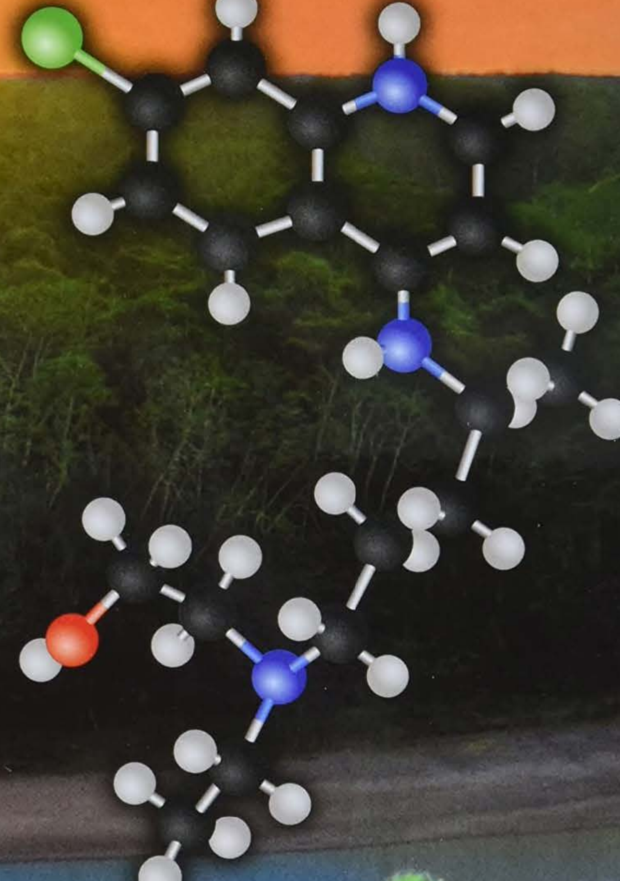
General, Organic, and BIOCHEMISTRY

eleventh edition



McGraw Hill

Denniston | Quirk | Topping | Caret

General, Organic, *and* Biochemistry

ELEVENTH EDITION

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GENERAL, ORGANIC, AND BIOCHEMISTRY

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Brief Contents

GENERAL CHEMISTRY

ORGANIC CHEMISTRY

BIOCHEMISTRY

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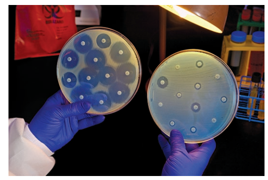

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ORGANIC CHEMISTRY

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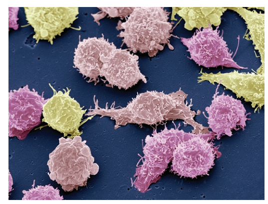
BIOCHEMISTRY



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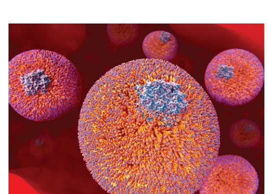

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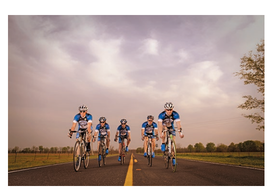

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Perspectives

A Human Perspective

A Medical Perspective

Green Chemistry

Kitchen Chemistry

Chemistry at the Crime Scene

Preface

To Our Students

Student engagement in the study of chemistry has been our primary aim since the first edition of this book. We wanted to show you that chemistry is much more than an onerous obstacle in the journey toward your career goals. Through the Perspectives boxes in each chapter, we have tried to show that chemistry is a fascinating discipline that has an enormous impact on all aspects of your life—whether chemistry in the kitchen, investigations at a crime scene, issues of environmental concern, medicine, or the chemical reactions that keep our bodies functioning.

While engagement in a subject is a good place to begin, effective study practices will ensure your success in learning the course content. In the preface of previous editions, we included suggestions for studying chemistry that included the five stages of the Study Cycle. Because education research has shown that effective use of the Study Cycle improves student performance in all subjects, we wanted to share this information with you. In this edition, we have expanded our attention to research-based learning strategies by including specific sections of the text devoted to effective study skills. In Section 1.1 you will learn about the Study Cycle, as well as some useful strategies that are specific to general chemistry. In Section 10.1, the beginning of the organic chemistry section of the course, you will be challenged to apply study strategies that are specific to that discipline. Similarly, in Section 16.1, the beginning of the biochemistry section, you will be introduced to practices and ideas that will help you master that content.

We have also introduced a new type of problem, multiple concept problems. These challenge you to apply your knowledge of many aspects of the topic to answer thought-provoking questions that will help you develop a much deeper understanding of the principles of chemistry. Research has shown that this type of deeper understanding is crucial to success in all areas of your education. It is our hope that these new elements of the text will provide you with the tools you need to successfully meet the challenges of this course.

To the Instructor

The eleventh edition of *General, Organic, and Biochemistry,* like our earlier editions, has been designed to help undergraduate majors in health-related fields understand key concepts and appreciate significant connections among chemistry, health, and the treatment of disease. We have tried to strike a balance between theoretical and practical chemistry, while emphasizing material that is unique to health-related studies. We have written at a level intended for students whose professional goals do not include a mastery of chemistry, but for whom an understanding of the principles and practice of chemistry is a necessity.

Although our emphasis is the importance of chemistry to the health-related professions, we wanted this book to be appropriate for all students who need a one- or two-semester introduction to chemistry. Students learn best when they are engaged. One way to foster that engagement is to help them see clear relationships between the subject and real life. For these reasons, we have included perspectives and essays that focus on medicine and the function of the human body, as well as the environment, forensic science, and even culinary arts.

We begin that engagement with the book cover. Students may wonder why the cover of a chemistry book has a photo of a tree in a Peruvian rainforest. What does a scenic sunset over a river in Peru have to do with the study of chemistry or the practice of medicine? Students will remember that a drug called hydroxychloroquine was considered as a treatment for Coronavirus 2019 (COVID-19). That drug is a synthetic version of quinine, the ancient treatment for malaria. The indigenous people of Peru extracted the bark of the cinchona tree (*Cinchona officinalis*) to produce a powder they used to treat chills and fever. In 1633 the Jesuits introduced this herbal medicine to Europe where it also was used against malaria. Quinine was isolated from the bark in 1820 and the synthetic analogue hydroxychloroquine was approved for medical use in 1955. Although it was not found to be effective against COVID-19, hydroxychloroquine is used in the treatment of rheumatoid arthritis, lupus erythematosus, and post-Lyme arthritis. In fact, it is the first-line treatment for lupus erythematosus.

