GENERAL CHEMISTRY
ATOMS FIRST

SECOND EDITION

John E. McMurry
Robert C. Fay

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SECOND EDITION

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PEARSON

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PEARSON

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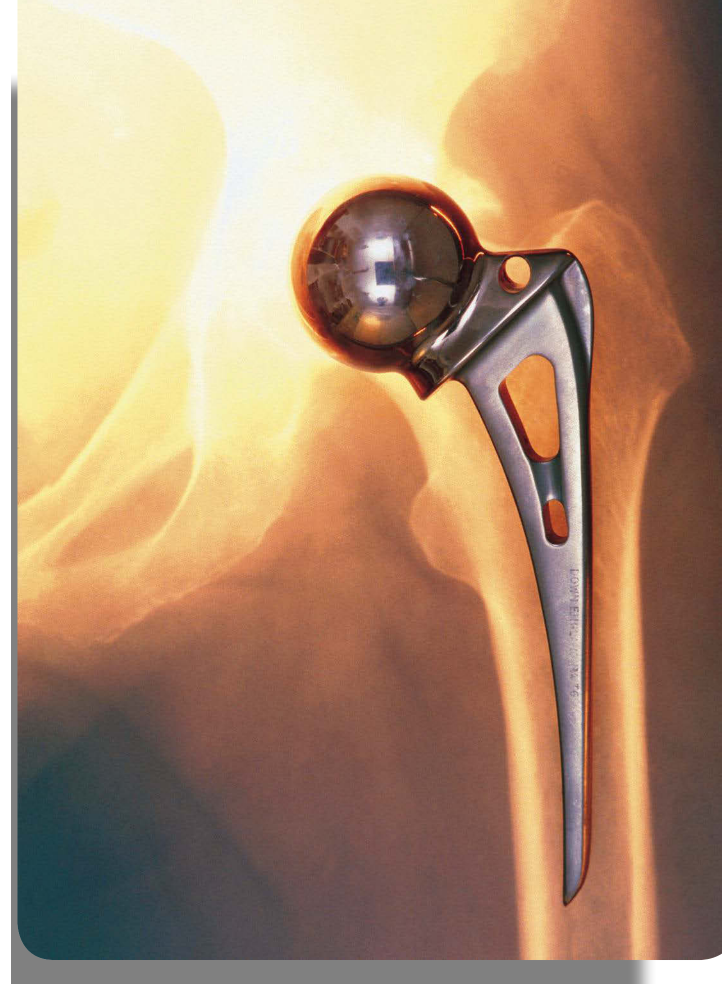
Brief Contents

Contents



20 Transition Elements and Coordination Chemistry 814

21 Metals and Solid-State Materials 866

22 Nuclear Chemistry 904

23 Organic and Biological Chemistry 926

Preface

Our primary purpose in writing this book has been to fashion a clear and cohesive introduction to chemistry, covering both important principles and important facts. We write to explain chemistry to students today the way we wish it had been explained to us years ago when we were students ourselves. We can't claim that learning chemistry will always be easy, but we *can* promise that we have done our best in planning, writing, and illustrating this book to make the learning process as smooth as possible.

Perhaps the first thing you will notice about this book is that its organization is different from that of other general chemistry textbooks. Rather than follow the typical ordering of topics, in which stoichiometry and aqueous reactions come first, this book takes what has come to be called an atoms-first approach. Instead of launching immediately into stoichiometry, we start at the logical beginning of the chemical story by discussing *atoms*—their history, stability, electronic structure, and consequent periodicity. This approach makes it possible to tell a cohesive story about chemistry that follows an intuitive logic in progressing from the simplest building blocks to successively more complex concepts.

Once atoms have been fully described in Chapters 1 and 2, we proceed next to discuss how and why atoms bond together to make chemical compounds. Ion formation and ionic bonding come first, in Chapter 3, followed by covalent bonding and the structures of molecules in Chapters 4 and 5. This organization takes students immediately into real chemistry rather than making them first spend time with chemical arithmetic. Only then, when all the fundamental pieces are in place, are chemical reactions and stoichiometric mass relationships introduced in Chapters 6 and 7.

At this point in the narrative, the ordering of topics becomes more familiar, starting with thermochemistry and chemical energy (Chapter 8), moving to bulk properties of pure substances (Chapters 9–10), and continuing with the properties of solutions (Chapter 11) and with all the topics necessary for a study of chemical transformations: kinetics, equilibrium, thermodynamics, and electrochemistry (Chapters 12–17). Then, in Chapters 18–21, the concepts described in earlier chapters are applied to discussing the chemistry of main-group and transition elements, metals, and modern solid-state materials. The book ends with a chapter devoted to nuclear transformations followed by a brief look at organic and biological chemistry.

It's important to note that our atoms-first approach is not the same thing as 'theory first.' Science nearly always begins with observation and experiment, and only later are theories developed to explain observations. While we begin with atoms and move on logically to increasing complexity, we do not put theory before experiment. For instance, we do not put the kinetic-molecular theory before the gas laws or the collision theory before rate laws. Our objective throughout is to present chemistry in the way that science actually works.

To help students succeed in learning chemistry, we have put extraordinary effort into this book. Transitions between topics are smooth, explanations are lucid, and reminders of earlier material are frequent. Insofar as possible, distractions within the text are minimized. Each chapter is broken into numerous sections to provide frequent breathers, and each section has a consistent format. Sections generally begin with an explanation of their subject, move to a Worked Example that shows how to solve problems, and end with one or more Problems for the reader to work through. Each chapter ends with a brief *FYI* (including five that are new to this edition) that describes an interesting application or extension of the chapter topic. Throughout the book, every attempt has been made to explain chemistry in a visual and intuitive way so that it can be understood by all who give it an honest effort.

NEW TO THE SECOND EDITION

In preparing this second edition, we have reworked the entire book at the sentence level and made many hundreds of alterations, updates, and reviewer-requested reorganizations to make it as easy as possible for our readers to understand and learn chemistry. In addition, a number of more substantial changes and rewrites have been made. Among the more important are the following:

- *Chapter 0 — Chemical Tools; Experimentation and Measurement* One of the most commonly voiced complaints about General Chemistry texts is that they begin with a chapter on units and measurement. Many students, however, learned this material in high school and are immediately bored, while many others have to struggle. This book takes a new approach to the problem by beginning with the eye-catching number, Chapter 0. Chapter 0 is a real chapter like any other, but its numbering clearly lets people know that it covers preliminary material to bring students who need it up to speed while letting others bypass it if they choose.
- *Chapter 1 — The Structure and Stability of Atoms* This first chemical chapter in the book is completely focused on covering *atoms.* It contains introductory material about elements, the periodic table, atomic structure, and atomic weights. Nuclear Chemistry is also briefly introduced in Chapter 1 and followed with a thorough treatment in Chapter 22.
- *Chapter 4 — Atoms and Covalent Bonds* and *Chapter 5 — Covalent Bonds and Molecular Structure* Coverage of covalent bonding and molecular structure has been broken into two chapters in this new edition to make the subject less intimidating and slow the pace of the discussion.
- *Chapter 18 — Hydrogen, Oxygen and Water* The chapter has been streamlined throughout, and the former Sections 18.2 and 18.14 on hydrogen isotopes and the reactivity of water have been deleted in this second edition.
- *Chapter 19 — Main-Group Elements* The chapter has been shortened by removing the former Section 19.9 on germanium, tin, and lead and eliminating the previous coverage of polyphosphoric acids.
- *Chapter 22 — Nuclear Chemistry* This new chapter has been added to the second edition at the request of users. It provides a cohesive discussion of nuclear reactions, fission, fusion, nuclear transmutation, and applications of nuclear chemistry, building on the brief introduction to nuclear chemistry provided in Chapter 1.
- *Chapter 23 — Organic and Biological Chemistry* The former Chapter 22 on organic chemistry in the first edition has been tightened in its previous coverage and expanded to provide new coverage of the major classes of biomolecules—amino acids, peptides, proteins, carbohydrates, lipids, and nucleic acids.
- The art in this new edition has been improved in many ways to make the numbered figures more self-contained, informative, and easily read:
  - Numbered figures are placed in an unobtrusive shadow box to make them more clearly distinguished.
  - **Figure** and **Table** references in the text are called out in bold color so that it's easy to find the text corresponding to a given figure or table.
  - Internal art captions in figures are set off in a different font from art labels so that students can more readily grasp the main points of each illustration.
  - Numerous small explanations are placed directly on the relevant parts of the figures themselves instead of having long captions beneath figures. The effect is to make the text flow naturally into the figures and thereby entice readers to spend more time understanding those figures.
  - Important text within the illustrations is color-coded to focus attention on it.
- More than 250 **NEW** problems have been added throughout the text to help build students' problem-solving skills and conceptual understanding of chemistry.
- **Remember...** notes are placed in the margin to help students connect concepts from previous chapters to current material. In addition, important forward references are also called out, with the subject described in the adjacent margin under the heading **Looking Ahead…**
- Lists of Learning Outcomes keyed to problem numbers and relevant Key Equations have been added to every chapter.

- Just as important as the addition of new material and features is that the best features of the previous edition have been retained:
  - The design remains spacious, readable, and unintimidating.
  - The writing style remains clear and concise.
  - Worked problems are identified by subject and are immediately followed by a similar problem for students to solve.
  - Each chapter ends with a summary, a list of key words with accompanying page references, and a large set of end-of-chapter problems.
  - Most end-of-chapter problems are classified by text section and paired by topic. These are followed by a group of unclassified Chapter Problems and a final set of Multiconcept Problems, which draw on and connect concepts from several chapters.
  - Extensive use of visual, non-numerical, Conceptual Problems continues, both within and at the ends of chapters. These Conceptual Problems, which test the understanding of principles rather than the ability to put numbers into a formula, have been a hallmark of this text since the first edition. Don't make the mistake of thinking that these problems are simple just because they don't have numbers. Many are real challenges that will test the ability of any student.
  - Ballpark Checks follow many of the Worked Examples to reinforce students' conceptual understanding and give them confidence that they have arrived at the right answer.

