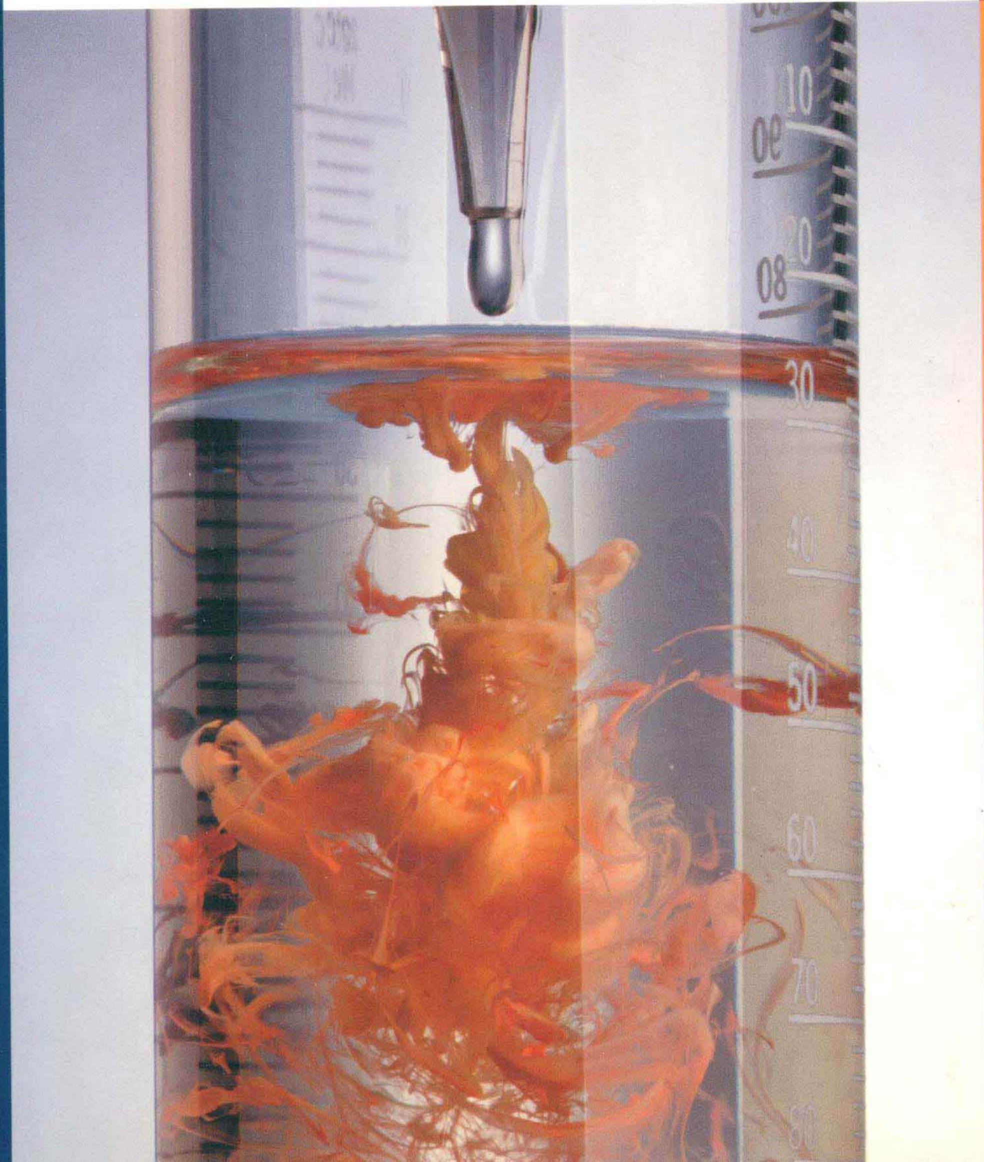
Pearson International Edition

CHEMISTRY

Principles, Patterns, and Applications



Averill
Eldredge

CHEMISTRY

Principles, Patterns, and Applications

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PERIODIC TABLE OF THE ELEMENTS

Group 1 (1A)

Period — 1

1 — Atomic number
H — Symbol
1.00794 — Atomic mass

- 🟦 Metals
- 🟧 Semimetals
- 🟫 Nonmetals

- ◥ Alkali metals
- ◥ Alkaline earths
- ◥ Halogens
- ◥ Noble gases

Main group elements (groups 1–2) · Transition metals (groups 3–12) · Main group elements (groups 13–18)