The cover sets the theme for the book: chemistry is not an abstract study, but one that has an immediate impact on our lives. We try to spark student interest with an art program that uses relevant photography, clear and focused figures, and perspectives and essays that bring life to abstract ideas. We reinforce key concepts by explaining them in a clear and concise way and encouraging students to apply the concept to solve problems. We provide guidance through the inclusion of a large number of in-chapter examples that are solved in a stepwise fashion and that provide students the opportunity to test their understanding through the practice problems that follow and the suggested end-of-chapter questions and problems that apply the same concepts.

Foundations for Our Revisions

Over the past thirty years, we have been guided by the collective wisdom of reviewers who are expert chemists and excellent teachers. They represent experience in community colleges, liberal arts colleges, comprehensive institutions, and research universities. We have followed their recommendations, while remaining true to our overriding goal of writing a readable, student-centered text. All of our editions have been designed to be amenable to a variety of teaching styles. Each feature incorporated into this edition has been carefully considered with regard to how it may be used to support student learning in both the traditional classroom and the flipped learning environment.

In addition to the faculty reviewers, we have been able to incorporate real student data points and input, derived from thousands of our LearnSmart users, to help guide our revision. LearnSmart Heat Maps provided a quick visual snapshot of usage of portions of the text and the relative difficulty students experienced in mastering the content.

With these data, we were able to hone not only our text content but also the LearnSmart probes.

- If the data indicated that the subject covered was more difficult than other parts of the book, as evidenced by a high proportion of students responding incorrectly, we substantively revised or reorganized the content to be as clear and illustrative as possible.
- In some sections, the data showed that a smaller percentage of the students had difficulty learning the material. In those cases, we revised the *text* to provide a clearer presentation by rewriting the section, providing additional examples to strengthen student problem-solving skills, designing new text art or figures to assist visual learners, etc.
- In other cases, one or more of the LearnSmart probes for a section was not as clear as it might be or did not appropriately reflect the content. In these cases, the *probe,* rather than the text, was edited.

The voices of these faculty and students have improved the quality of each edition and prepared us for the most recent revisions for students using the traditional printed text and those moving into the electronic world. Their input has been invaluable.

New in This Edition

Because many students are visual learners, we have paid particular attention to the **photos, artwork, chemical structures,** and **equations** throughout the text. This was particularly emphasized for relevant material and applications. All revisions have been focused on accessibility, clarity, and consistency. Color has also been used in many areas to help students better understand chemical structure, stereochemistry, and reactions. The Chapter Maps were also revised as necessary to better reflect key concepts emphasized in learning goals.

Perspective boxes help students relate the topics from the text to real-world situations and for this reason, they must be accurate and current. Particular attention has been focused in this edition to update the content, remove outdated Perspectives, and ensure that the content engages student interest.

The following is a summary of the additions and refinements that we have included in this edition. One of the most important revisions of the eleventh edition is the adoption of the International Union of Pure and Applied Chemistry (IUPAC) nomenclature system for organic chemistry. While this nomenclature was adopted many years ago, this is the year that IUPAC has mandated the use of the new system. For that reason, the nomenclature section of each chapter has been rewritten and all examples, questions, and problems have been revised.

Throughout the general chemistry chapters we have updated and validated the data using the CRC Handbook of Chemistry and Physics and the National Institute of Standards and Technology guidelines. In particular, we have focused on data for atomic masses, electronegativity values, constants, conversion factors, solubilities, melting points, boiling points, and radioactive half-lives in order to provide continuity with problems solved by students in ALEKS.

In the biochemistry section of the course, particular attention was paid to the structures of the molecules. Consistency in the use of structural formulas and skeletal structures has made these large, complex structures more easily understood by the students.

Applications

Each chapter contains applications that present short stories about real-world situations involving one or more topics students will encounter within the chapter. There are over 100 applications throughout the text, so students are sure to find many topics that spark their interest. Global climate change, DNA fingerprinting, the benefits of garlic, and gemstones are just a few examples of application topics.

- **Medical Perspectives** relate chemistry to a health concern or a diagnostic application.
- **Green Chemistry** explores environmental topics, including the impact of chemistry on the ecosystem and how these environmental changes affect human health.
- **Human Perspectives** delve into chemistry and society and include such topics as gender issues in science and historical viewpoints.
- **Chemistry at the Crime Scene** focuses on forensic chemistry, applying the principles of chemistry to help solve crimes.
- **Kitchen Chemistry** discusses the chemistry associated with everyday foods and cooking methods.

Learning Tools

In designing the original learning system we asked ourselves: "If we were students, what would help us organize and understand the material covered in this chapter?" Based on the feedback of reviewers and users of our text, we include a variety of learning tools:

- **Strategies for Success in Chemistry** are found at the beginning of each major unit of the course: general, organic, and biochemistry. These new sections provide students with research-based strategies for successful mastery of that content.
- **Chapter Overview** pages begin each chapter, with a chapter outline and an engaging Introduction, leading students directly to the learning goals of the chapter. Both students and professor can see, all in one place, the plan for the chapter.
- **Learning Goal Icons** mark the sections and examples in the chapter that focus on each learning goal.
- **Chapter Cross-References** help students locate pertinent background material. These references to previous chapters, sections, and perspectives are noted in the margins of the text. Marginal cross-references also alert students to upcoming topics related to the information currently being studied.
- **End-of-Chapter Questions and Problems** are arranged according to the headings in the chapter outline, with further subdivision into Foundations (basic concepts) and Applications.
- **Chapter Maps** are included just before the end-of-chapter Summaries to provide students with an overview of the chapter—showing connections among topics, how concepts are related, and outlining the chapter hierarchy.
- **Chapter Summaries** are now a bulleted list format of chapter concepts by major sections, with the integrated bold-faced **Key Terms** appearing in context. This more succinct format helps students to quickly identify and review important chapter concepts and to make connections with the incorporated Key Terms. Each Key Term is defined and listed alphabetically in the **Glossary** at the end of the book.

- **Answers to Practice Problems** are supplied in an appendix at the end of the text so that students can quickly check their understanding of important problem-solving skills and chapter concepts.
- **Summaries of Reactions** in the organic chemistry chapters highlight each major reaction type on a tan background. Major chemical reactions are summarized by equations at the end of the chapter, facilitating review.

Problem Solving and Critical Thinking

Perhaps the best preparation for a successful and productive career is the development of problem-solving and critical thinking skills. To this end, we created a variety of problems that require recall, fundamental calculations, and complex reasoning. In this edition, we have used suggestions from our reviewers, as well as from our own experience, to enhance our 2300 problems. This edition includes new problems and hundreds of example problems with step-by-step solutions.

