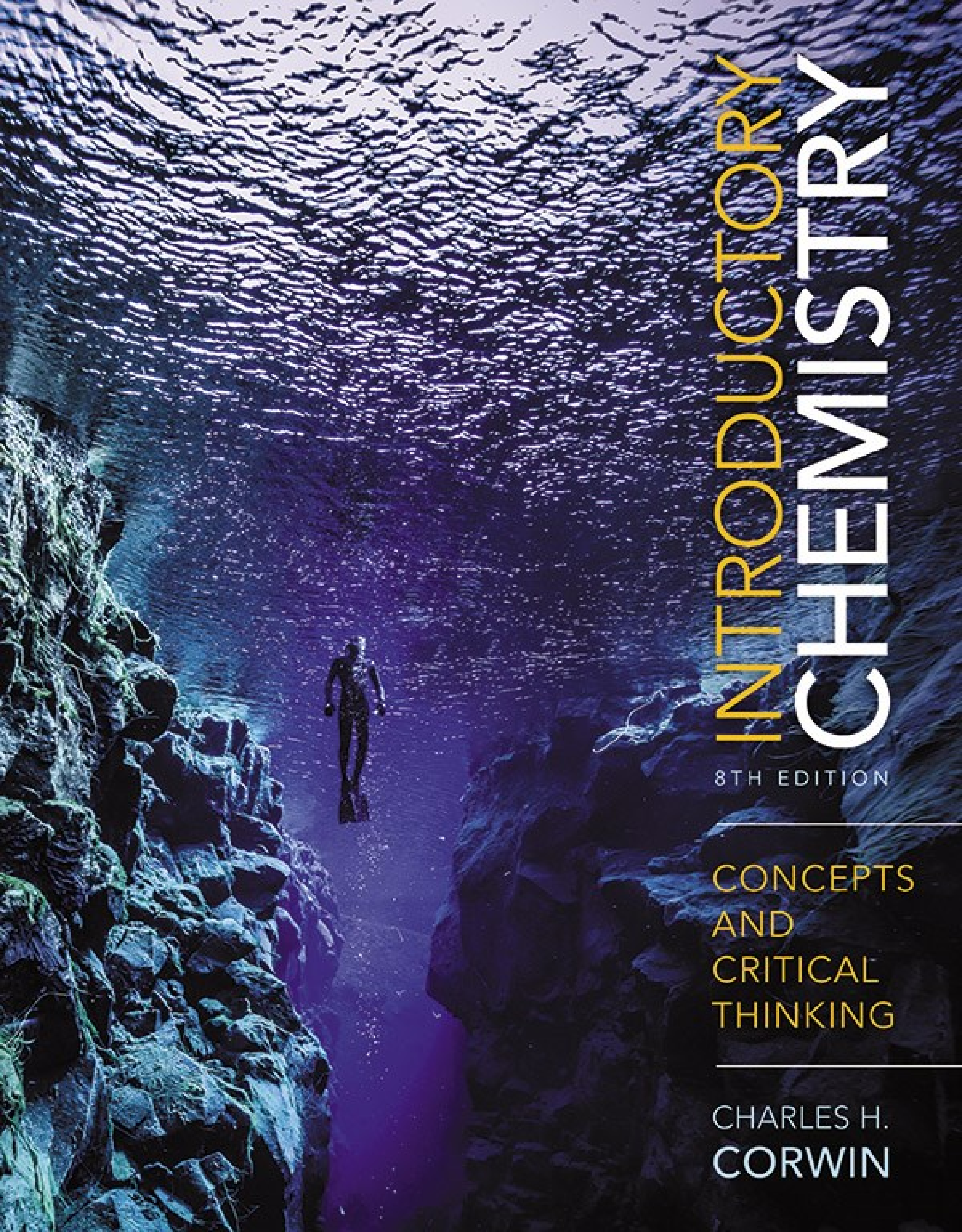

INTRODUCTORY CHEMISTRY

8TH EDITION

CONCEPTS AND CRITICAL THINKING

CHARLES H. CORWIN

INTRODUCTORY CHEMISTRY

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INTRODUCTORY CHEMISTRY

CONCEPTS AND CRITICAL THINKING

EIGHTH EDITION

Charles H. Corwin
American River College

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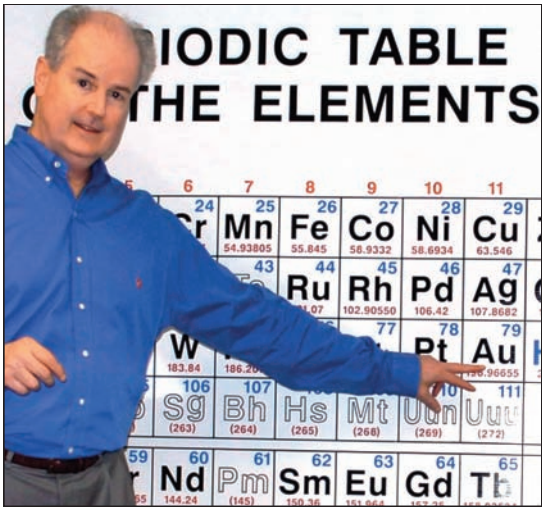
Brief Contents