We sincerely hope that this new edition will meet the goals we have set for it and that both students and faculty will find it to be friendly, accessible, and above all effective in teaching chemistry.

ACKNOWLEDGEMENTS

Our thanks go to our families and to the many talented people who helped bring this new edition into being. In addition, we are grateful to Terry Haugen, Senior Acquisitions Editor, and Coleen Morrison, Assistant Editor, for their insights and suggestions that improved the book, to Jonathan Cottrell, Senior Marketing Manager, who brought new energy to marketing the second edition, to Carol Pritchard-Martinez for her work in improving the art program and manuscript development, to Beth Sweeten and Gina Cheselka for their production efforts, and to Eric Schrader for his photo research.

We are particularly pleased to acknowledge the outstanding contributions of several colleagues who created the many important supplements that turn a textbook into a complete package:

- Lee Don Bienski at Blinn College, who updated the accompanying Test Bank
- Dennis Taylor at Clemson University, who updated the Instructor Resource Manual
- Joseph Topich at Virginia Commonwealth University, who prepared both the full and partial solutions manuals
- Mingming Xu at West Virginia University and Donald Linn at Indiana University–Purdue University Fort Wayne, who contributed valuable content for the Instructor Resource DVD
- Stephanie Dillon at Florida State University and Sandra Chimon-Peszek at DePaul University, who prepared a dedicated Atoms First Lab Manual to accompany the text.
- Amina El-Ashmawy and Dawn Richardson from Collin County Community College and Margie Haak from Oregon State University for consultation on writing the MasteringChemistry tutorials to reflect an atoms-first approach.

In addition, we are grateful to Mingming Xu, Donald Linn, and David Boatright of the University of West Georgia for error checking the entire text. And finally, we want to thank our colleagues at so many other institutions who read, criticized, and improved our work.

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Supplements

FOR THE STUDENT

MasteringChemistry® with Pearson eText. MasteringChemistry® from Pearson has been designed and refined with a single purpose in mind: to help educators create that moment of understanding with their students. The Mastering online homework and tutoring system delivers self-paced tutorials that provide individualized coaching, focus on your course objectives, and are responsive to each student's progress. The Mastering system helps instructors maximize class time with customizable, easy-to-assign, and automatically graded assessments that motivate students to learn outside of class and arrive prepared for lecture. By complementing their teaching with our engaging technology and content, instructors can be confident their students will arrive at that moment—the moment of true understanding.

Student Solutions Manual (0321813324) by Joseph Topich, Virginia Commonwealth University. This manual for students contains solutions to all in-chapter problems and even-numbered end-of-chapter problems.

Lab Manual (0321813375) by Stephanie Dillon, Florida State University, and Sandra Chimon-Peszek, DePaul University. This laboratory manual contains experiments written specifically to correspond with the Second Edition of General Chemistry: Atoms First by McMurry/Fay. Each experiment covers one or more topics discussed within a chapter of the textbook, with the dual goal of 1) helping students understand the underlying concepts covered in the lecture course, and 2) staying true to an atoms-first approach. This manual contains 31 experiments with a focus on real-world applications and a dedication to the atoms-first approach. Each experiment contains a set of pre-laboratory questions (also assignable in MasteringChemistry), an introduction, a background section explaining concepts that each student is expected to master for a full understanding of the experimental results, a step-by-step procedure (including safety information), and a report section featuring post-laboratory questions.

FOR THE INSTRUCTOR

MasteringChemistry® with Pearson eText. MasteringChemistry® from Pearson has been designed and refined with a single purpose in mind: to help educators create that moment of understanding with their students. The Mastering online homework and tutoring system delivers self-paced tutorials that provide individualized coaching, focus on your course objectives, and are responsive to each student's progress. The Mastering system helps instructors maximize class time with customizable, easy-to-assign, and automatically graded assessments that motivate students to learn outside of class and arrive prepared for lecture. By complementing their teaching with our engaging technology and content, instructors can be confident their students will arrive at that moment—the moment of true understanding.

MasteringChemistry® updates include:

- **NEW! 15 Pause and Predict Video Quizzes** bring chemistry to life with lab demonstrations illustrating key topics in general chemistry. Students are asked to predict the outcome of experiments as they watch the videos; a set of multiple-choice questions challenges students to apply the concepts from the video to related scenarios.
- **NEW! 10 PhET tutorials** have been developed around interactive applets that foster conceptual understanding and active learning. Topics include acid–base solutions, balancing chemical equations, and molecular polarity.
    - **Multiple-choice Reading Questions** are provided for each chapter, making it easy to hold students accountable for doing assigned readings before lecture.

- **Approximately 500 end-of-chapter questions are new or revised** and are supported by the tutorial questions in MasteringChemistry. The overall number of algorithmic and randomized problems has also been increased for the new edition.
- **All tutorials, end-of-chapter questions, reading quizzes, and test bank questions have been tagged to learning outcomes.**
- **A set of new and revised MasteringChemistry tutorials** has been developed to support the authors' atoms-first philosophy
- NEW! A dedicated atoms-first lab manual with pre-lab/post-lab question has been added to allow successful implementation of this approach with assignable questions in MasteringChemistry,

Instructor Solutions Manual (0321813057) by Joseph Topich, Virginia Commonwealth University. This solutions manual provides worked-out solutions to all in-chapter and end-of-chapter questions and problems. With instructor's permission, this manual may be made available to students.

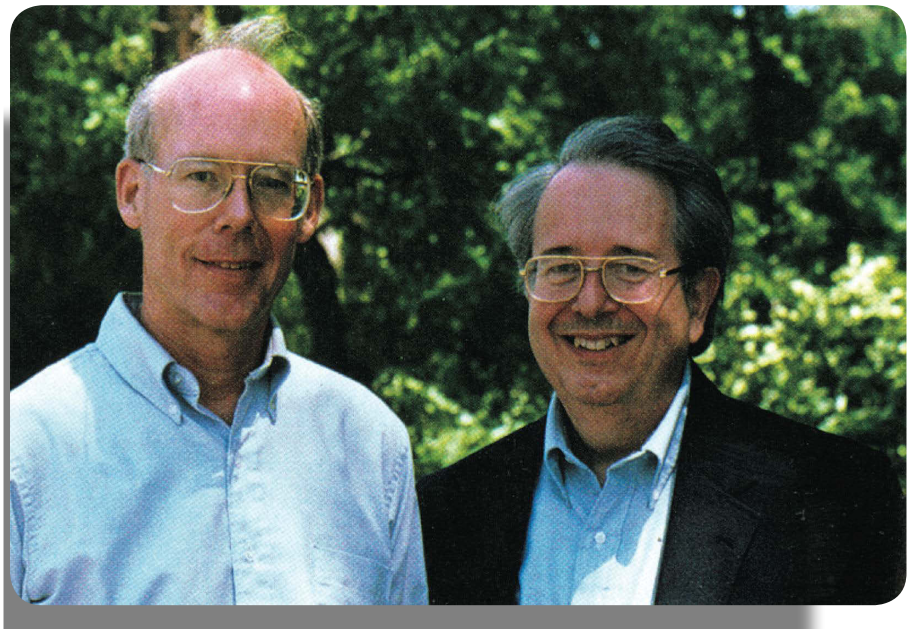
Test Bank (download only) (0321813049) by Lee Don Bienski, Blinn College. The test bank is downloadable directly from the Intstructor Resource Center in either Microsoft Word or TestGen formats and contains nearly 4000 multiple-choice questions

Instructor Resource Manual (0321813359) by Dennis Taylor, Clemson University. This Manual contains teaching tips, a list of common misconceptions, lecture outlines, and suggested chapter learning goals for students, as well as lecture/laboratory demonstrations and literature references. It also describes various resources, such as printed test bank questions, animations, and movies that are available to instructors.

Instructor's Resource DVD (0321813332). This IRDVD provides an integrated collection of resources designed to enhance your classroom lectures. The IRDVD contains all illustrations, tables and photos from the text in JPEG and PDF format. The DVD also includes four pre-built PowerPoint™ Presentations (lecture, worked examples, images, clicker questions), the Instructor Resource Manual, and interactive animations, movies and 3D molecules. Also included are word files and the TestGen computerized software with the TestGen version of the test bank.

Instructor Manual to the Lab Manual (0321813693) by Stephanie Dillon, Florida State University, and Sandra Chimon-Peszek, DePaul University. The Instructor Manual guides the instructor through the process of planning, setting up, and teaching each laboratory exercise. For each exercise, instructors can quickly and easily reference a master list of materials for ordering supplies, an approximate time frame for completing each exercise, a series of tips on preparation, and an answer key for all of the student activities and questions within the text.

About the Authors



John McMurry (*left*), educated at Harvard and Columbia, has taught more than 20,000 students in general and organic chemistry over a 40-year period. An Emeritus Professor of Chemistry at Cornell University, Dr. McMurry previously spent 13 years on the faculty at the University of California at Santa Cruz. He has received numerous awards, including the Alfred P. Sloan Fellowship (1969–71), the National Institute of Health Career Development Award (1975–80), the Alexander von Humboldt Senior Scientist Award (1986–87), and the Max Planck Research Award (1991). With the publication of this new edition, he has authored or coauthored 36 textbooks in various fields of chemistry.