	1 (1A)	2 (2A)	3 (3B)	4 (4B)	5 (5B)	6 (6B)	7 (7B)	8 (8B)	9 (8B)	10 (8B)	11 (11B)	12 (12B)	13 (3A)	14 (4A)	15 (5A)	16 (6A)	17 (7A)	18 (8A)
1	1 H 1.00794																	2 He 4.002602
2	3 Li 6.941	4 Be 9.012182											5 B 10.811	6 C 12.0107	7 N 14.0067	8 O 15.9994	9 F 18.9984032	10 Ne 20.1797
3	11 Na 22.98976928	12 Mg 24.3050											13 Al 26.9815386	14 Si 28.0855	15 P 30.973762	16 S 32.065	17 Cl 35.453	18 Ar 39.948
4	19 K 39.0983	20 Ca 40.078	21 Sc 44.955912	22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.938045	26 Fe 55.845	27 Co 58.933195	28 Ni 58.6934	29 Cu 63.546	30 Zn 65.409	31 Ga 69.723	32 Ge 72.64	33 As 74.92160	34 Se 78.96	35 Br 79.904	36 Kr 83.798
5	37 Rb 85.4678	38 Sr 87.62	39 Y 88.90585	40 Zr 91.224	41 Nb 92.90638	42 Mo 95.94	43 Tc [98]	44 Ru 101.07	45 Rh 102.90550	46 Pd 106.42	47 Ag 107.8682	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.90447	54 Xe 131.293
6	55 Cs 132.9054519	56 Ba 137.327	57 La 138.90547	72 Hf 178.49	73 Ta 180.94788	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.084	79 Au 196.966569	80 Hg 200.59	81 Tl 204.3833	82 Pb 207.2	83 Bi 208.98040	84 Po [209]	85 At [210]	86 Rn [222]
7	87 Fr [223]	88 Ra [226]	89 Ac [227]	104 Rf [267]	105 Db [268]	106 Sg [271]	107 Bh [267]	108 Hs [269]	109 Mt [276]	110 Ds [281]	111 Rg [280]	112 Uub [285]	113 Uut [284]	114 Uuq [289]	115 Uup [288]	116 Uuh [293]		

Lanthanides 6	58 Ce 140.116	59 Pr 140.90765	60 Nd 144.242	61 Pm [145]	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92535	66 Dy 162.500	67 Ho 164.93032	68 Er 167.259	69 Tm 168.93421	70 Yb 173.04	71 Lu 174.967
Actinides 7	90 Th 232.03806	91 Pa 231.03588	92 U 238.02891	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 [262]

Two systems for numbering periodic groups are shown: 1–18 is the system currently recommended by the International Union of Pure and Applied Chemistry (IUPAC); an older U.S. system, in which letters designate main group elements (A) and transition elements (B), is given in parentheses.

An atomic mass in brackets indicates the mass of the longest-lived isotope of an element having no stable isotopes.

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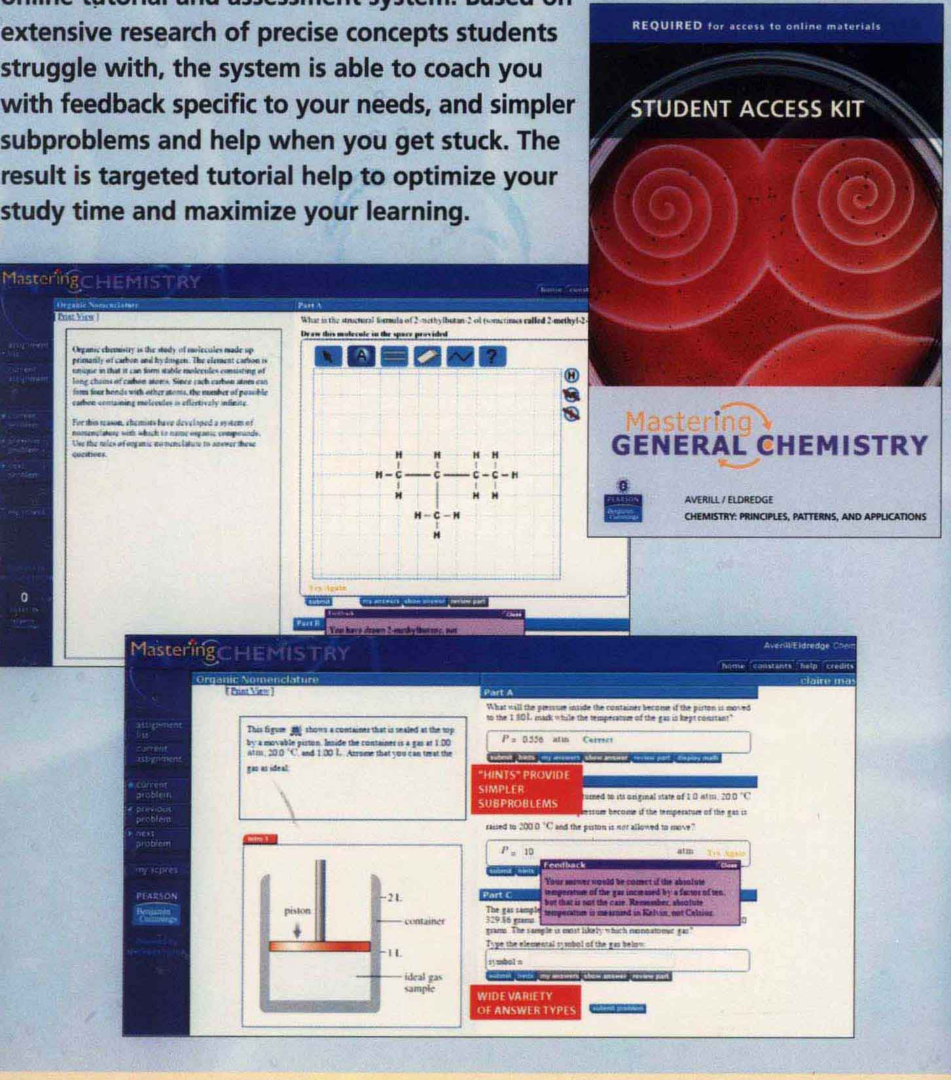