About the Author



Charles H. Corwin has instructed more than 10,000 students in both lecture and laboratory of introductory and general chemistry. He acknowledges the diversity of basic chemistry students and employs a variety of classroom pedagogies based on Bloom's taxonomy, Myers-Briggs inventory, critical thinking, and algorithmic versus conceptual heuristics. His teaching strategies include learning by objective, collaborative group learning, web-based assignments, chemical demonstrations, and multimedia presentations.

The author was awarded degrees from San Jose State University, where he was a member of Tau Delta Phi honor society. He did graduate research at Stanford Research Institute on dialysis membranes, and attended the University of Akron, Institute of Polymer Science. He spent a sabbatical with the chemical education group at Purdue University studying a constructivist approach to cognitive development based on the work of Jean Piaget. Previously, he was visiting professor at Grand Valley State University on an NSF grant, and participated in a self-paced, mastery-learning study. He is currently interested in developing a hybrid online chemistry course with a laboratory component.

Professor Corwin has been recognized as instructor of the year at American River College, and has received a teaching award from Purdue University. In addition, he has been faculty mentor, department chair, academic senate representative, served on the ACS Examinations Committee and the California Chemistry Diagnostic Test Committee, has given numerous presentations to secondary schools and 2YC3, judged science projects at California state fairs, and for two decades was the examiner for the greater Sacramento region chemistry contest.

To the Student

A Personal Note I have been with you in lecture and answered your questions. I have been with you in lab and given you encouragement. Perhaps I have not spoken to you personally, but I have had countless conversations with students who are trying to juggle college life, financial aid, employment hours, relationship issues, test anxiety, and stress in general. If you are a first-time student, or a reentry student, my advice is to maintain regular student and instructor contacts, and network with others who can help guide you toward your goals.

Introductory chemistry is a subject that builds systematically and culminates in a knowledge base for the physical sciences, life sciences, health sciences, and beyond. Therefore, it is essential that you set aside time each day to study chemistry, and avoid last-minute cramming for exams. On days when you lack motivation, open the textbook to the attractive art that illustrates the topic you are studying; or, go online to the textbook website and view one of the presentations in MasteringChemistry®.

The completion of a basic chemistry course begins to open doors to a rewarding career. A rewarding career is a source of personal satisfaction that spreads to all aspects of your life and helps you avoid making poor life choices. I know you can be successful in your chemistry class. I have seen others like you with different expressions on their faces at the end of the semester. It is a look of confidence after accepting the challenge, doing their best, and knowing they are better prepared for what lies ahead.

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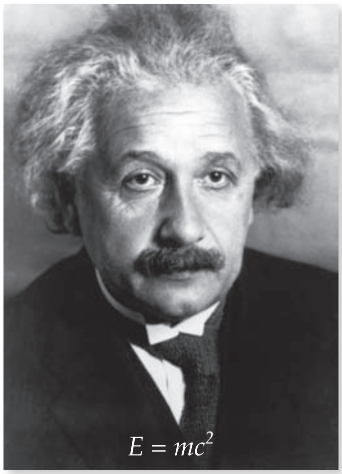

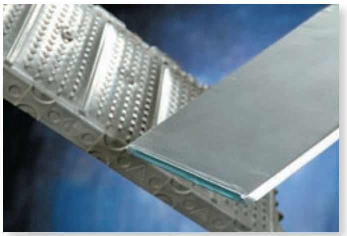

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Preface

It is my goal to hone each lecture presentation and improve my skill set each semester. Accordingly, I never leave campus without Post-It® notes for improving a presentation. I continually experiment with different topic organizations, employ multimedia and molecular models for visual concepts, perform chemical demonstrations to retain student interest, and alternate qualitative and quantitative topics to allow for topic assimilation and provide a fresh edge.

It is obvious from reviewer comments there is no consensus for the "right way" of presenting introductory chemistry. Each class situation varies with the course objectives and available facilities. In choosing an order of topic presentation in the *Eighth Edition,* I have weighed the arguments and made informed decisions.