- **In-Chapter Examples, Solutions, and Practice Problems:** Each chapter includes examples that show the student, step by step, how to properly reach the correct solution to model problems. Each example contains a practice problem, as well as a referral to further practice questions. These questions allow students to test their mastery of information and to build self-confidence. The answers to the practice problems can be found in the Answer Appendix so students can check their understanding.
- **Color-Coding System for In-Chapter Examples:** In this edition, we also introduced a color-coding and label system to help alleviate the confusion that students frequently have when trying to keep track of unit conversions. Introduced in Chapter 1, this color-coding system has been used throughout the problem-solving chapters.

$$3.01\ \cancel{\text{mol S}} \times \frac{32.059\text{ g S}}{1\ \cancel{\text{mol S}}} = 96.5\text{ g S}$$

Data Given × Conversion Factor = Desired Result

- **In-Chapter and End-of-Chapter Questions and Problems:** We have created a wide variety of paired concept problems. The answers to the odd-numbered questions are found in the Answer Appendix at the back of the book as reinforcement for students as they develop problem-solving skills. However, students must then be able to apply the same principles to the related even-numbered problems.
- **Multiple Concept Problems:** Each chapter includes a set of these problems intended to engage students to integrate concepts to solve more complex problems. They make a perfect complement to the classroom lecture because they provide an opportunity for in-class discussion of complex problems dealing with daily life and the health care sciences. The answers to the Multiple Concept Problems are available through the Instructor Resources in the Connect Library tab.

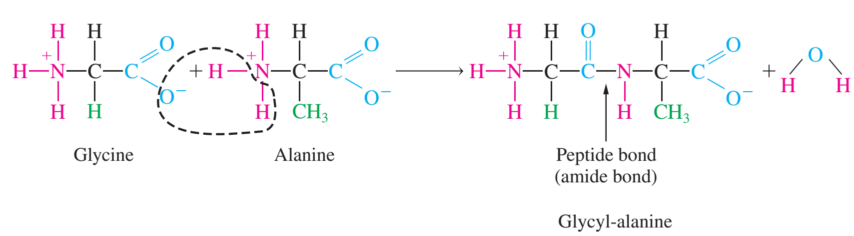
Over the course of the last ten editions, hundreds of reviewers have shared their knowledge and wisdom with us, as well as the reactions of their students to elements of this book. Their contributions, as well as our own continuing experience in the area of teaching and learning science, have resulted in a text that we are confident will provide a strong foundation in chemistry, while enhancing the learning experience of students.

The Art Program

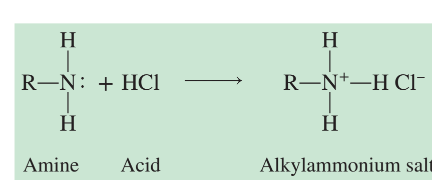
Today's students are much more visually oriented than previous generations. We have built upon this observation through the use of color, figures, and three-dimensional computer-generated models. This art program enhances the readability of the text and provides alternative pathways to learning.

- **Dynamic Illustrations:** Each chapter is amply illustrated using figures, tables, and chemical formulas. All of these illustrations are carefully annotated for clarity. To help students better understand difficult concepts, there are approximately 350 illustrations and 250 photos in the eleventh edition.
- **Color-Coding Scheme:** We have color-coded equations so that chemical groups being added or removed in a reaction can be quickly recognized.
  1. **Red print** is used in chemical equations or formulas to draw the reader's eye to key elements or properties in a reaction or structure.
  2. **Blue print** is used when additional features must be highlighted.
  3. **Green background** screens denote generalized chemical and mathematical equations. In the organic chemistry chapters, the Summary of Reactions at the end of the chapter is also highlighted for ease of recognition.

another amino acid. The reaction, shown below for the amino acids glycine and alanine, is a condensation reaction, because a water molecule is lost as the amide bond is formed.

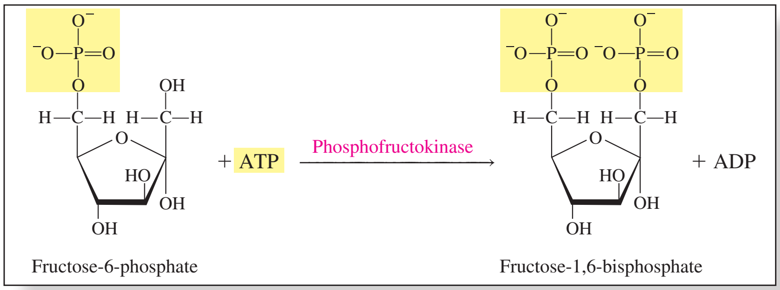


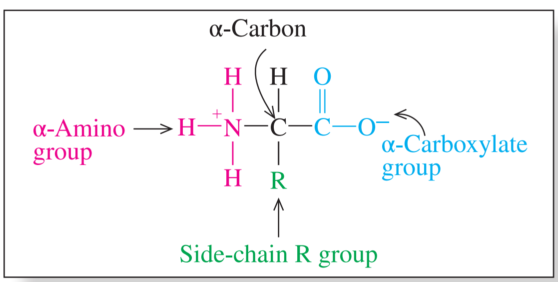
Because amines are bases, they react with acids to form alkylammonium salts.



The reaction of methylamine with hydrochloric acid shown is typical of these re
The product is an alkylammonium salt, methylammonium chloride.

4. **Yellow backgrounds** illustrate energy, stored either in electrons or groups of atoms, in the general and biochemistry sections of the text. In the organic chemistry section of the text, yellow background screens also reveal the parent chain of an organic compound.





5. There are situations in which it is necessary to adopt a unique color convention tailored to the material in a particular chapter. For example, in Chapter 18, the structures of amino acids require three colors to draw attention to key features of these molecules. For consistency, blue is used to denote the acid portion of an amino acid and red is used to denote the basic portion of an amino acid. Green print is used to denote the R groups.

- **Computer-Generated Models:** The ability of students to understand the geometry and three-dimensional structure of molecules is essential to the understanding of organic and biochemical reactions. Computer-generated models are used throughout the text because they are both accurate and easily visualized.