Organic chemistry is the study of molecules made up primarily of carbon and hydrogen. The element carbon is unique in that it can form stable molecules consisting of long chains of carbon atoms. Since each carbon atom can form four bonds with other atoms, the number of possible carbon-containing molecules is effectively infinite.

For this reason, chemists have developed a system of nomenclature with which to name organic compounds. Use the rules of organic nomenclature to answer these questions.

What is the structural formula of 2-methylbutan-2-ol (sometimes called 2-methyl-2-

Draw this molecule in the space provided

You have drawn 2-methylbutane, not

This figure shows a container that is sealed at the top by a movable piston. Inside the container is a gas at 1.00 atm, 20.0 °C, and 1.00 L. Assume that you can treat the gas as ideal.

What will the pressure inside the container become if the piston is moved to the 1.80 L mark while the temperature of the gas is kept constant?

P = 0.556 atm Correct

…turned to its original state of 1.0 atm, 20.0 °C …pressure become if the temperature of the gas is raised to 200.0 °C and the piston is not allowed to move?

P = 10 atm

Your answer would be correct if the absolute temperature of the gas increased by a factor of ten, but that is not the case. Remember, absolute temperature is measured in Kelvin, not Celsius.

Part C

The gas sample … 329.86 grams … grams. The sample is most likely which monatomic gas?

Type the elemental symbol of the gas below.

symbol =

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If you did not purchase a new textbook and your professor requires you to enroll in MasteringGeneralChemistry, you may purchase online access with a major credit card. Go to www.masteringgeneralchemistry.com and follow the links to purchasing online.

Minimum System Requirements

System requirements are subject to change. See website for the latest requirements.

Windows: 250 MHz CPU; OS Windows 98, NT, 2000, XP

Macintosh: 233 MHz CPU; OS 9.2, 10.2, 10.3

RedHat Linux 8.0, 9.0

All:

- 64 MB RAM
- 1024 x 768 screen resolution
- Browsers (OS dependent): Firefox 1.0, Internet Explorer 6.0, Mozilla 1.7, Netscape 7.2, Safari 1.3
- Flash 7.0

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System requirements are subject to change. See website for the latest requirements.

Windows: 266 MHz CPU; OS Windows 98, NT, 2000, XP

Macintosh: 266 MHz CPU; OS 9.2, 10.2, 10.3

Both:

- 64 MB RAM
- 1024 x 768 screen resolution
- Browsers (OS dependent): Internet Explorer 6.0, Netscape 7.2,
- Flash, Shockwave, QuickTime, and Chime

To Harvey, who opened the door

About the Authors

Bruce Averill

After growing up in New England, Bruce Averill received his B.S. with high honors in chemistry at Michigan State University in 1969, and his Ph.D. in inorganic chemistry at MIT in 1973. After three years as an NIH and NSF Postdoctoral Fellow at Brandeis University and the University of Wisconsin, he began his independent academic career at Michigan State University in 1976. He moved to the University of Virginia in 1982, and was promoted to Professor in 1988. In 1994, Dr. Averill moved to the University of Amsterdam in the Netherlands as Professor of Biochemistry. In 2001, he returned to the United States where he is a Distinguished University Professor at the University of Toledo. Dr. Averill's research focuses on the role of metal ions in biology.

While in Europe, Dr. Averill headed an EU-funded network of seven research groups from seven different European countries. In addition, he lead a 22-member team investigating biocatalysis within the E. C. Slater Institute of the University of Amsterdam.

From 2004 to 2005, Dr. Averill was a Jefferson Science Fellow at the U.S. State Department, where he acted as a senior science and technology adviser in the Bureau of Western Hemisphere Affairs and focussed on energy issues in Latin America. He has been asked to return to the State Department for 2006 and 2007 as a William C. Foster Fellow in the Bureau of Political-Military Affairs to work on R&D issues in the area of critical infrastructure protection and cybersecurity.

Dr. Averill's published papers are frequently cited by other researchers, and he has been invited to give more than 100 presentations at educational and research institutions and at national and international scientific meetings. Dr. Averill has been an Honorary Woodrow Wilson Fellow, an NSF Predoctoral Fellow, an NIH and NSF Postdoctoral Fellow, and an Alfred P. Sloan Foundation Fellow; he has also received an NSF Special Creativity Award.