Over a decade ago, many chemistry textbooks chose to move atomic theory and chemical bonding to later chapters. The genesis of this decision was based on Piagetian theory and the educational research that conceptual topics are a higher cognitive task, which dictates descriptive and algorithmic topics be covered early as a foundation. However, some chemistry texts prefer an "atoms first" approach, which is influenced by innate student interest in the atomic and molecular world.

Experienced instructors may have found that a mathematically "soft" approach resonates with students. In an effort to cultivate student interest, we can first discuss physical and chemical properties and assign easy tasks, such as learning names and symbols of chemical elements. The downside to this approach is that students who woefully lack basic math skills, will later experience difficulty with calculations, and may not succeed in spite of our best efforts.

The *Eighth Edition of Introductory Chemistry: Concepts and Critical Thinking* allows instructors great latitude in choosing their topic presentation. This was mandated by reviewers who argued for the early placement of certain topics, while others argued for a later placement. Suggestions for the order of topic presentation were particularly diverse in the following areas: atomic theory, chemical bonding, stoichiometry, and ionic equations.

We also asked reviewers to assess the rigor to which prerequisite science skills should be covered. The responses ranged from minimal to heavy emphasis; from relegation to an appendix to full chapter coverage. Obviously, a textbook cannot accommodate all views when there is such disparity. After weighing the alternatives, we opted for an interlude on *Prerequisite Science Skills* following Chapter 1. Students with a good preparation may find the material unnecessary; however, students with a weak preparation will find it invaluable.

A related area that has been considered at great length, is the depth of coverage for chemical calculations. In past editions, problem solving has received high marks by reviewers. In Chapter 15, *Advanced Problem Solving,* the chemical calculations are more rigorous, and the problem-solving covers a broad spectrum of techniques.

New to This Edition

In this Eighth Edition of *Introductory Chemistry: Concepts and Critical Thinking*, there have been substantial changes. In addition to a cover to cover revision, the *Eighth Edition* includes the following.

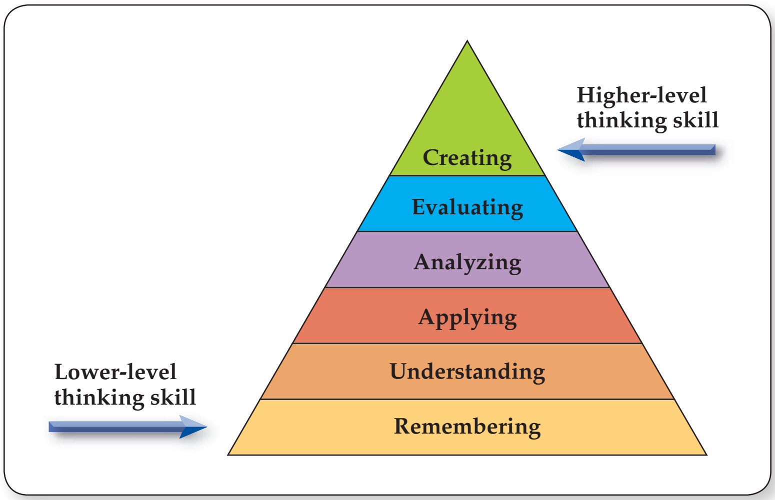
- Each **chapter opener** image is introduced with a numerical reference to an element in the periodic table. For example, Chapter 1 is introduced by the first element, hydrogen, along with a brief description.

1 H hydrogen

Element 1: Hydrogen
Hydrogen is the simplest and most abundant element in the universe. Beginning with the Big Bang 14 billion years ago, hydrogen atoms were scattered throughout

the universe. Subsequently, two hydrogen atoms fused to produce the second element helium, which in turn fused with another hydrogen atom to give the third element, lithium. Thus, each of the elements evolved beginning with hydrogen.

- New to this edition, are numerous **Helpful Hints**, in which the author addresses the student directly, as if to give private "coaching" based on points of known difficulty and confusion.
- New to this edition, there are features termed **A Closer Look,** which offer insights and thought-provoking information designed to maintain student interest, and often provide examples of misconceptions.
- Inorganic nomenclature has become an issue in introductory general chemistry. Historically, the Stock System and Latin System of nomenclature have both been provided in textbooks. Because the Stock System is preferred by IUPAC, some textbooks have deleted the Latin System. To address this issue, the Eighth Edition of this textbook added Section 6.7, **Latin System of Nomenclature,** which provides the instructor the option to assign, or not assign, the *Latin System* based on course objectives.