Instructor and Student Resources

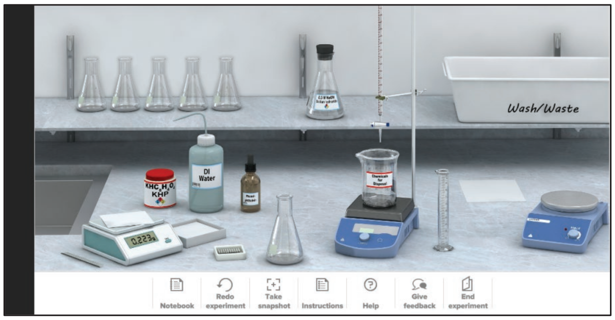
ALEKS (Assessment and LEarning in Knowledge Spaces) is a web-based system for individualized assessment and learning available 24/7 over the Internet. ALEKS uses artificial intelligence to accurately determine a student's knowledge and then guides her to the material that she is most ready to learn. ALEKS offers immediate feedback and access to ALEKSPedia—an interactive text that contains concise entries on chemistry topics. ALEKS is also a full-featured course management system with rich reporting features that allow instructors to monitor individual and class performance, set student goals, assign/grade online quizzes, and more. ALEKS allows instructors to spend more time on concepts while ALEKS teaches students practical problem-solving skills. And with ALEKS 360, your student also has access to this text's eBook. Learn more at **www.aleks.com/highered/science**

Instructors have access to the following instructor resources:

- **Instructor's Manual:** Written and developed for the eleventh edition, this ancillary contains many useful suggestions for organizing flipped classrooms, lectures, instructional objectives, perspectives on readings from the text, answers to the even-numbered problems and the Multiple Concept problems from the text, a list of each chapter's key concepts, and more. The Instructor's Manual is available through the ALEKS Instructor Resources.
- **Presentation Tools:** Build instructional material wherever, whenever, and however you want with assets such as photos, artwork, and other media that can be used to create customized lectures, visually enhanced tests and quizzes, compelling course websites, or attractive printed support materials. Accessible PowerPoint Lecture Outlines, ready-made presentations that combine art and lecture notes, are also provided for each chapter of the text. The Presentation Tools can be accessed from the ALEKS Instructor Resources.

- **More than 300 animations available through the eBook:** They supplement the textbook material in much the same way as instructor demonstrations. However, they are only a few mouse-clicks away, any time, day or night. Because many students are visual learners, the animations add another dimension of learning; they bring a greater degree of reality to the written word.
- **Computerized Test Bank:** Over 1,800 test questions that accompany *General, Organic, and Biochemistry* are available for creating exams or quizzes.
- **Instructor's Solutions Manual:** This supplement contains complete, worked-out solutions for even-numbered problems in the text.

McGraw Hill Virtual Labs is a must-see, outcomes-based lab simulation. It assesses a student's knowledge and adaptively corrects deficiencies, allowing the student to learn faster and retain more knowledge with greater success. First, a student's knowledge is adaptively leveled on core learning outcomes: Questioning reveals knowledge deficiencies that are corrected by the delivery of content that is conditional on a student's response. Then, a simulated lab experience requires the student to think and act like a scientist: recording, interpreting, and analyzing data using simulated equipment found in labs and clinics. The student is allowed to make mistakes—a powerful part of the learning experience! A virtual coach provides subtle hints when needed, asks questions about the student's choices, and allows the student to reflect on and correct those mistakes. Whether your need is to overcome the logistical challenges of a traditional lab, provide better lab prep, improve student performance, or make your online experience one that rivals the real world, McGraw Hill Virtual Labs accomplishes it all.



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Additional Student Resources

- **Student Solutions Manual:** A separate Student Solutions Manual is available. It contains the answers and complete solutions for the odd-numbered problems.
- **Schaum's Outline of General, Organic, and Biological Chemistry:** Written by George Odian and Ira Blei, this supplement provides students with more than 1400 solved problems with complete solutions. It also teaches effective problem-solving techniques.
- **Laboratory Manual for General, Organic, and Biological Chemistry:** Authored by Applegate, Neely, and Sakuta to be the most current lab manual available for the GOB course, incorporating the most modern instrumentation and techniques. Illustrations and chemical structures were developed by the authors to conform to the most recent IUPAC conventions. A problem-solving methodology is also utilized throughout the laboratory exercises. There are two online virtual labs for Nuclear Chemistry and Gas Laws. This Laboratory Manual is also designed with flexibility in mind to meet the differing lengths of GOB courses and the variety of instrumentation available in GOB labs. Helpful instructor materials are also available on this companion website, including answers, solution recipes, best practices with common student issues and TA advice, sample syllabi, and a calculation sheet for the Density lab.

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We are thankful to our families, whose patience and support made it possible for us to undertake this project. We are also grateful to our many colleagues at McGraw Hill for their support, guidance, and assistance. In particular, we would like to thank Jane Mohr, Content Project Manager; Mary Hurley, Product Developer; and Cassie Cloutier, Marketing Manager.

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Gregg Wilmes, *Eastern Michigan University*
Yakov Woldman, *Valdosta State University*

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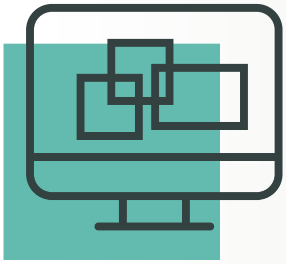

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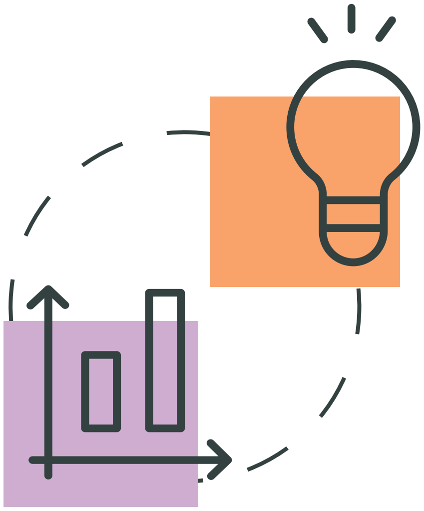

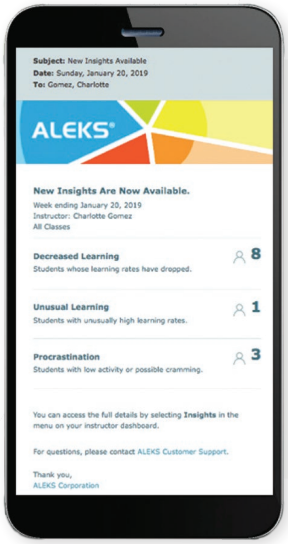

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1

METHODS AND MEASUREMENT

Chemistry

OUTLINE

INTRODUCTION

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Louis Pasteur, a chemist and microbiologist, said, "Chance favors the prepared mind." In the history of science and medicine, there are many examples in which individuals made important discoveries because they recognized the value of an unexpected observation.