Dr. Averill has published more than 140 articles on chemical, physical, and biological subjects in refereed journals, 15 chapters in books, and more than 80 abstracts from national and international meetings. In addition, he has co-edited a graduate text on catalysis and taught courses at all levels, including general chemistry, biochemistry, advanced inorganic, and physical methods.

Aside from his research program, Dr. Averill is an enthusiastic sailor and an avid reader. He also enjoys traveling with his family, and at some point in the future he would like to sail around the world in a classic wooden boat.

Patricia Eldredge

Having been raised in the U.S. diplomatic service, Patricia Eldredge has traveled and lived around the world. After receiving a B.A. in Spanish language and literature from Ohio State University, Dr. Eldredge developed an interest in chemistry while studying general chemistry at Kent State University. She obtained a B.S. in chemistry from the University of Central Florida. Following several years as an analytical research chemist in industry, she began her graduate studies at the University of Virginia and obtained her Ph.D. in inorganic chemistry from the University of North Carolina at Chapel Hill. In 1989, Dr. Eldredge was named the Science Policy Fellow for the American Chemical Society. While in Washington, D.C., she examined the impact of changes in federal funding priorities on academic research funding. She was awarded a Postdoctoral Research Fellowship with Oak Ridge Associated Universities, working with the U.S. Department of Energy on heterogeneous catalysis and coal liquefaction. Subsequently, she returned to the University of Virginia as a Research Scientist and a member of the General Faculty. In 1992, Dr. Eldredge moved to Europe for several years. While there, she studied advanced Maritime Engineering, Materials, and Oceanography at the University of Southampton in England, arising from her keen interest in naval architecture. Since her return to the United States in 2002, she has been a Visiting Assistant Professor and a Senior Research Scientist at the University of Toledo. Her current research interests include the use of protein scaffolds to synthesize biologically relevant clusters.

Dr. Eldredge has published more than a dozen articles dealing with synthetic inorganic chemistry and catalysis, including several seminal studies describing new synthetic approaches to metal–sulfur clusters. She has also been awarded a patent for her work on catalytic coal liquefaction. Her diverse teaching experience includes courses on chemistry for the life sciences, introductory chemistry, general, organic, and analytical chemistry.

When not writing scientific papers or textbooks, Dr. Eldredge enjoys traveling, reading political biographies, sailing high-performance vessels under rigorous conditions, and caring for her fourth child, her pet Havanese.

Preface to the Instructor

In this new millenium, as the world faces new and extreme challenges, the importance of acquiring a solid foundation in chemical principles has become increasingly central to understanding the challenges that lie ahead. Moreover, as the world becomes more integrated and interdependent, so too do the scientific disciplines. The divisions between fields such as chemistry, physics, biology, environmental sciences, geology, and materials science, among others, have become less clearly defined. This text addresses the closer relationships developing among various disciplines and shows the relevance of chemistry to contemporary issues in a friendly and approachable manner.

Because of the enthusiasm of the majority of first-year chemistry students for biologically and medically relevant topics, this text uses an integrated approach that includes explicit discussions of biological and environmental applications of chemistry. Topics relevant to materials science are also introduced in order to meet the more specific needs of engineering students. To integrate this material, simple organic structures, nomenclature, and reactions are introduced very early in the text, and both organic and inorganic examples are used wherever possible. This approach emphasizes the distinctions between ionic and covalent bonding, thus enhancing the students' chance of success in the organic chemistry course that traditionally follows general chemistry.

Our overall goal is to produce a text that introduces the students to the relevance and excitement of chemistry. Although much of first-year chemistry is taught as a service course, there is no reason that the intrinsic excitement and potential of chemistry cannot be the focal point of the text and the course. We emphasize the positive aspects of chemistry and its relationship to students' lives; this approach requires bringing in applications early and often. Unfortunately, we cannot assume that students in these courses today are highly motivated to study chemistry for its own sake. The explicit discussion of biological, environmental, and materials applications from a chemical perspective is intended to motivate the students and help them appreciate the relevance of chemistry to their lives. Material that has traditionally been relegated to boxes, and perhaps perceived as peripheral by the students, has been incorporated into the text to serve as a learning tool.

To begin the discussion of chemistry rapidly, the traditional first chapter introducing units, significant figures, conversion factors, dimensional analysis, and so on has been reorganized in this book. The material has been placed in the chapters where the relevant concepts are first introduced, thus providing three advantages: it eliminates the tedium of the traditional approach, which introduces mathematical operations at the outset, and thus avoids the perception that chemistry is a mathematics course; it avoids the early introduction of operations such as logarithms and exponents, which are typically not encountered again for several chapters and may easily be forgotten when they are needed; and it provides a review for those students who have already had relatively sophisticated high school chemistry and math courses, although the sections are designed primarily for students unfamiliar with the topics.

Our specific objectives include the following:

- To write the text at a level suitable for science majors, but using a less formal writing style that will appeal to modern students.
- To produce a *truly* integrated text that gives the student who takes only a single year of chemistry an overview of the most important subdisciplines of chemistry,

including organic, inorganic, biological, materials, environmental, and nuclear chemistry, thus emphasizing unifying concepts.