- New to the Eighth Edition, are additional **Example Exercises,** each of which includes a Practice Exercise and Concept Exercise. Because introductory chemistry students learn by working examples, this is an indispensable tool.
- Approximately one third of the end-of-chapter **Exercises** have been revised, along with the **Self-Test** that follows each end-of-chapter exercise.
- New to the Eighth Edition text is a revision of the learning objectives in accord with the action verb model, set forth by Benjamin Bloom and colleagues at the University of Chicago. **Bloom's Taxonomy** describes learning that takes place at different levels, which proceeds from simple remembering to creating. The pyramid icon to the left encapsulates the Bloom learning model. The Instructor's Manual lists the learning objectives for every chapter, and assigns each to a particular level. For instructors who demand much of their students, this resource may prove invaluable for predicting the difficulty of each objective relative to its skill level.

An Integrated Learning System

More than a textbook, *Introductory Chemistry: Concepts and Critical Thinking* is a comprehensive learning system that offers print and media resources as well as an extensive website. Unlike other chemistry texts, all the materials are coherently integrated with the textbook by a single author, including the student solutions manual, laboratory manual, instructor's manual, and test item file. Moreover, the genesis of the package is based on considerable classroom experience, student feedback, instructor feedback, and multiple rounds of reviewer feedback from dozens of institutions across the country.

Students are presented with the same topics, in the same sequence, using the same vocabulary, consistently in the textbook and all the supplements. Instructors are presented with a tightly integrated package including an Instructor's Resource Manual and a 3000-question Test Bank. The media resources include an Instructor Resource Center with lecture resources, including PowerPoint presentations, animations, and interactive activities. The Mastering platform provides customizable and automatically graded assessments that motivate students to come prepared for class.

Problem Solving

An important objective of this text is to help students become effective problem solvers. This is accomplished by a walk-through discussion of each new topic, followed by an example exercise, practice exercise, concept exercise, and a problem-solving organizer at the end of each quantitative chapter.

Previous editions have received positive reviews for systematic problem solving. In as much as basic chemistry students often have weak math skills, algebra has been scrupulously avoided in the early chapters in favor of the unit analysis method of problem solving. However, since many instructors prefer an algebraic approach to the gas laws, Chapter 10 offers both an algebraic and unit analysis approach to solving gas law problems.

To assist under-prepared students with a weak math/science background, the Eighth Edition offers a brief interlude on *Prerequisite Science Skills* that instructors can assign at their discretion.

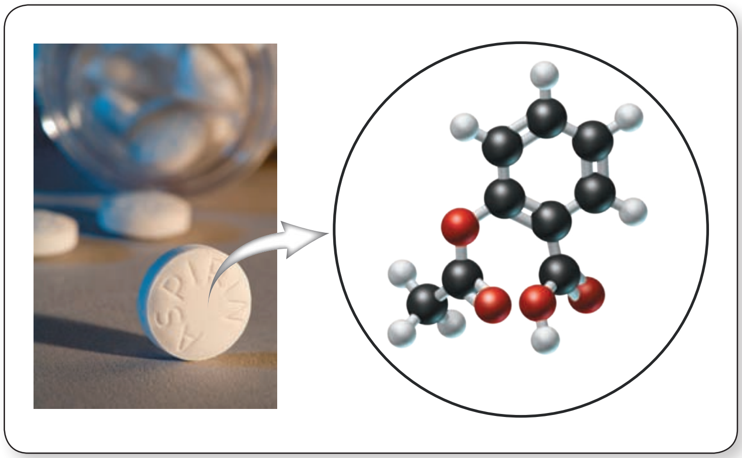
The Eighth Edition offers many end-of-chapter exercises (in matched pair format) correlated with each section of each chapter, as well as General Exercises and Challenge Exercises. Chapter 15, *Advanced Problems Solving,* discusses both the unit analysis method and algebraic method of problem solving; in addition, there is a discussion of the problem-solving techniques of visualization and drawing concept maps.

Language of Chemistry

Another important objective of this text is to help students learn the language of chemistry. To this end, each chapter has a unique matching exercise for all *key terms* that allows students to verify their definition in Appendix H. The *Study Guide and Selected Solutions Manual* has a computer-generated crossword puzzle of key terms for each chapter that provides a fun way to learn the language.

Conceptual Learning

Introductory chemistry students often require motivation to learn this subject. To this end, in the Eighth Edition we have refined the palette of colors and style of rendering to achieve a new level of sophistication in illustrations and photographs. The molecular art program has been enhanced by providing molecular structures for chemical formulas and chemical reactions. Moreover, photographs are enhanced by providing macro/micro molecular art. This visual presentation not only enhances interest in the topics, but adds an effective pedagogical tool for understanding concepts that students find difficult to grasp.