One such example is the use of ultraviolet (UV) light to treat infant jaundice. Infant jaundice is a condition in which the skin and the whites of the eyes appear yellow because of high levels of the bile pigment bilirubin in the blood. Bilirubin is a breakdown product of the oxygen-carrying blood protein hemoglobin. If bilirubin accumulates in the body, it can cause brain damage and death. The immature liver of the baby cannot remove the bilirubin.

In 1956, an observant nurse in England noticed that when jaundiced babies were exposed to sunlight, the jaundice faded. Research based on her observation showed that the UV light changes the bilirubin into another substance, which can be excreted. To this day, jaundiced newborns undergoing phototherapy are treated with UV light. Historically, newborns were diagnosed with jaundice based only on their physical appearance. However, it has been determined that this method is not always accurate. Now it is common to use either an instrument or a blood sample to measure the amount of bilirubin present in the serum.

In this first chapter of your study of chemistry, you will learn about the scientific method: the process of developing hypotheses to explain observations and the design of experiments to test those hypotheses.

You will also see that measurement of properties of matter, and careful observation and recording of data, are essential to scientific inquiry. So too is assessment of the precision and accuracy of measurements. Measurements (data) must be reported to allow others to determine their significance. Therefore, an understanding of significant figures, and the ability to represent data in the most meaningful units, enables other scientists to interpret data and results.

Continued

The following Learning Goals of this chapter will help you develop the skills needed to represent and communicate data and results from scientific inquiry.

1 Outline a strategy for learning general chemistry.
2 Explain the relationship between chemistry, matter, and energy.
3 Discuss the approach to science, the scientific method, and distinguish among the terms *hypothesis, theory,* and *scientific law.*
4 Distinguish between *data* and *results.*
5 Describe the properties of the solid, liquid, and gaseous states.
6 Classify matter according to its composition.
7 Provide specific examples of physical and chemical properties and physical and chemical changes.
8 Distinguish between intensive and extensive properties.
9 Identify the major units of measure in the English and metric systems.
10 Report data and calculate results using scientific notation and the proper number of significant figures.
11 Distinguish between *accuracy* and *precision* and their representations: *error* and *deviation.*
12 Convert between units of the English and metric systems.
13 Know the three common temperature scales, and convert values from one scale to another.
14 Use density, mass, and volume in problem solving, and calculate the specific gravity of a substance from its density.

1.1 Strategies for Success in Chemistry

The Science of Learning Chemistry

A growing body of scientists, including neurobiologists, chemists, and educational psychologists, study the process of learning. Their research has shown that there are measurable changes in the brain as learning occurs. While the research on brain chemistry and learning continues, the results to date have taught us some very successful strategies for learning chemistry. One of the important things we have learned is that, in the same way that repetition in physical exercise builds muscle, long-term retention of facts and concepts also requires repetition. As in physical exercise, a proven plan of action is invaluable for learning. Repetition is a central component of the **Study Cycle,** Figure 1.1, a plan for learning. Following this approach can lead to success, not only in chemistry, but in any learning endeavor.

Learning General Chemistry

LEARNING GOAL

1 Outline a strategy for learning general chemistry.

The first nine chapters of this book focus on the basic principles of **general chemistry.** General chemistry incorporates concepts that connect most aspects of chemistry. The thought of mastering this information can appear to be a daunting task. As the authors, we have combined our experiences (first as students, then as instructors), along with input from dozens of fellow chemistry professors, to design a book with content and features that will support you as you learn chemistry.

We suggest several strategies that you can use to help convert the concepts in Chapters 1–9 into an organized framework that facilitates your understanding of general chemistry:

1. Several researchers have demonstrated the importance of previewing materials prior to each class. As you look through the chapter, identify the concepts that are unclear to you. It is critical to address these unclear ideas because if you don't, they will become barriers to your understanding throughout the course, not just in the chapter you are currently studying. Ask for clarification. Your instructor

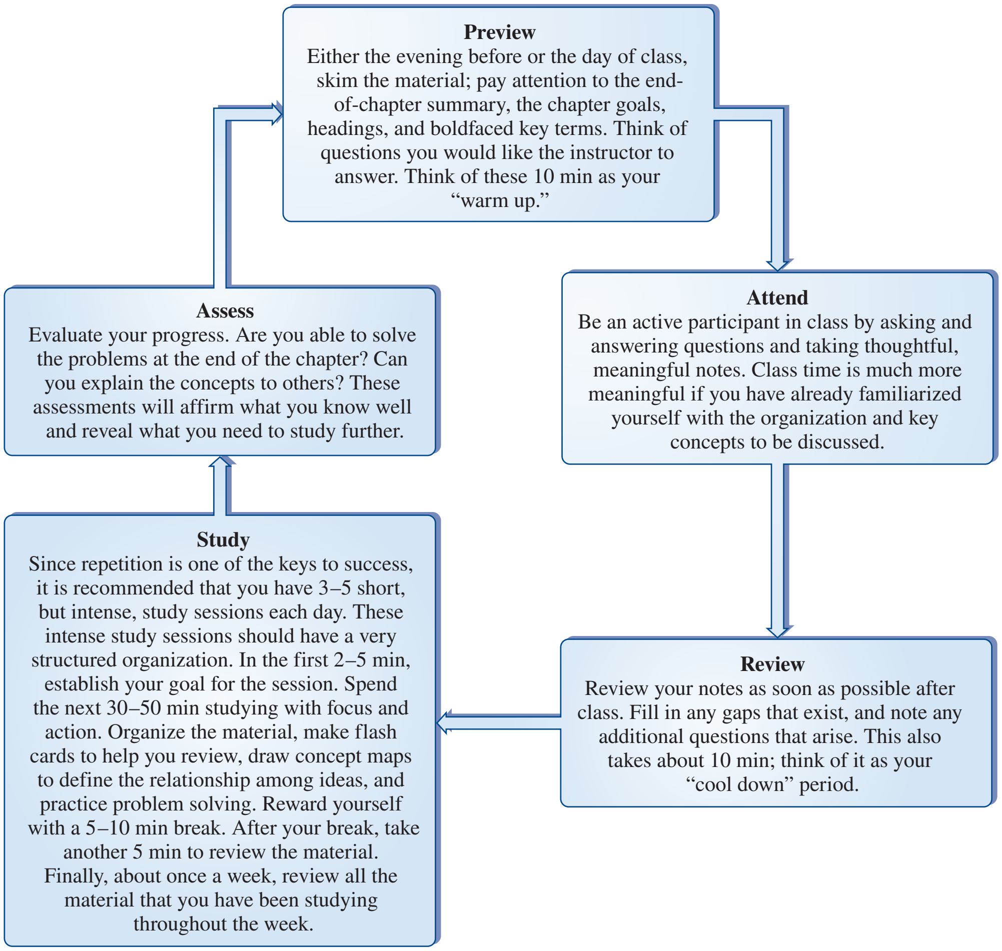
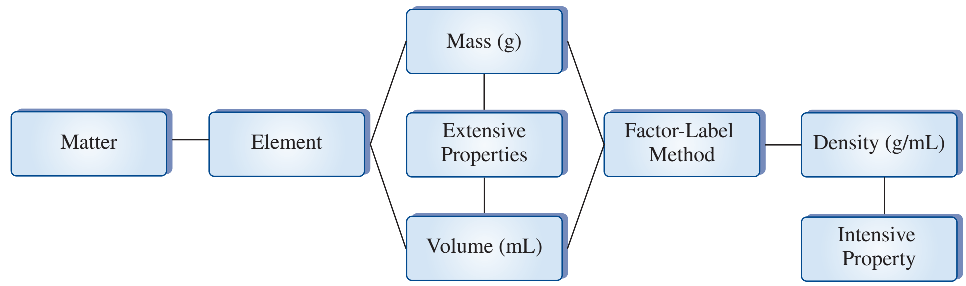