- To introduce fundamental concepts in the first two-thirds of the chapter and then applications relevant to the health sciences or engineers, thus providing a flexible text that can be tailored to the specific needs and interests of the audience.
- To ensure the accuracy of the material presented, which is enhanced by the authors' breadth of professional and research experience.
- To produce a spare, clean, uncluttered text that is not distracting to the student, one in which each piece of art serves as a pedagogical device.
- To introduce the distinction between ionic and covalent bonding and reactions early in the text, and to continue to build on this foundation in the subsequent discussions while emphasizing the relationship between structure and reactivity.
- To use established pedagogical devices to maximize students' ability to learn directly from the text. Copious worked examples in the text, problem-solving strategies, and similar unworked exercises with solutions are included. End-of-chapter problems are designed to ensure that students have grasped major concepts in addition to testing their ability to solve numerical problems. Problems emphasizing applications are drawn from many disciplines.
- To emphasize an intuitive and predictive approach to problem solving that relies on a thorough understanding of key concepts and recognition of important patterns rather than on memorization. Many patterns are indicated throughout the text by a "Note the Pattern" feature in the margin.

The text is organized by units that discuss introductory concepts, atomic and molecular structure, the states of matter, kinetics and equilibria, and descriptive inorganic chemistry. The text divides the traditional chapter on liquids and solids into two chapters in order to expand the coverage of important topics such as semiconductors and superconductors, polymers, and engineering materials. Part V, included in the complete edition of the text, is a systematic summary of the descriptive chemistry of the elements organized by position in the periodic table; it is designed to bring together the key concepts introduced in the preceding chapters: chemical bonding, molecular structure, kinetics, and equilibrium. A great deal of descriptive chemistry will have been introduced prior to this point, but only in ways that are germane to particular points of interest.

In summary, our hope is that this text represents a step in the evolution of the general chemistry textbook toward one that reflects the increasing overlap between chemistry and other disciplines. Most important, the text discusses exciting and relevant aspects of biological, environmental, and materials science that are usually relegated to the last few chapters, and it provides a format that allows the instructor to tailor the emphasis to the needs of the class. By the end of Part I (Chapter 5), the student will have been introduced to environmental topics such as acid rain, the ozone layer, and periodic extinctions, and to biological topics such as antibiotics and the caloric content of foods. Nonetheless, the new material is presented in a way that minimally perturbs the traditional sequence of topics in a first-year course, making the adaptation easier for instructors.

Supplements

A full set of print and media supplements is available for the student and the instructor, which are designed to enhance in-class presentations, to engage students in classroom discussion, and to assist students outside the classroom.

For the instructor:

Instructor Solutions Manual: Complete solutions to all of the end-of-chapter problems in the textbook.

Instructor Guide: Includes chapter overviews and outlines, suggestions for lecture demonstrations, teaching tips, and a guide to the print and media resources available for each chapter.

Test Bank (print and electronic formats): More than 1000 questions to use in creating tests, quizzes, and homework assignments.

Transparency Acetates: 300 full-color illustrations and tables to enhance classroom lectures.

Instructor Resource CD-ROM: All images and tables from the book in jpeg and PowerPoint format, a PowerPoint lecture outline for each chapter, Clicker Questions, interactive graphs, interactive 3-D molecular structures, and links to student resources online.

Clicker Questions (for use with Classroom Response Systems): Five questions per chapter written to inspire in-class discussion and test student understanding of material.

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Acknowledgments

Although putting a text together is always a team effort, there are several individuals at Benjamin Cummings whom we would like to particularly acknowledge for their tireless efforts and commitment to this project. We would especially like to thank the following individuals: Jim Smith for believing so strongly in this project; Kay Ueno for her superhuman efforts in the face of excruciating deadlines (we still have to get out for a sail!); Linda Davis, who, despite all the twists and turns, made sure that it happened; Sonia DiVittorio, whose enormous dedication and attention to detail produced a stellar art program, while keeping track of where everything was at any given time; and Moira Nelson, a truly impressive master of the American English language, who taught us that Los Angeles and Washington, D.C., aren't so different after all. Special thanks, too, are due to Neil Weinstein, who helped enormously in scrubbing the page proofs of errors and inconsistencies in data, and to Mike Helmstadter, whose expertise with Excel was crucial in generating many of the plots used in the figures. We would also like to thank the rest of the team at Benjamin Cummings for creating such a cordial and supportive environment despite the pressures of production.

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Reviewers

Several drafts of the manuscript were informed by the meticulous and considered comments of the instructors listed here. Their review of our work was invaluable to us as we polished the book. We acknowledge and thank them for their generous efforts on our behalf.

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Forum Participants

Beneficial to our crafting of this text have been the numerous Chemistry Forum participants, who took time to read and remark thoughtfully on our manuscript as it was in progress and share their ideas about the future of chemical education. Participants at the Chemistry Forums held in cities across the country include the following people:

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All of the end-of-chapter problems were examined for consistency, clarity, and relevance. We warmly thank the following instructors for their contributions. Their efforts helped us considerably.