Aspirin, acetylsalicylic acid, has the molecular formula $C_9H_8O_4$.

Critical Thinking

Cognitive scientists define *"critical thinking"* as mental activity associated with three processes: applying reason, making decisions, and solving problems. In this textbook, critical thinking is especially evident in the different approaches to solving chemistry problems. Critical thinking questions are in the end-of-chapter *Self-Tests,* and misconceptions are probed in many of the vignettes entitled *A Closer Look;* for example, *Metric Labels* and *Lower Gasoline Bills.*

Flexible Chapter Sequence

For a variety of reasons, no two introductory chemistry classes present topics in the same exact order. Accordingly, the chapter sequence in *Introductory Chemistry: Concepts and Critical Thinking,* Eighth Edition is constructed in such a way so as to accommodate alternate sequences. For example, chemical bonding (Chapter 12) can immediately follow atomic theory and periodicity (Chapters 4 and 5); ionic equations can follow chemical reactions (Chapter 7); and gas stoichiometry can be deferred to the gas laws (Chapter 10).

Acknowledgments

I would like to thank the reviewers, instructors, and students who have helped make this learning package so successful. I teach chemistry at a large community college (~40,000 students) with a high enrollment for introductory chemistry. Students and colleagues continually keep me on my toes, and emails from students and instructors around the country assure broad success in the classroom.

I also want to acknowledge the "team members" for their contribution to the Eighth Edition. Scott Dustan, Senior Courseware Portfolio Manager, arrived with extensive experience, and from the outset placed a firm hand on the project. A special thank you to Brett Coker, Content Producer, who indulged me with lengthy phone conversations that ironed out issues, while keeping the project on schedule. Matt Walker, Courseware Analyst, reviewed each chapter of the previous edition and had many suggestions that were implemented. Julie Lafflin, photo researcher, provided high-quality photos within new constraints for photo usage. T. J. Mullen, accuracy reviewer, had the difficult task of ferreting out miscues introduced from a variety of sources. Nancy Moyer, proofreader, was amazingly meticulous and taught me the difference between "since" and "because" and other grammatical fine points. To each of these individuals, singly and collectively, I extend my sincere appreciation.

Reviewers of The Eighth Edition

The reviewers of this and previous editions of *Introductory Chemistry* continue to define that vague line between the simplifications that students require and the explanations that accuracy and detailed breadth of coverage demand. I thank them for working with me to make this a better resource for students learning chemistry.

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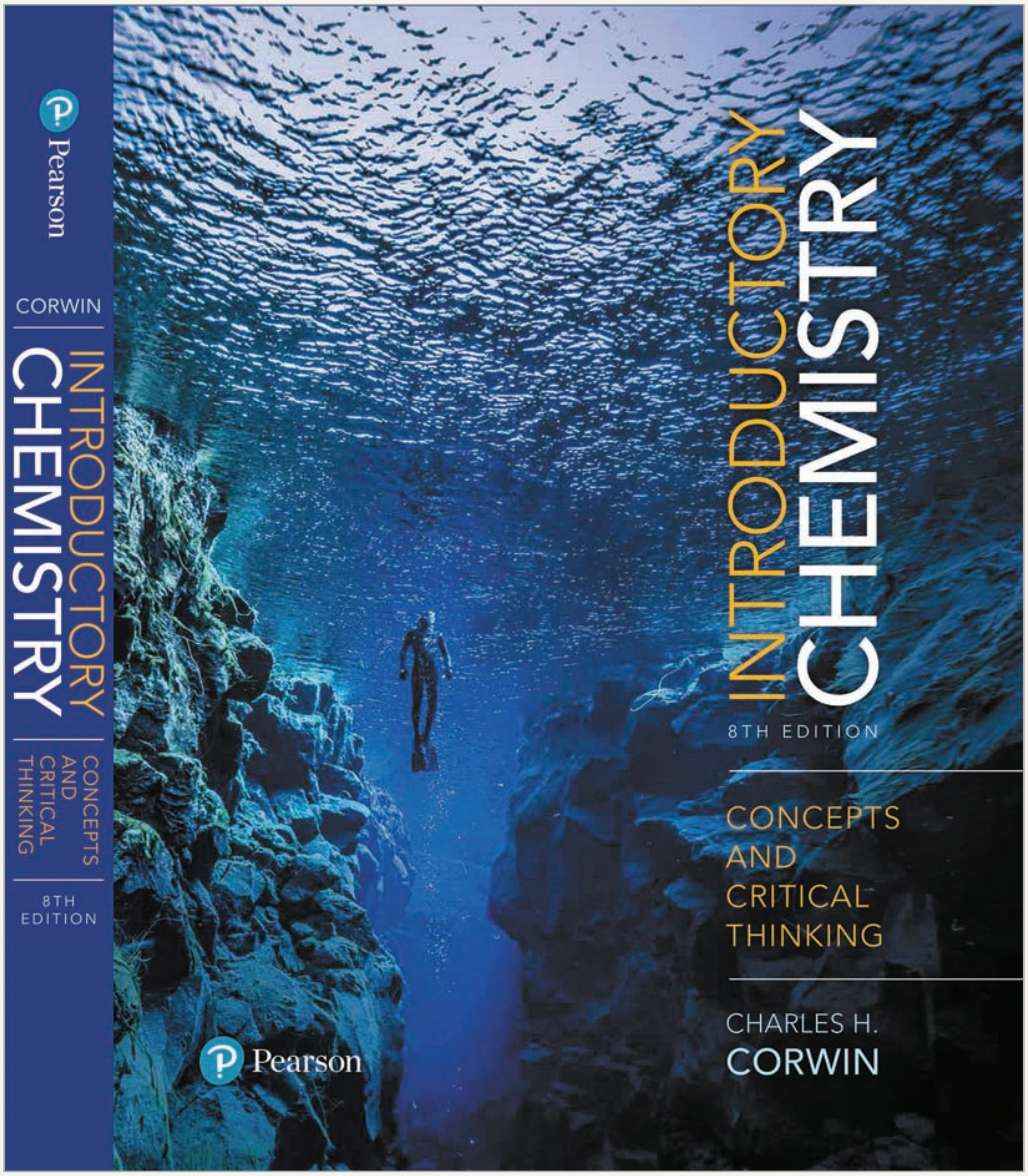
Inspire your students' curiosity around chemistry