Robert C. Fay (*right*), Professor Emeritus of Chemistry at Cornell University, has taught general and inorganic chemistry at Cornell for 45 years, beginning in 1962. Known for his clear, well-organized lectures, Dr. Fay was the 1980 recipient of the Clark Distinguished Teaching Award. He has also taught as a visiting professor at Harvard University and the University of Bologna (Italy). A Phi Beta Kappa graduate of Oberlin College, Dr. Fay received his Ph.D. from the University of Illinois. He has been an NSF Science Faculty Fellow at the University of East Anglia and the University of Sussex (England) and a NATO/Heineman Senior Fellow at Oxford University.

Understanding the Cohesive Story of Chemistry:

Friends,

Our primary purpose in writing this text is to explain chemistry to students today the way we wish it had been explained to us years ago, when we were students.

The great advantage of an atoms-first organization is that **it allows us to start at the logical beginning of the chemical story by discussing atoms**—their history, stability, electronic structure, and consequent periodicity—and then continue on to bonding and reactions.

We are particularly grateful to the many instructors with experience teaching from our book who took the time to tell us how they adjusted to the organization of an atoms-first text and **helped their students appreciate connections between topics.**

- The second edition begins with Chapter 0 Chemical Tools: Experimentation and Measurement to bring students with widely diverse backgrounds up to speed on the topics of units and measurements so that Chapter 1 can focus entirely on atoms and elements.
- Chapter 2 then presents atomic structure and periodicity, which allows for a seamless transition to learning in Chapters 3–5.
- Chapters 3-5 show how atoms join to form chemical compounds. As a result, students come to see the various kinds of bonding as a continuum of atomic interactions. Our coverage of bonding models is distinguished by many well-received molecular drawings and conceptual problems.
- Chapters 6 and 7 introduce reaction chemistry in response to requests from coordinators of accompanying laboratory courses.

The changes to the Second Edition have been made with the goal of creating a unified thread of ideas that helps students build a better foundation and gain a deeper understanding of the chapters that follow.

As you strive to help your students establish an appreciation and understanding of general chemistry, we hope you will consider using this book in your endeavors.

Sincerely,
John McMurry and Bob Fay

The great advantage of an atoms-first organization is that it allows us to start at the logical beginning of the chemical story by discussing atoms—their history, stability, electronic structure, and consequent periodicity—and then continue on to bonding and reactions.

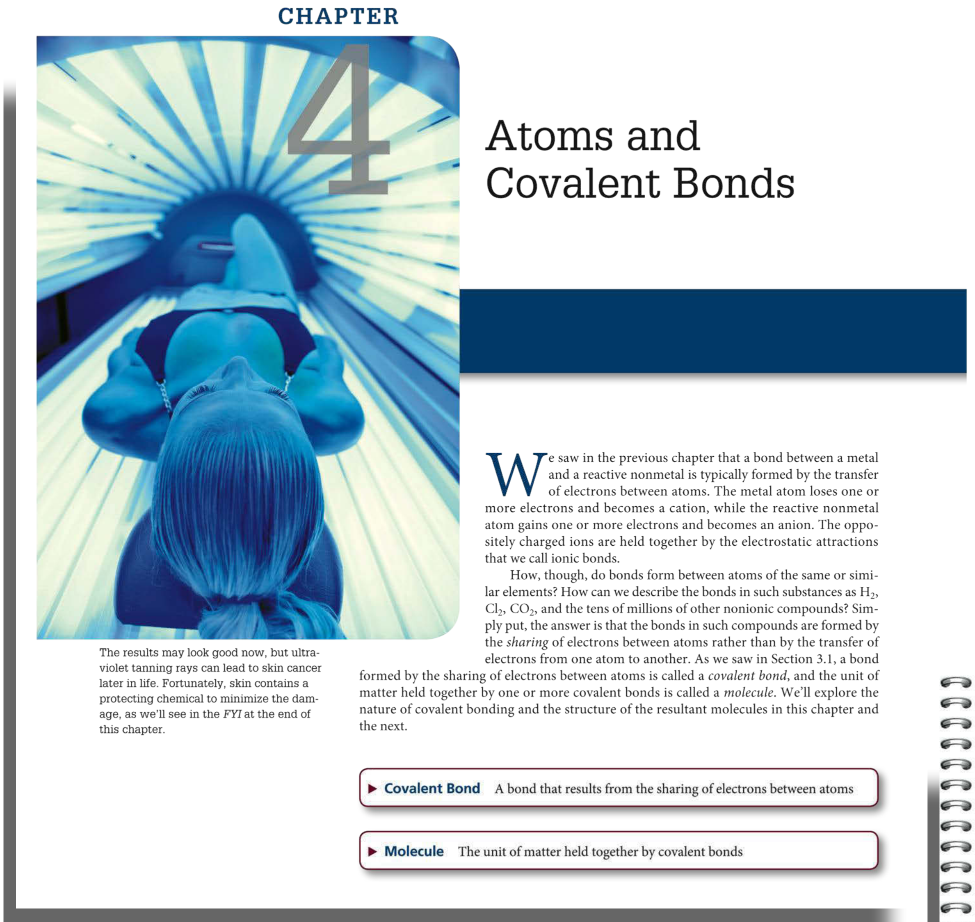
Annotated Table of Contents
Chapters 1– 7: Atoms-First Chapters

Chapters 1 and 2 start at the logical beginning of the chemical story by discussing atoms—their history, stability, electronic structure, and consequent periodicity. Nuclear Chemistry is briefly introduced in Chapter 1.

In this edition, chapters 4 and 5 have been split into two chapters to slow the pace and make these topics less intimidating.

Stoichiometric mass relationships are introduced in Chapters 6. After the foundation has been set in Chapters 1–6, Chapter 7 follows with chemical reactions in aqueous solutions.

The Atoms First Approach



CHAPTER 4

Atoms and Covalent Bonds

The results may look good now, but ultraviolet tanning rays can lead to skin cancer later in life. Fortunately, skin contains a protecting chemical to minimize the damage, as we'll see in the *FYI* at the end of this chapter.

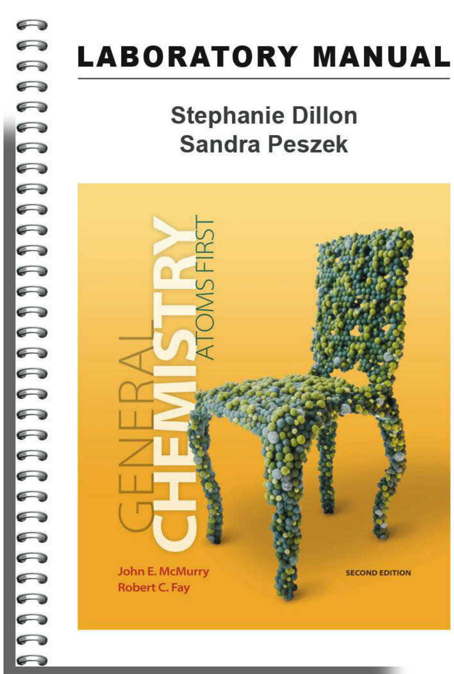
We saw in the previous chapter that a bond between a metal and a reactive nonmetal is typically formed by the transfer of electrons between atoms. The metal atom loses one or more electrons and becomes a cation, while the reactive nonmetal atom gains one or more electrons and becomes an anion. The oppositely charged ions are held together by the electrostatic attractions that we call ionic bonds.

How, though, do bonds form between atoms of the same or similar elements? How can we describe the bonds in such substances as H_2, Cl_2, CO_2, and the tens of millions of other nonionic compounds? Simply put, the answer is that the bonds in such compounds are formed by the *sharing* of electrons between atoms rather than by the transfer of electrons from one atom to another. As we saw in Section 3.1, a bond formed by the sharing of electrons between atoms is called a *covalent bond*, and the unit of matter held together by one or more covalent bonds is called a *molecule*. We'll explore the nature of covalent bonding and the structure of the resultant molecules in this chapter and the next.

▶ **Covalent Bond** A bond that results from the sharing of electrons between atoms

▶ **Molecule** The unit of matter held together by covalent bonds

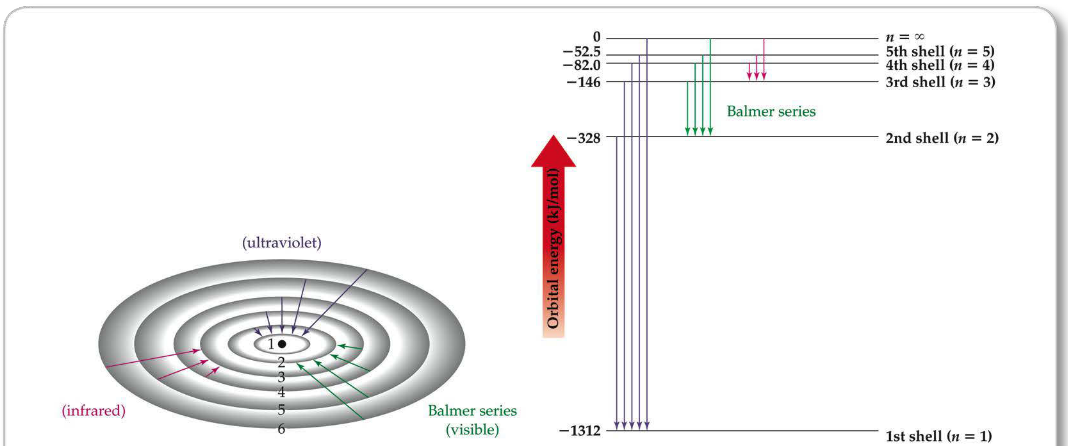
Chapter Openers employ a conceptual approach by telling the story of chemistry. Openers are followed by learning objectives that focus students on key concepts.