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We welcome feedback from colleagues and students who use this text. Please send your comments to the Chemistry Editor, Benjamin Cummings, 1301 Sansome Street, San Francisco, California 94111.

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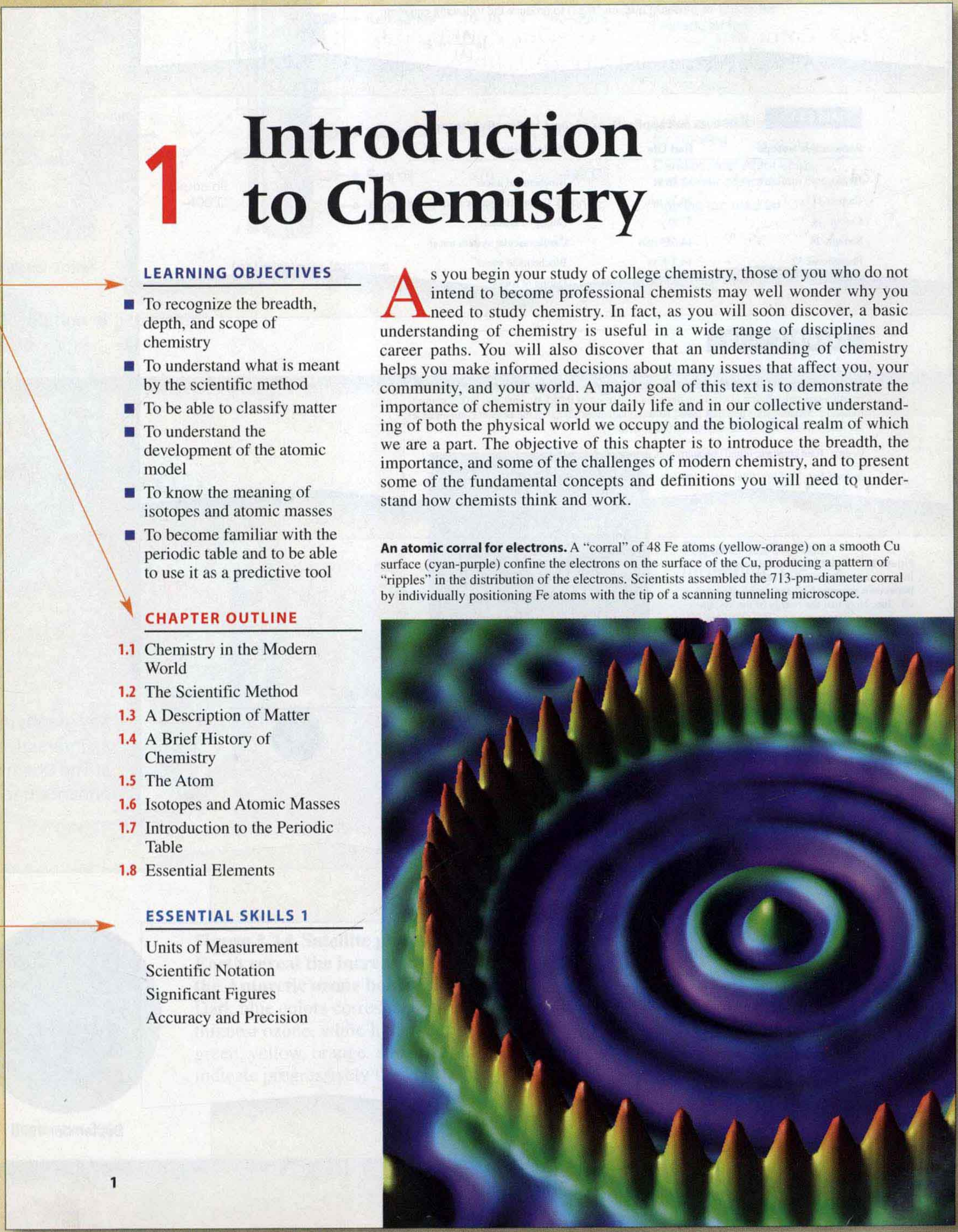
RELEVANT, INNOVATIVE, INFORMATIVE

Chemistry: Principles, Patterns, and Applications is rich in applications that make chemistry relevant to students' lives and provides an innovative approach to learning principles, recognizing patterns, and solving problems.

What the student needs to know

Chapter openers provide **Learning Objectives** and **Chapter Outlines**.

Selected chapters include **Essential Skill** sets, which help students build the requisite skills for understanding the equations and working the problems featured in the chapter.