Introductory Chemistry: Concepts and Critical Thinking will truly inspire your students to engage with the chemistry concepts presented in the text and see the world around them in a new light.

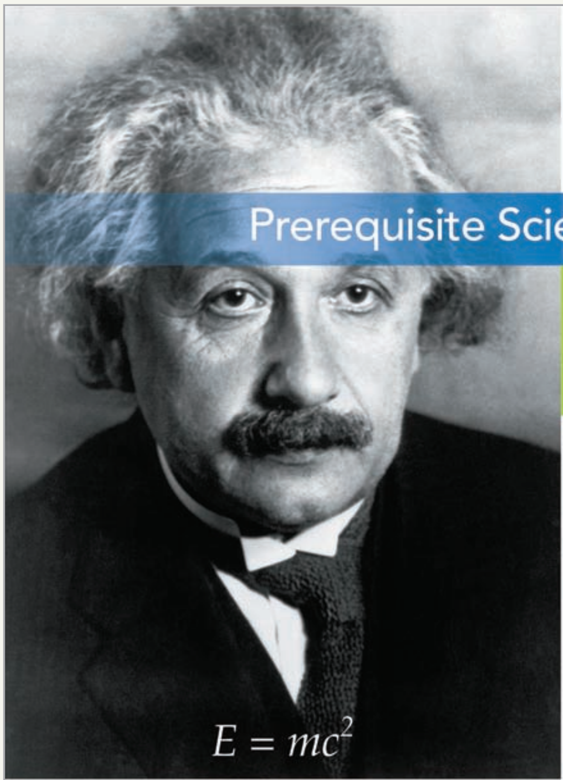
Written in an incredibly student-friendly style by experienced teacher Chuck Corwin, *Introductory Chemistry: Concepts and Critical Thinking* is a comprehensive learning system that offers print and media resources all written by the author himself, as well as an extensive MasteringChemistry course.

With this new edition, you will find two key themes woven throughout the text: addressing student needs when, where, and how they arise and engaging students through rich media and compelling applications. Turn the page to see more.



Build skills critical to student success

Problem Solving Skills



Prerequisite Science Skills

"Logic will get you from A to B. Imagination will take you everywhere."
Albert Einstein, German-Swiss-American Physicist (1879–1955)

Albert Einstein (1879–1955)
Although Einstein was slow to speak and had difficulty in school as a child, he would go on to become the most famous scientist of the twentieth century. From his theory of relativity, we have the equation $E = mc^2$, which relates energy (E), mass (m), and the speed of light (c).