NEW! Author-written lab manual reflects the text's atoms-first approach with 28 experiments focusing on real-world applications.

Seeing chemical concepts in contex

Numerous example types are incorporated throughout the text to help build students' problem-solving skills and a conceptual understanding of chemistry.



When an electron falls from a higher-energy outer-shell orbital to a lower-energy inner-shell orbital, it emits electromagnetic energy whose frequency corresponds to the energy difference between the orbitals.

The different spectral series correspond to electronic transitions from outer-shell orbitals to different inner-shell orbitals.

Clear **quantitative examples** help students make the connection between chemical reasoning and math.

Looking Ahead feature helps students more logically link key concepts, while **Remember**... margin notes jog their memories on related topics from previous chapters.

REMEMBER...

Lattice energy (U) is the amount of energy that must be supplied to break an ionic solid into its individual gaseous ions and is thus a measure of the strength of the solid's ionic bonds. (Section 3.10)

LOOKING AHEAD...

The bulk materials we see in everyday life are usually solids or liquids rather than gases. In **Chapter 10**, we'll look at the forces that operate between molecules to hold them in close contact and at the resultant melting and boiling processes that happen when the forces are overcome.

A multi-layered approach to problem solving

Worked Conceptual Examples follow many worked examples to emphasize the conceptual nature of problem solving, often using molecular illustrations.

Worked Example 6.5

Converting Mass to Moles

How many moles of sucrose are in a tablespoon of sugar containing 2.85 g? (The molar mass of sucrose, $C_{12}H_{22}O_{11}$, was calculated in Worked Example 6.4 to be 342.0 g/mol)

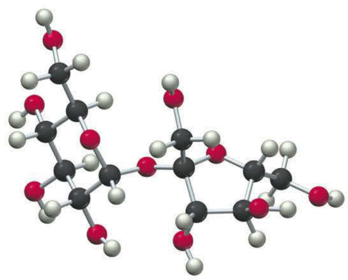
STRATEGY

The problem gives the mass of sucrose and asks for a mass-to-mole conversion. Use the molar mass of sucrose as a conversion factor, and set up an equation so that the unwanted unit cancels.

SOLUTION

$$2.85\ \cancel{\text{g sucrose}} \times \frac{1\ \text{mol sucrose}}{342.0\ \cancel{\text{g sucrose}}} = 0.008\ 33\ \text{mol sucrose}$$

$$= 8.33 \times 10^{-3}\ \text{mol sucrose}$$



Sucrose

✔ BALLPARK CHECK

Because the molecular weight of sucrose is 342.0, 1 mol of sucrose has a mass of 342.0 g. Thus, 2.85 g of sucrose is a bit less than one-hundredth of a mole, or 0.01 mol. The estimate agrees with the detailed solution.

Ballpark Checks follow many worked examples to reinforce students' conceptual understanding of the concept just expressed numerically.

PROBLEM 3.11 Which atom or ion in each of the following pairs would you expect to be larger? Explain.

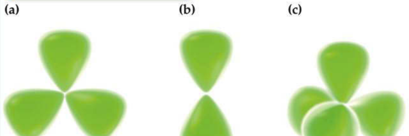
(a) O or O^{2-} **(b)** O or S **(c)** Fe or Fe^{3+} **(d)** H or H^-

CONCEPTUAL PROBLEM 3.12 Which of the following spheres represents a K^+ ion, which a K atom, and which a Cl^- ion?

r = 227 pm r = 184 pm r = 133 pm

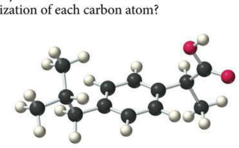
CONCEPTUAL PROBLEM 5.11 Identify each of the following sets of hybrid orbitals:

(a) (b) (c)



CONCEPTUAL PROBLEM 5.12 The following ball-and-stick molecular model is a representation of ibuprofen, a nonprescription drug used for minor pain and inflammation. Only the connections between atoms are shown, not whether the bonds are single, double, or triple (red = O, gray = C, ivory = H).

(a) Indicate the positions of the multiple bonds and lone pairs in ibuprofen.
(b) What is the geometry around each carbon atom?
(c) What is the hybridization of each carbon atom?



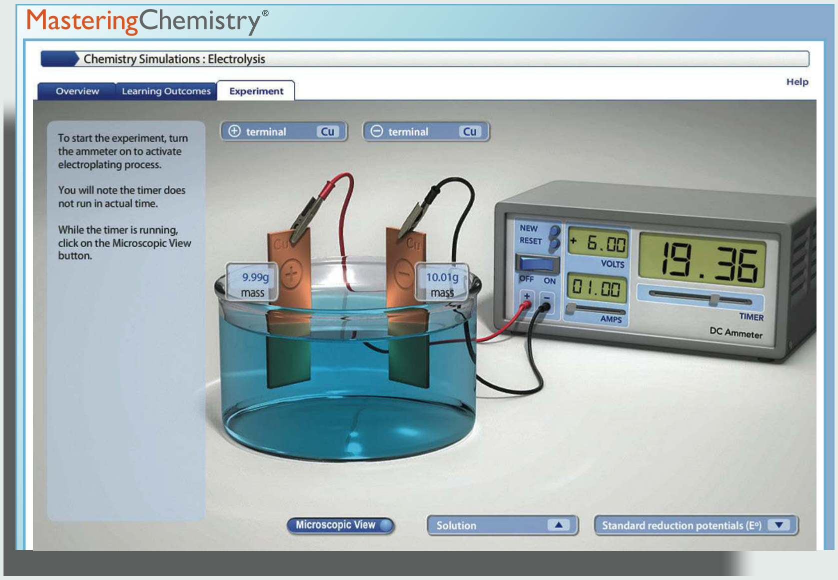
Ibuprofen

Non-numerical **Concept Problems** measure understanding of principles rather than the ability to simply plug numbers into a formula.

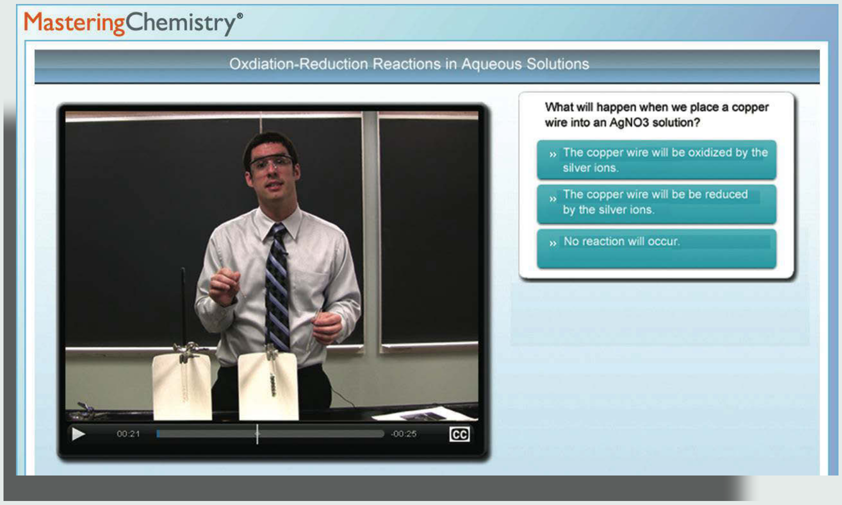
MasteringChemistry®

MasteringChemistry provides dynamic, engaging experiences that personalize and activate learning for each student, delivering self-paced tutorials that provide students with individualized coaching set to your course objectives. MasteringChemistry helps students arrive better prepared for lecture and lab.

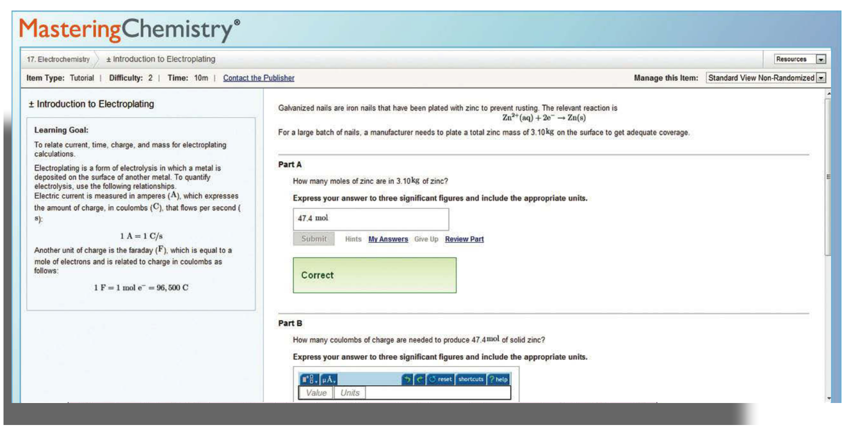
Engaging Experiences



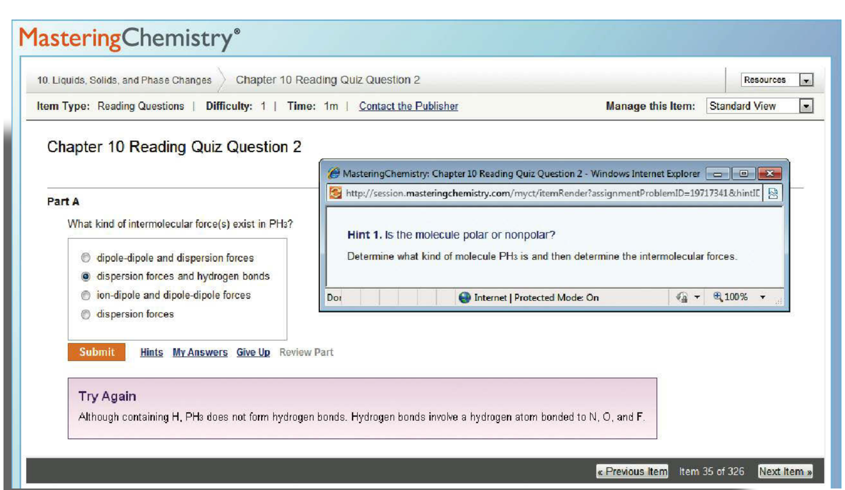
NEW! Visualizations are tutorials that enable students to make connections between real-life phenomena and the underlying chemistry that explains such phenomena. The tutorials increase students' understanding of chemistry and clearly illustrate cause-and-effect relationships and include Interactive Simulations.