Figure 1.1 Research has shown that it can be effective for students to incorporate these five phases of the Study Cycle into their study plan.

should be a primary contact; additionally, the department or college may have a student resource center with tutors to help you.

2. Class time is another opportunity to improve your understanding. Students who actively participate in class, asking questions and participating in the discussion, gain a better understanding of the materials and achieve better grades.
3. Your class notes are another important study tool. As you review them after class, take note of questions you have and use the text to try to answer those questions.
4. You will find it very useful to design flash cards for use as a study tool for key equations, definitions, or relationships.
5. Identify big ideas. The learning goals at the beginning of each chapter are an excellent place to start. Additionally, the boldfaced terms throughout each chapter highlight the most important concepts.
6. Organize the material in a way that lends itself to processing not only individual concepts but the interrelationships that exist among these concepts. As you organize the big ideas, look for these connections. Use the chapter maps and summaries at the end of each chapter to help you visualize the organization of topics within and among the various chapters.
7. Concept maps are excellent tools to help you define and understand the relationships among ideas. For example, Chapter 1 introduces classification of matter and properties of matter. The use of "chemical arithmetic" is also presented to make

useful chemical and physical calculations. To understand these connections, you might begin with a diagram such as:



Then, next to each line you can write the relationship between these concepts. You can also continue to build upon your concept map as you continue to learn new material. The concepts and calculations introduced in Chapter 1 are used and expanded upon in subsequent chapters, enabling a fuller understanding of more complex chemical behavior.

8. Use the in-chapter and end-of-chapter questions and problems as your own personal quiz. Attempt to answer the questions and problems dealing with a certain topic; then check the answers in the textbook. Use the textbook explanations and Solutions Manual to help you determine where you may have gone wrong. Remember that numerous example problems in the chapter model solutions to the most frequently encountered situations.

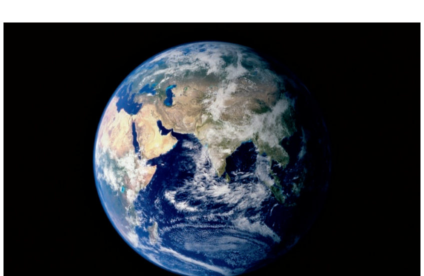
Remember, these are suggestions. You may find that some work well for you and others, perhaps, not as well. The goal is active learning; you are ultimately responsible for learning the material. Preparation builds confidence; confidence is a key component of success in exams and, importantly, success in the course.

Question 1.1 Each student is a unique individual; not all students learn in the same way. Based on what you have read above, coupled with your own experience, design a learning strategy for Chapter 1 that you believe will work for you.

Question 1.2 Discuss how you can determine what the big ideas are within a chapter.

LEARNING GOAL

2 Explain the relationship between chemistry, matter, and energy.



Chemistry is the study of anything that has mass and occupies space.
Purestock/SuperStock

1.2 The Discovery Process

Chemistry

Chemistry is the study of matter, its chemical and physical properties, the chemical and physical changes it undergoes, and the energy changes that accompany those processes.

Matter is anything that has mass and occupies space. The air we breathe, our bodies, our planet earth, our universe; all are made up of an immense variety and quantity of particles, collectively termed matter. Matter undergoes change. Sometimes this change occurs naturally or we change matter when we make new substances (creating drugs in a pharmaceutical laboratory). All of these changes involve **energy,** the ability to do work to accomplish some change. Hence, we may describe chemistry as a study of matter and energy and their interrelationship.

Chemistry is an experimental science. A traditional image of a chemist is someone wearing a white coat and safety goggles while working in solitude in a laboratory. Although much chemistry is still accomplished in a traditional laboratory setting, over the last 40 years the boundaries of the laboratory have expanded to include the power of modern technology. For example, searching the scientific literature for information no longer involves a trip to the library as it is now done very quickly via the Internet. Computers are also invaluable in the laboratory because they control sophisticated instrumentation that measures, collects, processes, and interprets information. The behavior of matter can also be modeled using sophisticated computer programs.

Additionally, chemistry is a collaborative process. The solitary scientist, working in isolation, is a relic of the past. Complex problems dealing with topics such as the environment, disease, forensics, and DNA require input from other scientists and mathematicians who can bring a wide variety of expertise to problems that are chemical in nature.

The boundaries between the traditional sciences of chemistry, physics, and biology, as well as mathematics and computer science, have gradually faded. Medical practitioners, physicians, nurses, and medical technologists use therapies that contain elements of all these disciplines. The rapid expansion of the pharmaceutical industry is based on recognition of the relationship between the function of an organism and its basic chemical makeup. Function is a consequence of changes that chemical substances undergo.

For these reasons, an understanding of basic chemical principles is essential for anyone considering a medically related career; indeed, a worker in any science-related field will benefit from an understanding of the principles and applications of chemistry.