PSS.1 Measurements

In chemistry, we express a **measurement** using the metric system. A common unit of length is a **centimeter (cm)**, a unit of mass is a **gram (g)**, and a unit of volume is a **milliliter (mL)**. Figure PSS.1 shows metric estimates for length, mass, and volume.

Measurements require the use of an **instrument**. The exactness of the measurement depends on the sensitivity of the instrument. For instance, an electronic balance can measure mass to 0.001 g. However, an exact measurement is not

The Prerequisite Science Skills interlude helps students with weak math or science backgrounds prepare for chemical calculations. The brief interlude is an optional assignment at the discretion of the instructor and can be found between chapters one and two in the text, as well as within MasteringChemistry (many topics are available as assignable tutorials).

EXAMPLE EXERCISE 4.3 Calculation of Atomic Mass

Silicon is the second most abundant element in Earth's crust. Calculate the atomic mass of silicon given the following data for its three natural isotopes:

Isotope	Mass	Abundance
^{28}Si	27.977 amu	92.21%
^{29}Si	28.976 amu	4.70%
^{30}Si	29.974 amu	3.09%

Solution
We can find the atomic mass of silicon as follows:

$$^{28}\text{Si: } 27.977\text{ amu} \times 0.9221 = 25.80\text{ amu}$$
$$^{29}\text{Si: } 28.976\text{ amu} \times 0.0470 = 1.36\text{ amu}$$
$$^{30}\text{Si: } 29.974\text{ amu} \times 0.0309 = 0.926\text{ amu}$$
$$28.09\text{ amu}$$

The average mass of a silicon atom is 28.09 amu, although we should note that there are no silicon atoms with a mass of 28.09 amu.

Practice Exercise
Calculate the atomic mass of copper given the following data:

Isotope	Mass	Abundance
^{63}Cu	62.930 amu	69.09%
^{65}Cu	64.928 amu	30.91%

Answer: 63.55 amu

Concept Exercise
A bag of marbles has 75 large marbles with a mass of 2.00 g each, and 25 small marbles with a mass of 1.00 g each. Calculate (a) the simple average mass, and (b) the weighted average mass of the marble collection.

Answer: See Appendix G, 4.3.

NEW to the eighth edition are many additional **Example Exercises**, each including an accompanying **Practice Exercise and Concept Exercise,** which walk students through this important skill. This indispensable tool has been informed by the author's many years' experience of teaching thousands of introductory chemistry students.

in Future courses and careers

Critical Thinking and Conceptual Understanding

NEW to this edition, numerous **Helpful Hints** have been added; marginal notes in which the author addresses the student directly, as if giving private "coaching" based on points of known difficulty and confusion. This helps students think critically about what they are learning and gives them the confidence to move forward once they understand the concept.

122 CHAPTER 4 MODELS OF THE ATOM

Helpful Hint
Bohr Model vs. Quantum Mechanics
Just as the Thomson model of the atom was simplistic compared to the Bohr model of the atom, the Bohr model is far less sophisticated than the quantum mechanical model of the atom. Studying the Bohr model of the atom, we can visualize electrons circling the atomic nucleus in orbits of fixed energy. Electrons that occupy orbits farther from the nucleus have greater energy than those closer to the nucleus.
The quantum mechanical model of the atom considers electrons to have both a wave and particle nature. Rather than stating the precise orbit that an electron occupies, quantum mechanics states the probability of finding an electron with a given energy within a spatial volume. The term "orbit" applies to the Bohr model, while the term "orbital" is reserved for the quantum mechanical model.

simultaneously. In fact, the more accurately the location of an electron in an atom is known, the less precisely its energy can be determined.

In 1932, Heisenberg won the Nobel Prize in physics for his uncertainty principle. Not everyone, however, subscribed to the principle of uncertainty. Some physicists found it unsettling to consider that they might live in a universe ruled by chance. Albert Einstein (1879–1955) was sufficiently troubled by the uncertainty principle that he offered the famous quote: "It seems hard to look into God's cards, but I cannot for a moment believe He plays dice as the current quantum theory alleges He does." Although the uncertainty principle was initially controversial, it was a crucial concept for explaining the new model of the atom.

Gradually, the deeper nature of the atom came into focus. The new model retained the idea of quantized energy levels, but incorporated the concept of uncertainty. The new model that emerged became known as the **quantum mechanical atom**. Recall that in the Bohr model the energy of an electron is defined in terms of a fixed-energy orbit about the nucleus. In the quantum mechanical model, the energy of an electron can be described in terms of the probability of it being within a spatial volume surrounding the nucleus. This region of high probability (~95%) for finding an electron of given energy is called an **orbital**.