NEW! 15 Pause and Predict Video Quizzes bring chemistry to life with lab demonstrations illustrating key topics in general chemistry. Students are asked to predict the outcome of experiments as they watch the videos; a set of multiple-choice questions challenges students to apply the concepts from the video to related scenarios.



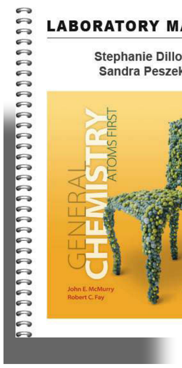
NEW! MasteringChemistry tutorials have all been evaluated and in many cases edited, revised or rewritten by an advisory board of expert chemists, all teaching with the atoms-first approach, to ensure the reinforcement of this approach.



NEW! Multiple-choice Reading Questions are provided for each chapter, making it easy to hold students accountable for doing assigned readings before lecture.

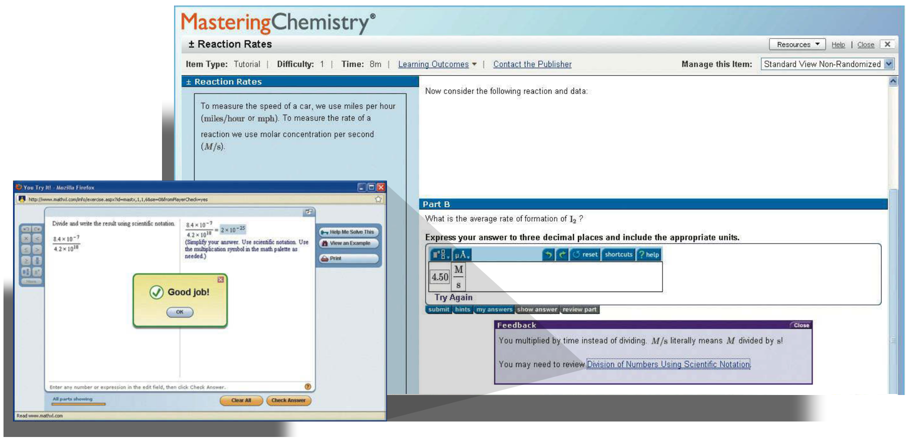
MasteringChemistry®

The new atoms-first lab manual is integrated with MasteringChemistry through assignable pre-laboratory questions for each experiment.



NEW! A dedicated atoms-first lab manual written by authors teaching with this approach reflects the changes needed to successfully integrate the lab with the course. Each experiment covers one or more topics discussed within a chapter of the textbook, helping students understand the underlying concepts covered in the lecture course and staying true to an Atoms First Approach.

The lab manual features 28 experiments that focus on real-world applications. Experiments include an introduction, a background section explaining concepts that each student is expected to master for a full understanding of the experimental results, a step-by-step procedure (including safety information), and a report section featuring post-laboratory questions.



Math Remediation links found in selected tutorials launch algorithmically generated math exercises that give students unlimited opportunity for practice and mastery of math skills. Math Remediation exercises provide additional practice and free up class and office-hour time to focus on the chemistry. Exercises include guided solutions, sample problems, and learning aids for extra help, and offer helpful feedback when students enter incorrect answers.

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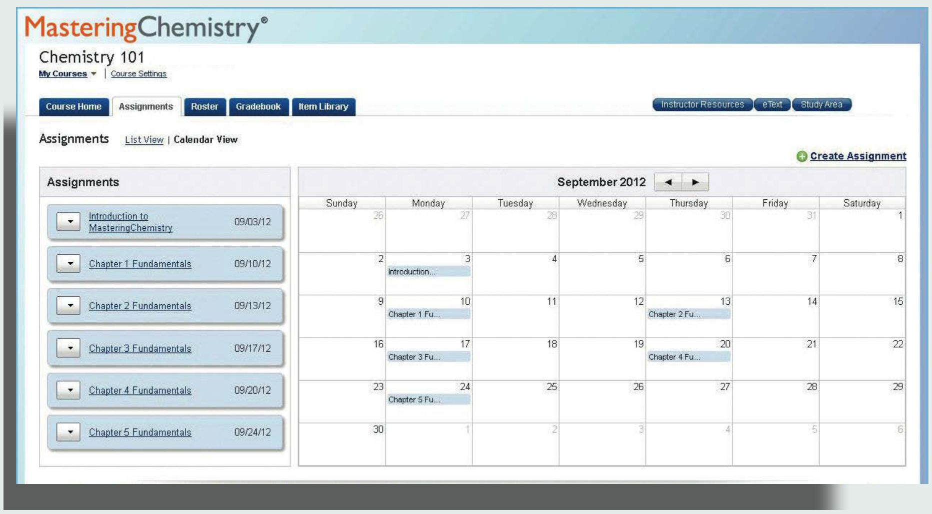
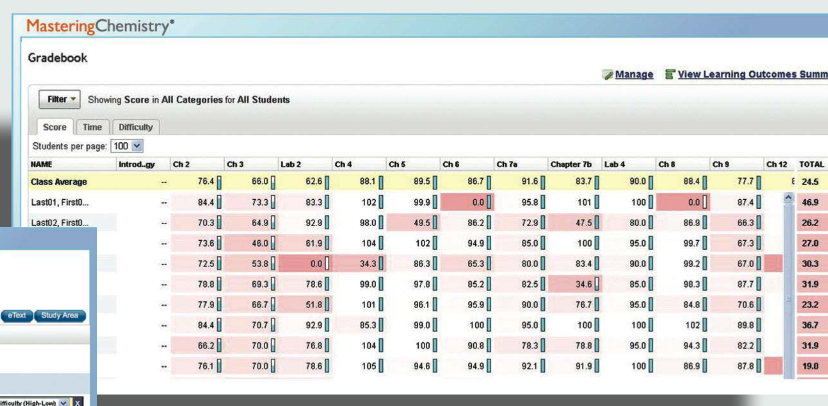


NEW! Calendar Features

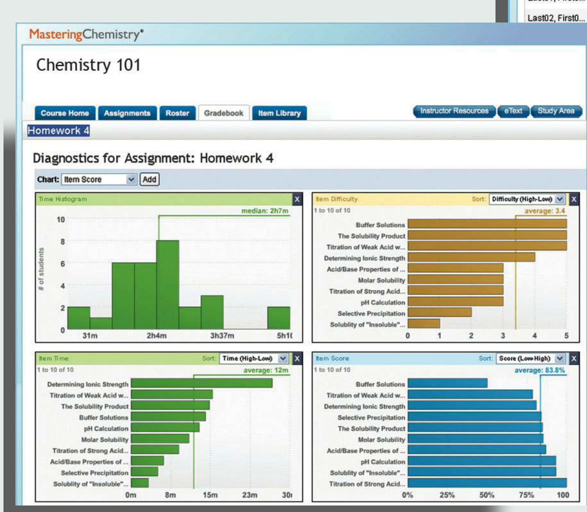
The Course Home default page now features a **Calendar View** displaying upcoming assignments and due dates.

- Instructors can schedule assignments by dragging and dropping the assignment onto a date in the calendar. If the due date of an assignment needs to change, instructors can drag the assignment to the new due date and change the "available from and to dates" accordingly.
- The calendar view gives students a syllabus-style overview of due dates, making it easy to see all assignments due in a given month.



Gradebook

Every assignment is automatically graded. Shades of red highlight struggling students and challenging assignments.



Gradebook Diagnostics

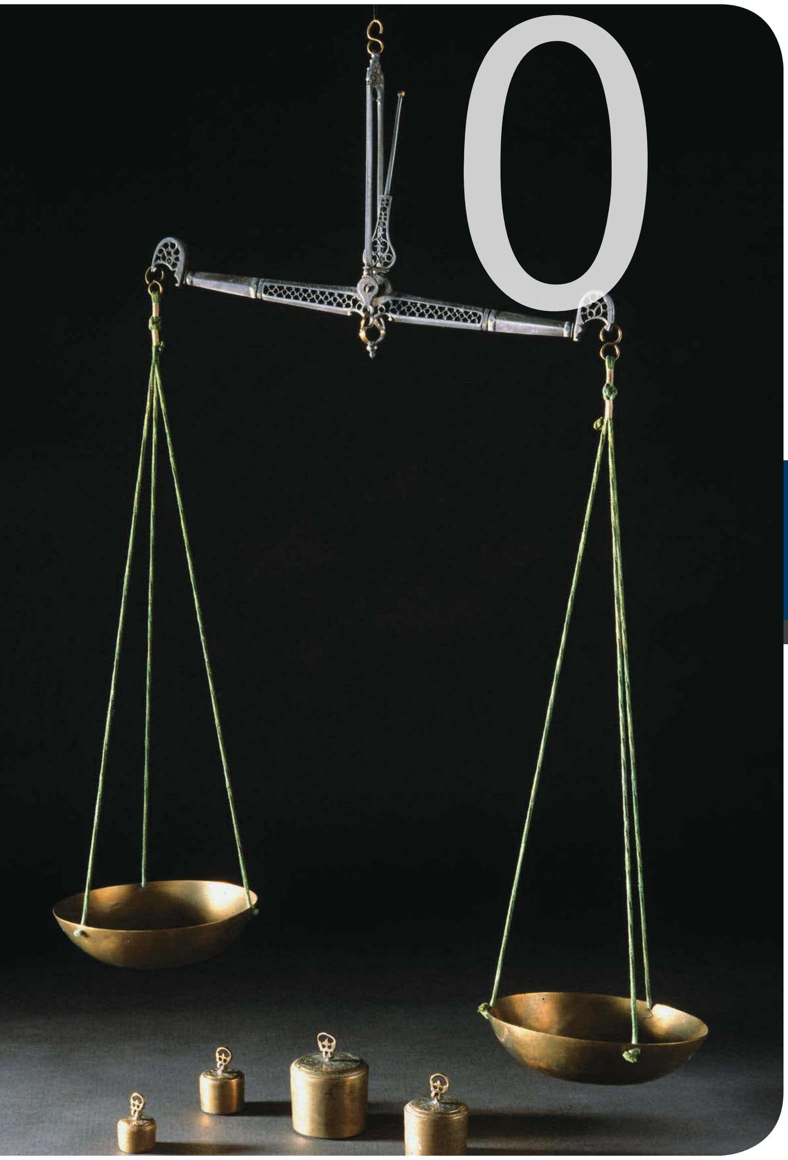
This screen provides you with your favorite diagnostics. With a single click, charts summarize the most difficult problems, vulnerable students, grade distribution, and even score improvement over the course.

