

Observation: The food they buy is free of lead.

Hypothesis: The dishes they use are the source of the lead poisoning.

Experiment: Find out whether their dishes contain lead. David and Susan learned that lead compounds are often used to put a shiny finish on pottery objects. And laboratory analysis of their Italian pottery dishes showed that lead was present in the glaze.

Observation: Lead is present in their dishes, so the dishes are a possible source of their lead poisoning.

Hypothesis: The lead is leaching into their food.

Experiment: Place a beverage, such as orange juice, in one of the cups and then analyze the beverage for lead. The results showed high levels of lead in drinks that had been in contact with the pottery cups.

Photo by Ken O'Donoghue © Cengage Learning

Italian pottery.

After many applications of the scientific method, the problem is solved. We can summarize the answer to the problem (David and Susan's illness) as follows: the Italian pottery they used for everyday dishes contained a lead glaze that contaminated their food and drink with lead. This lead accumulated in their bodies to the point where it interfered seriously with normal functions and produced severe symptoms. This overall explanation, which summarizes the hypotheses that agree with the experimental results, is called a *theory* in science. This explanation accounts for the results of all the experiments performed.*

We could continue to use the scientific method to study other aspects of this problem, such as

What types of food or drink leach the most lead from the dishes?

Do all pottery dishes with lead glazes produce lead poisoning?

As we answer questions using the scientific method, other questions naturally arise. By repeating the three steps over and over, we can come to understand a given phenomenon thoroughly.

*"David" and "Susan" recovered from their lead poisoning and are now publicizing the dangers of using lead-glazed pottery. This happy outcome is the answer to the third part of their overall problem, "Can the disease be cured?" They simply stopped eating from that pottery!

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?

The point is that we don't stop asking questions just because we have devised a theory that seems to account satisfactorily for some aspect of natural behavior. We continue doing experiments to refine our theories. We generally do this by using the theory to make a prediction and then doing 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 our attempts to explain observed natural behavior in terms of our human experiences. We

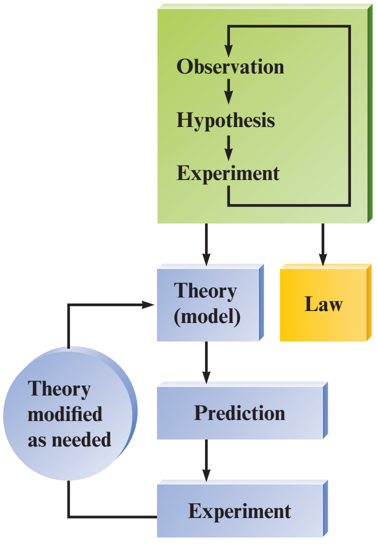

Figure 1.1 The various parts of the scientific method.

must continue to do experiments and refine our theories to be consistent with new knowledge if we hope to approach a more nearly complete understanding of nature.

As we observe nature, we often see that the same observation applies to many different systems. For example, studies of innumerable chemical changes have shown that the total mass of the materials involved is the same before and after the change. We often formulate such generally observed behavior into a statement called a **natural law.** 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.

You must recognize the difference between a law and a theory. A law is a summary of observed (measurable) behavior, whereas a theory is an explanation of behavior. *A law tells what happens; a theory (model) is our attempt to explain why it happens.*

In this section, we have described the scientific method (which is summarized in Fig. 1.1) as it might ideally be applied. However, it is important to remember that science does not always progress smoothly and efficiently. Scientists are human. They have prejudices; they misinterpret data; they can 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. And great progress in the chemistry of nitrogen fertilizers resulted from the desire to produce explosives to fight wars. The progress of science is often slowed more by the frailties of humans and their institutions than by the limitations of scientific measuring devices. The scientific method is only as effective as the humans using it. It does not automatically lead to progress.

1.5 Learning Chemistry

OBJECTIVE ■ To develop successful strategies for learning chemistry.

Chemistry courses have a universal reputation for being difficult. There are some good reasons for this. For one thing, the language of chemistry is unfamiliar in the beginning; many terms and definitions need to be memorized. As with any language, *you must know the vocabulary* before you can communicate effectively. We will try to help you by pointing out those things that need to be memorized.

But memorization is only the beginning. Don't stop there or your experience with chemistry will be frustrating. Be willing to do some thinking, and learn to trust yourself to figure things out. To solve a typical chemistry problem, you must sort through the given information and decide what is really crucial.