1 Introduction to Chemistry

LEARNING OBJECTIVES

- To recognize the breadth, depth, and scope of chemistry
- To understand what is meant by the scientific method
- To be able to classify matter
- To understand the development of the atomic model
- To know the meaning of isotopes and atomic masses
- To become familiar with the periodic table and to be able to use it as a predictive tool

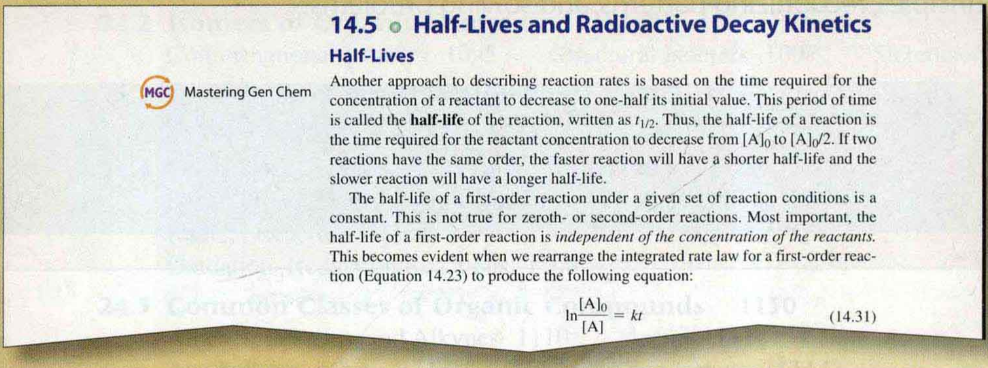
CHAPTER OUTLINE

ESSENTIAL SKILLS 1

As you begin your study of college chemistry, those of you who do not intend to become professional chemists may well wonder why you need to study chemistry. In fact, as you will soon discover, a basic understanding of chemistry is useful in a wide range of disciplines and career paths. You will also discover that an understanding of chemistry helps you make informed decisions about many issues that affect you, your community, and your world. A major goal of this text is to demonstrate the importance of chemistry in your daily life and in our collective understanding of both the physical world we occupy and the biological realm of which we are a part. The objective of this chapter is to introduce the breadth, the importance, and some of the challenges of modern chemistry, and to present some of the fundamental concepts and definitions you will need to understand how chemists think and work.

An atomic corral for electrons. A "corral" of 48 Fe atoms (yellow-orange) on a smooth Cu surface (cyan-purple) confine the electrons on the surface of the Cu, producing a pattern of "ripples" in the distribution of the electrons. Scientists assembled the 713-pm-diameter corral by individually positioning Fe atoms with the tip of a scanning tunneling microscope.

Contemporary applications embody modern chemistry ...



14.5 ∘ Half-Lives and Radioactive Decay Kinetics

Half-Lives

MGC Mastering Gen Chem

Another approach to describing reaction rates is based on the time required for the concentration of a reactant to decrease to one-half its initial value. This period of time is called the **half-life** of the reaction, written as $t_{1/2}$. Thus, the half-life of a reaction is the time required for the reactant concentration to decrease from $[A]_0$ to $[A]_0/2$. If two reactions have the same order, the faster reaction will have a shorter half-life and the slower reaction will have a longer half-life.

The half-life of a first-order reaction under a given set of reaction conditions is a constant. This is not true for zeroth- or second-order reactions. Most important, the half-life of a first-order reaction is *independent of the concentration of the reactants.* This becomes evident when we rearrange the integrated rate law for a first-order reaction (Equation 14.23) to produce the following equation:

$$\ln\frac{[A]_0}{[A]} = kt \qquad (14.31)$$

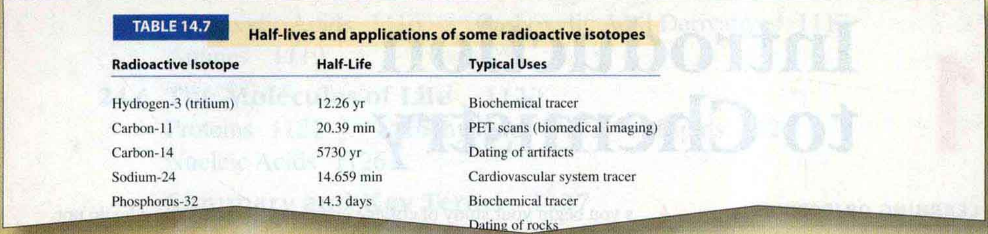
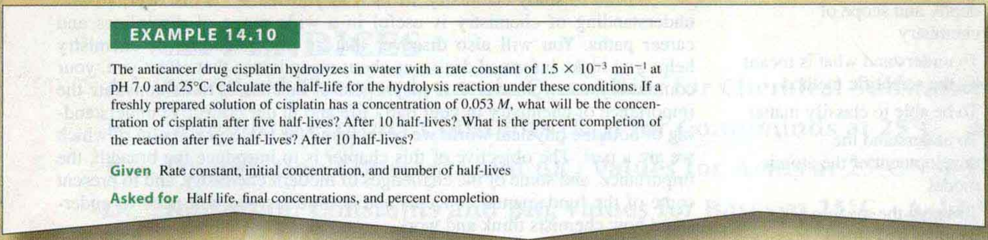