STUDENTS – PLEASE READ. REALLY.

Who ever heard of beginning a book with Chapter 0? It's not that the material in this chapter is unimportant. In fact, it's *very* important because it gives you some tools that you must know how to use before beginning your study of chemistry. The problem is that you and your classmates, who typically take Introductory Chemistry in the first year of college, are so diverse in your backgrounds and preparations that many of you will have

CHAPTER 0

Chemical Tools: Experimentation and Measurement



Accurate measurements, such as those obtained on this 300-year-old Persian balance, have always been a crucial part of scientific experiments.

Life has changed more in the past two centuries than in all the previously recorded span of human history. The Earth's population has increased sevenfold since 1800, from about 1 billion to 7 billion, and life expectancy has nearly doubled because of our ability to control diseases, increase crop yields, and synthesize medicines. Methods of transportation have changed from horses and buggies to automobiles and airplanes because of our ability to harness the energy in petroleum. Many goods are now made of polymers and ceramics instead of wood and metal because of our ability to manufacture materials with properties unlike any found in nature.

In one way or another, all these changes involve **chemistry**, the study of the composition, properties, and transformations of matter. Chemistry is deeply involved in both the changes that take place in nature and the profound social changes of the past two centuries. In addition, chemistry is central to the current revolution in molecular biology that is now exploring the details of how life is genetically controlled. No educated person today can understand the modern world without a basic knowledge of chemistry.

already taken a chemistry Advanced Placement course in high school while many others of you will have had either no high school background in chemistry or at best a one-semester introduction. Thus, some of you will have already learned the material in this chapter and will be comfortable using it, while others of you will have to carefully brush up on it or learn it for the first time.

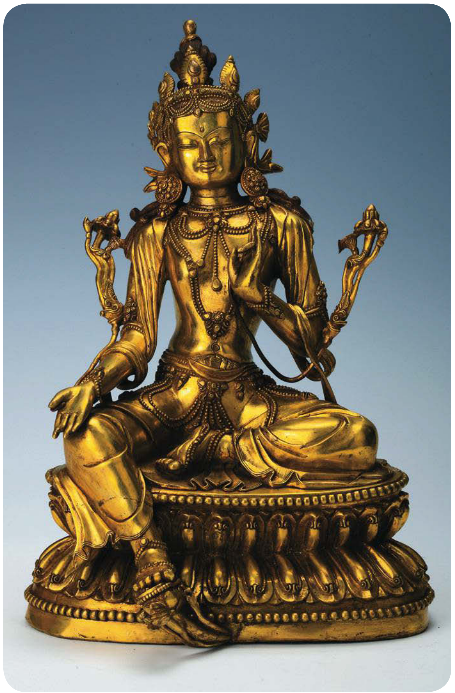
The choice about whether you need to learn, brush up on, or move quickly past the material in Chapter 0 is yours (or your professor's). But be careful in making your choice. You *do* need to master and feel comfortable with this chapter before going on.

CONTENTS

0.1 EXPERIMENT → HYPOTHESIS → THEORY: APPROACHING CHEMISTRY

By opening this book, you have already decided that you need to know more about chemistry. Perhaps you want to learn how medicines are made, how genes can be sequenced and manipulated, how fertilizers and pesticides work, how living organisms function, how new high-temperature ceramics are used in space vehicles, or how microelectronic circuits are etched onto silicon chips. How do you approach chemistry?

One way to approach chemistry or any other science is to look around you and try to think of logical explanations for what you see. You would certainly observe, for instance, that different substances have different forms and appearances. Some substances are gases, some are liquids, and some are solids; some are hard and shiny, but others are soft and dull. You'd also observe that different substances behave differently: Iron rusts but gold does not; copper conducts electricity but sulfur doesn't. How can these and a vast number of other observations be explained?



▶ Gold, one of the most valuable of elements, has been prized since antiquity for its beauty and resistance to corrosion.

In fact, the natural world is far too complex to be understood by looking and thinking alone, so a more active approach is needed. Specific questions must be asked and experiments must be carried out to find their answers. Only when the results of many experiments are known can we devise a tentative interpretation, or *hypothesis*, that explains the results. The hypothesis, in turn, can be used to make more predictions and to suggest more experiments until a consistent explanation, or **theory**, is finally arrived at.

Experiments and observations come first in chemistry or any other science, and theories to explain those observations come later after much hard work and a lot of thought. Nevertheless, it's important to keep in mind that scientific theories are not laws of nature and can never be absolutely proven. There's always the chance that a new experiment might give results that can't be explained by present theory. All a theory can do is to represent the best explanation that we can come up with at any given time. If new experiments uncover results that present theories can't explain, the theories will have to be modified or perhaps even replaced.

0.2 EXPERIMENTATION AND MEASUREMENT IN CHEMISTRY

Chemistry is an experimental science. But if our experiments are to be reproducible, we must be able to describe fully the substances we're working with—their amounts, volumes, temperatures, and so forth. Thus, one of the most important requirements in chemistry is that we have a way to measure things.

Under an international agreement concluded in 1960, scientists throughout the world now use the International System of Units for measurement, abbreviated **SI** for the French *Système Internationale d'Unités*. Based on the metric system, which is used in all countries except the United States, Liberia, and Myanmar, the SI system has seven fundamental units (**Table 0.1**). These seven fundamental units, along with others derived from them, suffice for all scientific measurements. We'll look at three of the most commonly used units in this chapter—those for mass, length, and temperature—and will discuss others as the need arises in later chapters.

TABLE 0.1 The Seven Fundamental SI Units of Measure

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

One problem with any system of measurement is that the sizes of the units often turn out to be inconveniently large or small. For example, a chemist describing the diameter of a sodium atom (0.000 000 000 372 m) would find the meter (m) to be inconveniently large, but an astronomer describing the average distance from the Earth to the Sun (150,000,000,000 m) would find the meter to be inconveniently small. For this reason, SI units are modified by using prefixes when they refer to either smaller or larger quantities. For example, the prefix *milli-* means one-thousandth, so a *milli*meter (mm) is 1/1000 of 1 meter. Similarly, the prefix *kilo-* means one thousand, so a *kilo*meter (km) is 1000 meters. [Note that the SI unit for mass (kilogram) already contains the *kilo-* prefix.] A list of prefixes is shown in **Table 0.2**, with the most commonly used ones in red.

TABLE 0.2 Some Prefixes for Multiples of SI Units

Factor	Prefix	Symbol	Example
$1,000,000,000,000 = 10^{12}$	tera	T	1 teragram (Tg) $= 10^{12}$ g
$1,000,000,000 = 10^{9}$	giga	G	1 gigameter (Gm) $= 10^{9}$ m
$1,000,000 = 10^{6}$	mega	M	1 megameter (Mm) $= 10^{6}$ m
$1,000 = 10^{3}$	kilo	k	1 kilogram (kg) $= 10^{3}$ g
$100 = 10^{2}$	hecto	h	1 hectogram (hg) $= 100$ g
$10 = 10^{1}$	deka	da	1 dekagram (dag) $= 10$ g
$0.1 = 10^{-1}$	deci	d	1 decimeter (dm) $= 0.1$ m
$0.01 = 10^{-2}$	centi	c	1 centimeter (cm) $= 0.01$ m
$0.001 = 10^{-3}$	milli	m	1 milligram (mg) $= 0.001$ g
$*0.000\,001 = 10^{-6}$	micro	μ	1 micrometer (μm) $= 10^{-6}$ m
$*0.000\,000\,001 = 10^{-9}$	nano	n	1 nanosecond (ns) $= 10^{-9}$ s
$*0.000\,000\,000\,001 = 10^{-12}$	pico	p	1 picosecond (ps) $= 10^{-12}$ s
$*0.000\,000\,000\,000\,001 = 10^{-15}$	femto	f	1 femtomole (fmol) $= 10^{-15}$ mol

*It is becoming common in scientific work to leave a thin space every three digits to the right of the decimal point in very small numbers, analogous to the comma placed every three digits to the left of the decimal point in large numbers.

Notice how numbers that are either very large or very small are indicated in Table 0.2 using an exponential format called **scientific notation**. For example, the number 55,000 is written in scientific notation as 5.5×10^{4}, and the number 0.003 20 as 3.20×10^{-3}. Review Appendix A if you are uncomfortable with scientific notation or if you need to brush up on how to do mathematical manipulations on numbers with exponents.