It is important to realize that chemical systems tend to be complicated—there are typically many components—and we must make approximations in describing them. Therefore, trial and error play a major role in solving chemical problems. In tackling a complicated system, a practicing chemist really does not expect to be right the first time he or she analyzes the problem. The usual practice is to make several simplifying assumptions and then give it a try. If the answer obtained doesn't make sense, the chemist adjusts the assumptions, using feedback from the first attempt, and tries again. The point is this: in dealing with chemical systems, do not expect to understand immediately everything that is going on. In fact, it is typical (even for an experienced chemist) *not* to understand at first. Make an attempt to solve the problem and then analyze the feedback. *It is no disaster to make a mistake as long as you learn from it.*

The only way to develop your confidence as a problem solver is to practice solving problems. To help you, this book contains examples worked out in detail. Follow these through carefully, making sure you understand each step. These examples are usually followed by a similar exercise (called a self-check exercise) that you should try on your own (detailed solutions of the self-check exercises are given at the end

CHEMISTRY IN FOCUS

Chemistry: An Important Component of Your Education

What is the purpose of education? Because you are spending considerable time, energy, and money to pursue an education, this is an important question.

Some people seem to equate education with the storage of facts in the brain. These people apparently believe that education simply means memorizing the answers to all of life's present and future problems. Although this is clearly unreasonable, many students seem to behave as though this were their guiding principle. These students want to memorize lists of facts and to reproduce them on tests. They regard as unfair any exam questions that require some original thought or some processing of information. Indeed, it might be tempting to reduce education to a simple filling up with facts because that approach can produce short-term satisfaction for both student and teacher. And of course, storing facts in the brain *is* important. You cannot function without knowing that red means stop, electricity is hazardous, ice is slippery, and so on.

However, mere recall of abstract information, without the ability to process it, makes you little better than a talking encyclopedia. Former students always seem to bring the same message when they return to campus. The characteristics that are most important to their success are a knowledge of the fundamentals of their fields, the ability to recognize and solve problems, and the ability to communicate effectively. They also emphasize the importance of a high level of motivation.

How does studying chemistry help you achieve these characteristics? The fact that chemical systems are complicated is really a blessing, although one that is well disguised. Studying chemistry will not by itself make you a good problem solver, but it can help you develop a positive, aggressive attitude toward problem solving and can help boost your confidence. Learning to "think like a chemist" can be valuable to anyone in any field. In fact, the chemical industry is heavily populated at all levels and in all areas by chemists and chemical engineers. People who were trained as chemical professionals often excel not only in chemical research and production but also in the areas of personnel, marketing, sales, development, finance, and management. The point is that much of what you learn in this course can be applied to any field of endeavor. So be careful not to take too narrow a view of this course. Try to look beyond short-term frustration to long-term benefits. It may not be easy to learn to be a good problem solver, but it's well worth the effort.

See Problem 1.18


kali9/iStockphoto.com

Students discussing a chemistry experiment.

of each chapter). Use the self-check exercises to test whether you are understanding the material as you go along.

There are questions and problems at the end of each chapter. The questions review the basic concepts of the chapter and give you an opportunity to check whether you properly understand the vocabulary introduced. Some of the problems are really just exercises that are very similar to examples done in the chapter. If you understand the material in the chapter, you should be able to do these exercises in a straightforward way. Other problems require more creativity. These contain a knowledge gap—some unfamiliar territory that you must cross—and call for thought and patience on your part. For this course to be really useful to you, it is important to go beyond the questions and exercises. Life offers us many exercises, routine events that we deal with rather automatically, but the real challenges in life are true problems. This course can help you become a more creative problem solver.

As you do homework, be sure to use the problems correctly. If you cannot do a particular problem, do not immediately look at the solution. Review the relevant material in the text, then try the problem again. Don't be afraid to struggle with a problem. Looking at the solution as soon as you get stuck short-circuits the learning process.

Learning chemistry takes time. Use all the resources available to you, and study on a regular basis. Don't expect too much of yourself too soon. You may not understand everything at first, and you may not be able to do many of the problems the first time you try them. This is normal. It doesn't mean you can't learn chemistry. Just remember to keep working and to keep learning from your mistakes, and you will make steady progress.