Investigating the causes of the rapid melting of glaciers is a global application of chemistry. How does this illustrate the interaction of matter and energy?
Vadim Balakin/Getty Images

The Scientific Method

LEARNING GOAL

3 Discuss the approach to science, the scientific method, and distinguish among the terms *hypothesis, theory,* and *scientific law.*

The **scientific method** is a systematic approach to the discovery of new information. How do we learn about the properties of matter, the way it behaves in nature, and how it can be modified to make useful products? Chemists do this by using the scientific method to study the way in which matter changes under carefully controlled conditions.

The scientific method is not a "cookbook recipe" that, if followed faithfully, will yield new discoveries; rather, it is an organized approach to solving scientific problems. Every scientist brings his or her own curiosity, creativity, and imagination to scientific study. Yet, scientific inquiry does involve some of the "cookbook recipe" approach.

Characteristics of the scientific process include the following:

- *Observation.* The description of, for example, the color, taste, or odor of a substance is a result of observation. The measurement of the temperature of a liquid or the size or mass of a solid results from observation.
- *Formulation of a question.* Humankind's fundamental curiosity motivates questions of why and how things work.
- *Pattern recognition.* When a cause-and-effect relationship is found, it may be the basis of a generalized explanation of substances and their behavior.
- *Theory development.* When scientists observe a phenomenon, they want to explain it. The process of explaining observed behavior begins with a hypothesis. A **hypothesis** is simply an attempt to explain an observation, or series of observations. If many experiments support a hypothesis, it may attain the status of a theory. A **theory** is a hypothesis supported by extensive testing (experimentation) that explains scientific observations and data and can accurately predict new observations and data.
- *Experimentation.* Demonstrating the correctness of hypotheses and theories is at the heart of the scientific method. This is done by carrying out carefully designed experiments that will either support or disprove the hypothesis or theory. A scientific experiment produces **data.** Each piece of data is the individual result of a single measurement or observation.

  A **result** is the outcome of an experiment. Data and results may be identical, but more often, several related pieces of data are combined, and logic is used to produce a result.

LEARNING GOAL

4 Distinguish between *data* and *results.*

- *Information summarization.* A **scientific law** is nothing more than the summary of a large quantity of information. For example, the law of conservation of matter states that matter cannot be created or destroyed, only converted from one form to another. This statement represents a massive body of chemical information gathered from experiments.

LEARNING GOAL

4 Distinguish between *data* and *results*.

EXAMPLE 1.1 Distinguishing Between Data and Results

In many cases, a drug is less stable in the presence of moisture, and excess moisture can hasten the breakdown of the active ingredient, leading to loss of potency. Bupropion (Wellbutrin) is an antidepressant that is moisture sensitive. Describe an experiment that will allow for the determination of the quantity of water gained by a certain quantity of bupropion when it is exposed to air.

Solution

To do this experiment, we must first weigh the buproprion sample, and then expose it to the air for a period of time and reweigh it. The change in weight,

$$[\text{weight}_{\text{final}} - \text{weight}_{\text{initial}}] = \text{weight difference}$$

indicates the weight of water taken up by the drug formulation. The initial and final weights are individual bits of *data;* by themselves they do not answer the question, but they do provide the information necessary to calculate the answer: the results. The difference in weight and the conclusions based on the observed change in weight are the *results* of the experiment.

Note: This is actually not a very good experiment because many conditions were not measured. Measurement of the temperature, humidity of the atmosphere, and the length of time that the drug was exposed to the air would make the results less ambiguous.

Practice Problem 1.1

Describe an experiment that demonstrates that the boiling point of water changes when salt (sodium chloride) is added to the water.

▶ For Further Practice: **Questions 1.41 and 1.42.**

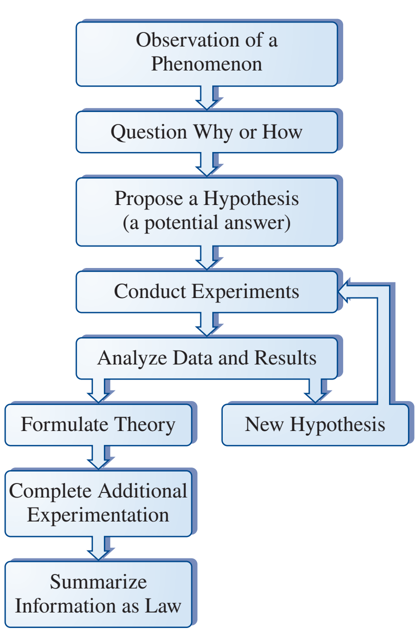


Figure 1.2 The scientific method is an organized way of doing science that incorporates a degree of trial and error. If the data analysis and results do not support the initial hypothesis, the cycle must begin again.

The scientific method involves the interactive use of hypotheses, development of theories, and thorough testing of theories using well-designed experiments. It is summarized in Figure 1.2.

Models in Chemistry

Hypotheses, theories, and laws are frequently expressed using mathematical equations. These equations may confuse all but the best of mathematicians. For this reason, a *model* of a chemical unit or system is often used to help illustrate an idea. A good model based on everyday experience, although imperfect, gives a great deal of information in a simple fashion.

Consider the fundamental unit of methane, the major component of natural gas, which is composed of one carbon atom (symbolized by C) and four hydrogen atoms (symbolized by H).

A geometrically correct model of methane can be constructed from balls and sticks. The balls represent the individual atoms of hydrogen and carbon, and the sticks correspond to the attractive forces that hold the hydrogen and carbon together. The model consists of four balls representing hydrogen symmetrically arranged around a center ball representing carbon.

A Human Perspective

The Scientific Method

The discovery of penicillin by Alexander Fleming is an example of the scientific method at work. Fleming was studying the growth of bacteria. One day, his experiment was ruined because colonies of mold were growing on his plates. From this failed experiment, Fleming made an observation that would change the practice of medicine: Bacterial colonies could not grow in the area around the mold colonies. Fleming hypothesized that the mold was making a chemical compound that inhibited the growth of the bacteria. He performed a series of experiments designed to test this hypothesis.

The success of the scientific method is critically dependent upon carefully designed experiments that will either support or disprove the hypothesis. This is what Fleming did.

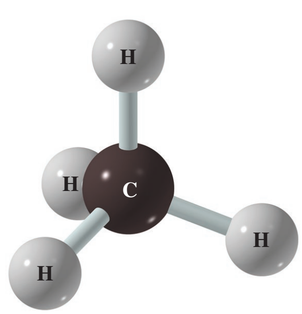
In one experiment, he used two sets of tubes containing sterile nutrient broth. To one set he added mold cells. The second set (the control tubes) remained sterile. The mold was allowed to grow for several days. Then the broth from each of the tubes (experimental and control) was passed through a filter to remove any mold cells. Next, bacteria were placed in each tube. If Fleming's hypothesis was correct, the tubes in which the mold had grown would contain the chemical that inhibits growth, and the bacteria would not grow. On the other hand, the control tubes (which were never used to grow mold) would allow bacterial growth. This is exactly what Fleming observed.