TABLE 14.7 Half-lives and applications of some radioactive isotopes

Radioactive Isotope	Half-Life	Typical Uses
Hydrogen-3 (tritium)	12.26 yr	Biochemical tracer
Carbon-11	20.39 min	PET scans (biomedical imaging)
Carbon-14	5730 yr	Dating of artifacts
Sodium-24	14.659 min	Cardiovascular system tracer
Phosphorus-32	14.3 days	Biochemical tracer
		Dating of rocks



EXAMPLE 14.10

The anticancer drug cisplatin hydrolyzes in water with a rate constant of 1.5×10^{-3} min^{-1} at pH 7.0 and 25°C. Calculate the half-life for the hydrolysis reaction under these conditions. If a freshly prepared solution of cisplatin has a concentration of 0.053 *M*, what will be the concentration of cisplatin after five half-lives? After 10 half-lives? What is the percent completion of the reaction after five half-lives? After 10 half-lives?

Given Rate constant, initial concentration, and number of half-lives

Asked for Half life, final concentrations, and percent completion

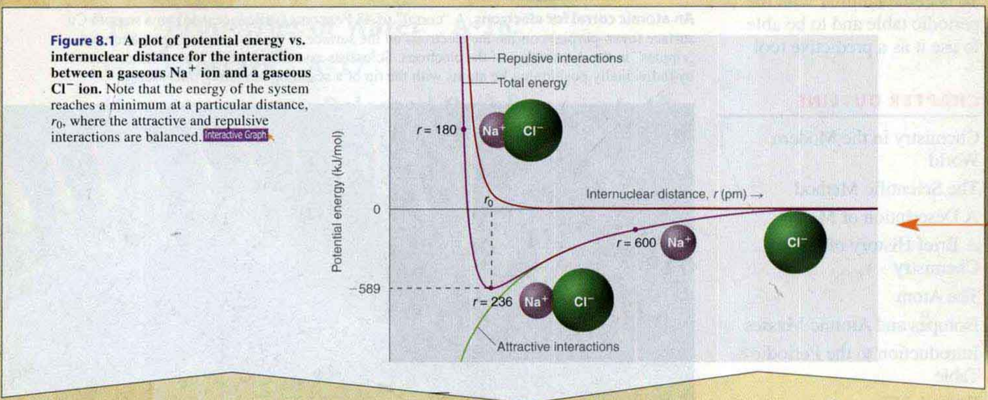
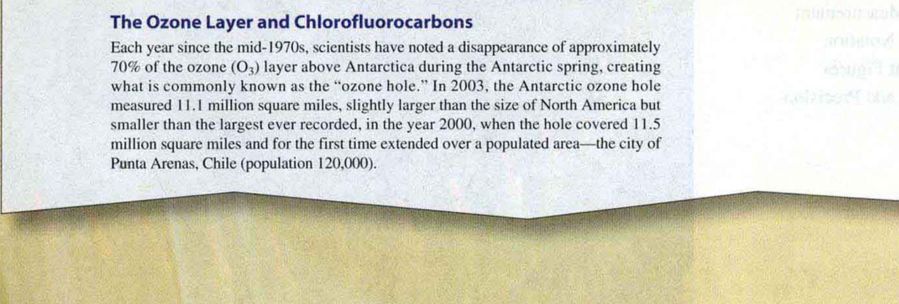


Figure 8.1 A plot of potential energy vs. internuclear distance for the interaction between a gaseous Na^+ ion and a gaseous Cl^- ion. Note that the energy of the system reaches a minimum at a particular distance, r_0, where the attractive and repulsive interactions are balanced. Interactive Graph

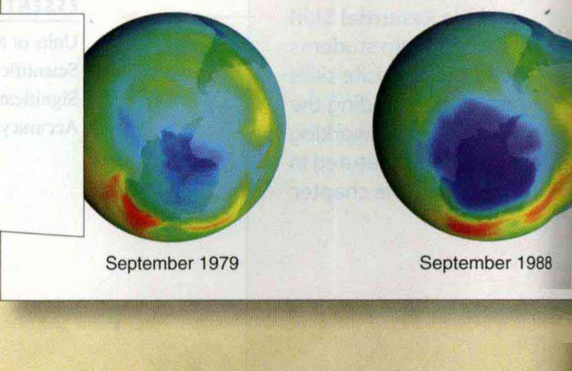
Key graphs are provided in an interactive format online at The Chemistry Place to enhance understanding.

Contemporary applications in text discussions, illustrations, worked examples, and problem sets ...



The Ozone Layer and Chlorofluorocarbons

Each year since the mid-1970s, scientists have noted a disappearance of approximately 70% of the ozone (O_3) layer above Antarctica during the Antarctic spring, creating what is commonly known as the "ozone hole." In 2003, the Antarctic ozone hole measured 11.1 million square miles, slightly larger than the size of North America but smaller than the largest ever recorded, in the year 2000, when the hole covered 11.5 million square miles and for the first time extended over a populated area—the city of Punta Arenas, Chile (population 120,000).



September 1979

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