Notice also that all measurements contain both a number and a unit label. A number alone is not much good without a unit to define it. If you asked a friend how far it was to the nearest tennis court, the answer "3" alone wouldn't tell you much. 3 blocks? 3 kilometers? 3 miles?

PROBLEM 0.1 Express the following quantities in scientific notation:
(a) The diameter of a sodium atom, 0.000 000 000 372 m
(b) The distance from the Earth to the Sun, 150,000,000,000 m

PROBLEM 0.2 What units do the following abbreviations represent?
(a) μg **(b)** dm **(c)** ps **(d)** kA **(e)** mmol

0.3 FUNDAMENTAL UNITS: MEASURING MASS

Let's look in more detail at the measurement of some common quantities in chemistry, beginning with mass. **Mass** is defined as the amount of *matter* in an object. **Matter**, in turn, is a catchall term used to describe anything with a physical presence—anything you can touch, taste, or smell. (Stated more scientifically, matter is anything that has mass.) Mass is measured in SI units by the **kilogram (kg**; 1 kg = 2.205 U.S. lb). Because the kilogram is too large for many purposes in chemistry, the metric **gram** (**g**; 1 g = 0.001 kg), the **milligram** (**mg**; 1 mg = 0.001 g = 10^{-6} kg), and the **microgram** (***μg***; 1 μg = 0.001 mg = 10^{-6} g = 10^{-9} kg) are more commonly used. One gram is a bit less than half the mass of a new U.S. dime.

$$1 \text{ kg} = 1000 \text{ g} = 1{,}000{,}000 \text{ mg} = 1{,}000{,}000{,}000\ \mu\text{g} \qquad (2.205 \text{ lb})$$
$$1 \text{ g} = 1000 \text{ mg} = 1{,}000{,}000\ \mu\text{g} \qquad (0.035\,27 \text{ oz})$$
$$1 \text{ mg} = 1000\ \mu\text{g}$$

▲ The mass of a U.S. dime is approximately 2.27 g. How many milligrams is this?

The standard kilogram is defined as the mass of the *international prototype kilogram*, a cylindrical bar of platinum–iridium alloy stored in a vault in a suburb of Paris, France. There are 40 original copies of this bar distributed throughout the world, with two (Numbers K4 and K20) stored at the U.S. National Institute of Standards and Technology near Washington, D.C.

The terms "mass" and "weight," although often used interchangeably, have quite different meanings. *Mass* is a measure of the amount of matter in an object, whereas *weight* is a measure of the force that gravity exerts on an object. Mass is independent of an object's location: Your body has the same amount of matter whether you're on Earth or on the Moon. Weight, however, *does* depend on an object's location. If you weigh 140 lb on Earth, you would weigh only about 23 lb on the Moon, which has a lower gravity than Earth.

At the same location on Earth, two objects with identical masses experience an identical pull of Earth's gravity and have identical weights. Thus, the mass of an object can be measured by comparing its weight to the weight of a reference standard of known mass. Much of the confusion between mass and weight is simply due to a language problem. We speak of "weighing" when we really mean that we are measuring mass by comparing two weights. **Figure 0.1** shows two types of balances normally used for measuring mass in the laboratory.

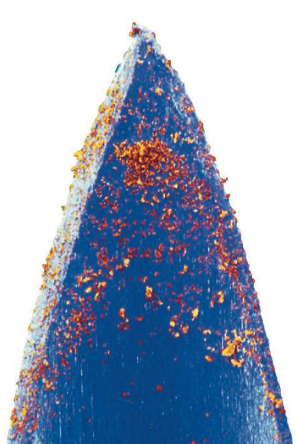
FIGURE 0.1

Some balances used for measuring mass in the laboratory.

0.4 FUNDAMENTAL UNITS: MEASURING LENGTH

The **meter (m)** is the standard unit of length in the SI system. Although originally defined in 1790 as being 1 ten-millionth of the distance from the equator to the North Pole, the meter was redefined in 1889 as the distance between two thin lines on a bar of platinum–iridium alloy stored near Paris, France. To accommodate an increasing need for precision, the meter was redefined again in 1983 as equal to the distance traveled by light through a vacuum in 1/299,792,458 second. Although this new definition isn't as easy to grasp as the distance between two scratches on a bar, it has the great advantage that it can't be lost or damaged.

One meter is 39.37 inches, about 10% longer than an English yard and much too large for most measurements in chemistry. Other, more commonly used measures of length are the **centimeter (cm**; 1 cm = 0.01 m, a bit less than half an inch), the **millimeter (mm**; 1 mm = 0.001 m, about the thickness of a U.S. dime), the **micrometer** (**μm**; 1 μm = 10^{-6} m), the **nanometer** (**nm**; 1 nm = 10^{-9} m), and the **picometer** (**pm**; 1 pm = 10^{-12} m). Thus, a chemist might refer to the diameter of a sodium atom as 372 pm (3.72×10^{-10} m).



▲ The bacteria on the tip of this pin have a length of about 5×10^{-7} m. How many nanometers is this?

$$1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm} = 1{,}000{,}000\ \mu\text{m} = 1{,}000{,}000{,}000 \text{ nm} \qquad (1.0936 \text{ yd})$$

$$1 \text{ cm} = 10 \text{ mm} = 10{,}000\ \mu\text{m} = 10{,}000{,}000 \text{ nm} \qquad (0.3937 \text{ in.})$$

$$1 \text{ mm} = 1000\ \mu\text{m} = 1{,}000{,}000 \text{ nm}$$

0.5 FUNDAMENTAL UNITS: MEASURING TEMPERATURE

Just as the kilogram and the meter are slowly replacing the pound and the yard as common units for mass and length measurement in the United States, the **degree Celsius** (**°C**) is slowly replacing the degree Fahrenheit (°F) as the common unit for temperature measurement. In scientific work, however, the **kelvin (K)** has replaced both. (Note that we say only "kelvin," not "degree kelvin.")

For all practical purposes, the kelvin and the degree Celsius are the same size—both are one-hundredth of the interval between the freezing point of water and the boiling point of water at standard atmospheric pressure. The only real difference between the two units is that the numbers assigned to various points on the scales differ. Whereas the Celsius scale assigns a value of 0 °C to the freezing point of water and 100 °C to the boiling point of water, the Kelvin scale assigns a value of 0 K to the coldest possible temperature, −273.15 °C, sometimes called *absolute zero*. Thus, 0 K = −273.15 °C and 273.15 K = 0 °C. For example, a warm spring day with a Celsius temperature of 25 °C has a Kelvin temperature of 25° + 273.15° = 298 K.

$$\text{Temperature in K} = \text{Temperature in °C} + 273.15°$$
$$\text{Temperature in °C} = \text{Temperature in K} - 273.15°$$

In contrast to the Kelvin and Celsius scales, the common Fahrenheit scale specifies an interval of 180° between the freezing point (32 °F) and the boiling point (212 °F) of water. Thus, it takes 180 degrees Fahrenheit to cover the same range as 100 degrees Celsius (or kelvins) so a degree Fahrenheit is only 100/180 = 5/9 as large as a degree Celsius. **Figure 0.2** compares the Fahrenheit, Celsius, and Kelvin scales.

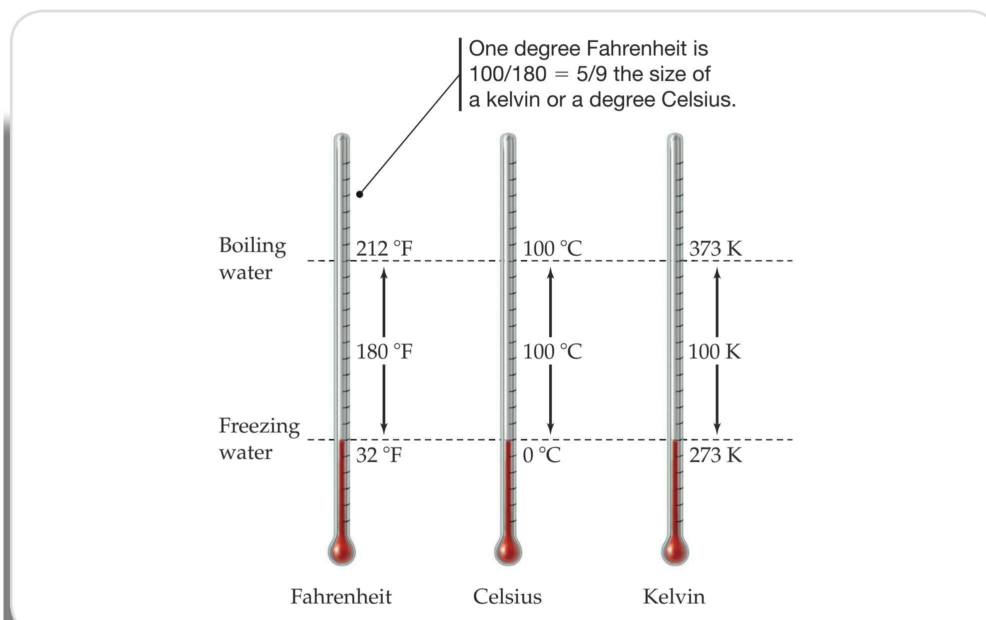


FIGURE 0.2

A comparison of the Fahrenheit, Celsius, and Kelvin temperature scales.