Within a few years this *antibiotic,* penicillin, was being used to treat bacterial infections in patients. You can learn more about how modern chemistry and technology have improved the pharmaceutical properties of penicillin antibiotics in *A Medical Perspective:* Semisynthetic Penicillins in Chapter 15.

Phenoxymethylpenicillin is a form of penicillin that can be taken orally.
Julian Claxton/Alamy Stock Photo

For Further Understanding

- What is the purpose of the control tubes used in this experiment?
- Match the features of this article with the flowchart items in Figure 1.2.



Color-coding the balls distinguishes one type of atom from another; the geometrical form of the model, all of the angles and dimensions of a tetrahedron, are the same for each methane unit found in nature. Methane is certainly not a collection of balls and sticks, but such models are valuable because they help us understand the chemical behavior of methane and other more complex substances.

The structure-properties concept has advanced so far that compounds are designed and synthesized in the laboratory with the hope that they will perform very specific functions, such as curing diseases that have been resistant to other forms of treatment. Figure 1.3 shows some of the variety of modern technology that has its roots in scientific inquiry.

Chemists and physicists have used the observed properties of matter to develop models of the individual units of matter. These models collectively make up what we now know as the atomic theory of matter, which is discussed in detail in Chapter 2.

Figure 1.3 Examples of technology originating from scientific inquiry: (a) synthesizing a new drug, (b) playing a game with virtual reality goggles, (c) using UV light to set adhesive, and (d) wireless printing from a smart phone.
(a) Adam Gault/age fotostock; (b) Rommel Canlas/Innovatedcaptures/123RF; (c) AJ Photo/Science Photo Library/Alamy Stock Photo; (d) Piotr Adamowicz/Shutterstock

1.3 The Classification of Matter

Matter is a large and seemingly unmanageable concept because it includes everything that has mass and occupies space. Chemistry becomes manageable as we classify matter according to its **properties**—that is, the characteristics of the matter. Matter will be classified in two ways in this section, by *state* and by *composition.*

States of Matter

We will examine each of the three states of matter in detail in Chapter 5.

LEARNING GOAL

5 Describe the properties of the solid, liquid, and gaseous states.

There are three *states of matter:* the **gaseous state,** the **liquid state,** and the **solid state.** A gas is made up of particles that are widely separated. In fact, a gas will expand to fill any container; it has no definite shape or volume. In contrast, particles of a liquid are closer together; a liquid has a definite volume but no definite shape; it takes on the shape of its container. A solid consists of particles that are close together and often have a regular and predictable pattern of particle arrangement (crystalline). The particles in a solid are much more organized than the particles in a liquid or a gas. As a result, a solid has both fixed volume and fixed shape. Attractive forces, which exist between all particles, are very pronounced in solids and much less so in gases.

Composition of Matter

LEARNING GOAL

6 Classify matter according to its composition.

We have seen that matter can be classified by its state as a solid, liquid, or gas. Another way to classify matter is by its composition. This very useful system, described in the following paragraphs and summarized in Figure 1.4, will be utilized throughout the textbook.

All matter is either a *pure substance* or a *mixture.* A **pure substance** has only one component. Pure water is a pure substance. It is made up only of particles containing two hydrogen (symbolized by H) atoms and one oxygen (symbolized by O) atom—that is, water molecules (H_2O).

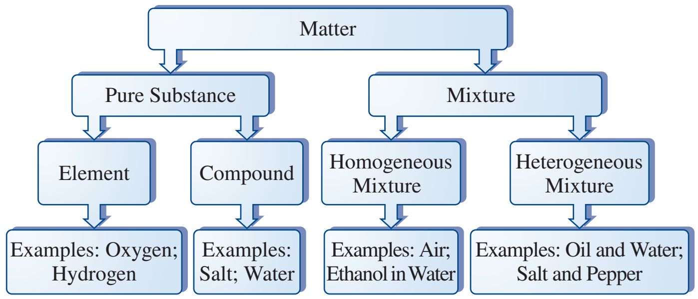


Figure 1.4 Classification of matter by composition. All matter is either a pure substance or a mixture of pure substances. Pure substances are either elements or compounds, and mixtures may be either homogeneous (uniform composition) or heterogeneous (nonuniform composition).

There are different types of pure substances. Elements and compounds are both pure substances. An **element** is a pure substance that generally cannot be changed into a simpler form of matter. Hydrogen and oxygen, for example, are elements. Alternatively, a **compound** is a substance resulting from the combination of two or more elements in a definite, reproducible way. The elements hydrogen and oxygen, as noted earlier, may combine to form the compound water, H_2O.

At present, more than 100 elements have been characterized. A complete listing of the elements and their symbols is found in Chapter 2.

A **mixture** is a combination of two or more pure substances in which each substance retains its own identity. Ethanol, the alcohol found in beer, and water can be combined in a mixture. They coexist as pure substances because they do not undergo a chemical reaction. A mixture has variable composition; there are an infinite number of combinations of quantities of ethanol and water that can be mixed. For example, the mixture may contain a small amount of ethanol and a large amount of water or vice versa. Each is, however, an ethanol-water mixture.

A mixture may be either *homogeneous* or *heterogeneous* (Figure 1.5). A **homogeneous mixture** has uniform composition. Its particles are well mixed, or thoroughly intermingled. A homogeneous mixture, such as alcohol and water, is described as a *solution*. Air, a mixture of gases, is an example of a gaseous solution. A **heterogeneous mixture** has a nonuniform composition. A mixture of salt and pepper is a good example of a heterogeneous mixture. Concrete is also composed of a heterogeneous mixture of materials (a nonuniform mixture of various types and sizes of stone and sand combined with cement).

A detailed discussion of solutions (homogeneous mixtures) and their properties is presented in Chapter 6.

(a) (b) (c)

Figure 1.5 Schematic representations of some classes of matter. (a) A pure substance, water, consists of a single component. (b) A homogeneous mixture, blue dye in water, has a uniform distribution of components. The blue spheres represent the blue dye molecules. (c) The mineral orbicular jasper is an example of a heterogeneous mixture. The lack of homogeneity is apparent from its nonuniform distribution of components. *(a) Image Source Plus/Alamy Stock Photo; (b) Image Source/Getty Images; (c) Danaè R. Quirk, Ph.D.*