Two adjustments are needed to convert between Fahrenheit and Celsius scales—one to adjust for the difference in degree size and one to adjust for the difference in zero points. The size adjustment is made using the relationships 1 °C = 9/5 °F and 1 °F = 5/9 °C. The zero-point adjustment is made by remembering that the freezing point of water is higher by 32° on the Fahrenheit scale than on the Celsius scale. Thus, if you want to convert from Celsius to Fahrenheit, you first change the size of the Celsius value to that of a Fahrenheit value (multiply °C by 9/5) and then adjust the zero point of that Fahrenheit value (add 32°). If you want to convert from Fahrenheit to Celsius, you first adjust the zero-point of the Fahrenheit value (by subtracting 32°) and then change the size of that Fahrenheit value to a Celsius value (multiply by 5/9). The following formulas describe the conversions, and Worked Example 0.1 shows how to do a calculation.

Celsius to Fahrenheit

$$°\text{F} = \left(\frac{9\ °\text{F}}{5\ °\cancel{\text{C}}} \times °\cancel{\text{C}}\right) + 32\ °\text{F}$$

Fahrenheit to Celsius

$$°\text{C} = \frac{5\ °\text{C}}{9\ °\cancel{\text{F}}} \times (°\cancel{\text{F}} - 32\ °\cancel{\text{F}})$$

Worked Example 0.1

Converting from Fahrenheit to Celsius

The melting point of table salt is 1474 °F. What temperature is this on the Celsius and Kelvin scales?

SOLUTION

There are two ways to do this and every other problem in chemistry. One is to plug numbers into a formula and hope for the best; the other is to think things through to be sure you understand what's going on. The formula approach works only if you use the right equation; the thinking approach always works. Let's try both ways.

The formula approach: Set up an equation using the temperature conversion formula for changing from Fahrenheit to Celsius:

$$°\text{C} = \left(\frac{5\ °\text{C}}{9\ °\cancel{\text{F}}}\right)(1474\ °\cancel{\text{F}} - 32\ °\cancel{\text{F}}) = 801\ °\text{C}$$

Converting to kelvin gives a temperature of 801° + 273.15° = 1074 K.

The thinking approach: We're given a temperature in degrees Fahrenheit, and we need to convert to degrees Celsius. A temperature of 1474 °F corresponds to 1474 °F − 32 °F = 1442 °F above the freezing point of water. Because a degree Fahrenheit is only 5/9 as large as a degree Celsius, 1442 degrees Fahrenheit above freezing equals 1442 × 5/9 = 801 degrees Celsius above freezing (0 °C), or 801 °C. The same number of degrees above freezing on the Kelvin scale (273.15 K) corresponds to a temperature of 273.15 + 801 = 1074 K.

Because the answers obtained by the two approaches agree, we can feel fairly confident that our thinking is following the right lines and that we understand the subject. (If the answers did *not* agree, we'd be alerted to a misunderstanding somewhere.)

▲ The melting point of sodium chloride is 1474 °F, or 801 °C.

PROBLEM 0.3 The normal body temperature of a healthy adult human is 98.6 °F. What is this value on both Celsius and Kelvin scales?

PROBLEM 0.4 Carry out the indicated temperature conversions.
(a) −78 °C = ? K **(b)** 158 °C = ? °F **(c)** 375 K = ? °F

0.6 DERIVED UNITS: MEASURING VOLUME

Look back at the seven fundamental SI units given in Table 0.1 and you'll find that measures for such familiar quantities as area, volume, density, speed, and pressure are missing. All are examples of *derived* quantities rather than fundamental quantities because they can be expressed by using a combination of one or more of the seven fundamental units (**Table 0.3**).

TABLE 0.3 Some Derived Units and the Quantities They Measure

Quantity	Definition	Derived Unit (Name)
Area	Length times length	m^2
Volume	Area times length	m^3
Density	Mass per unit volume	kg/m^3
Speed	Distance per unit time	m/s
Acceleration	Change in speed per unit time	m/s^2
Force	Mass times acceleration	$(kg \cdot m)/s^2$ (newton, N)
Pressure	Force per unit area	$kg/(m \cdot s^2)$ (pascal, Pa)
Energy	Force times distance	$(kg \cdot m^2)/s^2$ (joule, J)

Volume, the amount of space occupied by an object, is measured in SI units by the **cubic meter** ($\mathbf{m^3}$), defined as the amount of space occupied by a cube 1 meter on edge (**Figure 0.3**).

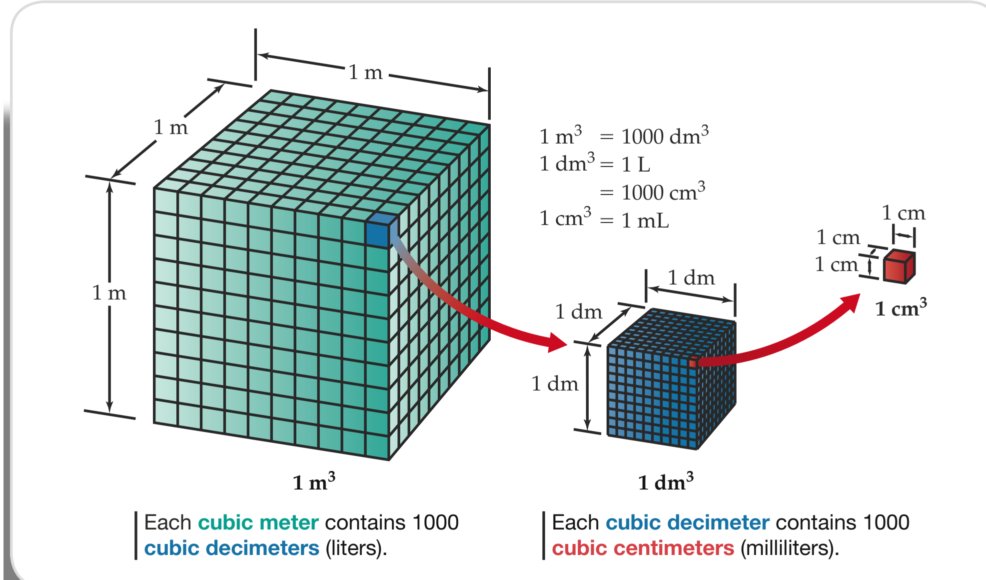


FIGURE 0.3

Units for measuring volume. A cubic meter is the volume of a cube 1 meter along each edge.

A cubic meter equals 264.2 U.S. gallons, much too large a quantity for normal use in chemistry. As a result, smaller, more convenient measures are commonly employed. Both the **cubic decimeter** (1 $\mathbf{dm^3}$ = 0.001 m^3), equal in size to the more familiar metric **liter (L)**, and the **cubic centimeter** (1 $\mathbf{cm^3}$ = 0.001 dm^3 = 10^{-6} m^3), equal in size to the metric **milliliter (mL)**, are particularly convenient. Slightly larger than 1 U.S. quart, a liter has the volume of a cube 1 dm on edge. Similarly, a milliliter has the volume of a cube 1 cm on edge (Figure 0.3).

$$1\ m^3 = 1000\ dm^3 = 1{,}000{,}000\ cm^3 \qquad (264.2\ gal)$$
$$1\ dm^3 = 1\ L = 1000\ mL \qquad (1.057\ qt)$$

Figure 0.4 shows some of the equipment frequently used in the laboratory for measuring liquid volume.

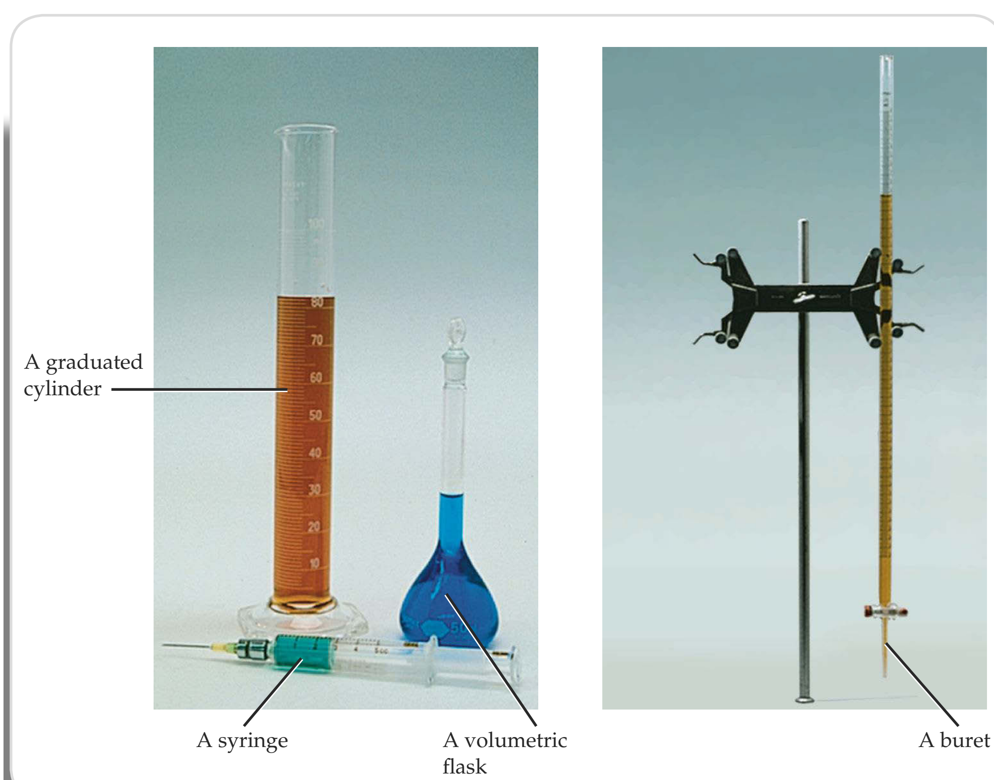


FIGURE 0.4

Common items of laboratory equipment used for measuring liquid volume.