Sizes and Shapes of *s* and *p* Orbitals

In the quantum mechanical atom, orbitals are arranged about the nucleus according to their size and shape. In general, electrons having higher energy are found in larger orbitals. Similar to the energy levels in the Bohr atom, the energy of orbitals is quantized and assigned a whole number value such as 1, 2, 3, 4, ... As the number increases, the energy and size of an orbital also increases.

We can describe the shapes of orbitals by the letters *s*, *p*, *d*, and *f*. For example, the shape of an *s* orbital is that of a sphere, and the shape of a *p* orbital is that of a dumbbell. We can designate the size and shape of an orbital by combining the number that indicates its energy, and the letter that indicates its shape. For example, the designations 1*s*, 2*p*, and 3*d* indicates three orbitals that differ in size, energy, and shape. All *s* orbitals are spherical, but they are not all the same size. A 3*s* orbital is a larger sphere than a 2*s*, and a 2*s* orbital is larger than a 1*s*. That is, the size and energy of the orbital increase as the energy level increases. Figure 4.17 illustrates the relationship between *s* orbitals about the nucleus.

A CLOSER LOOK "Nuking" Food in a Microwave Oven

Q: How is food heated in a microwave oven?

◀ Microwave oven

The term "nuking" food originated after World War II, which is when the United States developed the first atomic bomb and nuclear weapons. The microwave oven was developed during this same period; hence, the term "nuking" food became popular. The term is still popular today, but do microwave ovens "nuke" food in order to heat it?

The microwave region of the radiant energy spectrum spans wavelengths of approximately 0.1 cm to 100 cm. The radiation in a microwave oven has a wavelength of 12 cm. Refer to Figure 4.9 and notice that microwaves have a longer wavelength (less energy) than infrared radiation, which has a longer wavelength (less energy) than visible light.

When placing food in a microwave oven, the food is exposed to microwave energy that heats the food by causing the water molecules in the food to rotate faster. When the water molecules lose rotational energy and return to their normal energy state at room temperature, the energy lost by the water molecules heats the food.

When an atomic nucleus loses energy, the radiant energy corresponds to very high energy gamma rays (see Figure 4.9). Gamma rays have wavelengths that are a billion times shorter than microwaves, but much higher frequency and energy. Exposing food to gamma radiation would completely destroy the food.

Although microwave cooking is generally considered healthy, and food retains more vitamins than stove-cooked food, not all microwaved food is safe. According to the U.S. Department of Agriculture, we should avoid microwave cooking in disposable plastic containers as microwaves can leach harmful chemicals into the food. The alternative is to use microwave-safe plastic or glass containers.

A: The energy inside a microwave oven causes the water molecules in food to rotate faster. When these molecules lose rotational energy and return to their normal energy state at room temperature, the energy lost by the water molecules heats the food.

NEW to this edition **A Closer Look** boxes offer insights and thought-provoking information on topics such as "Nuking" Food in a Microwave Oven, Nitrogen in Tires, Household Chemicals, The Ozone Hole, and Water Fluoridation, designed to connect students to the chemical world around them and, often, provide examples of common misconceptions.

Extend student learning before, during, and after class

BEFORE CLASS

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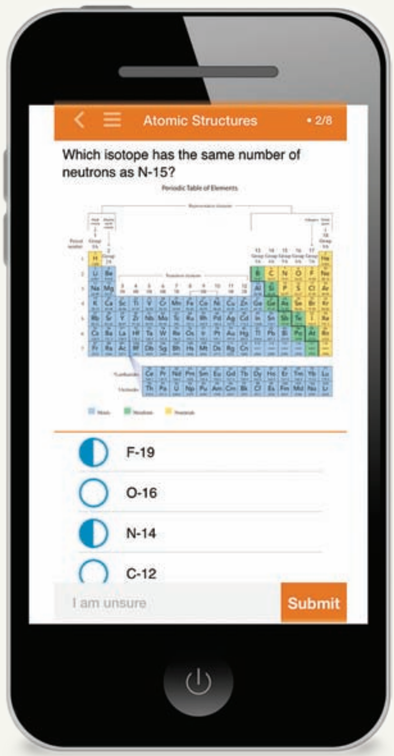

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- Students complete a set of questions with a unique answer format that also asks them to indicate their confidence level. Questions repeat until the student can answer them all correctly and confidently. These are available as graded assignments prior to class and are accessible on smartphones, tablets, and computers.
- Topics include key math skills such as significant figures and scientific notation, as well as general chemistry concepts such as understanding matter, chemical reactions, and understanding the periodic table & atomic structure. Topics can be added or removed to match your coverage.

NEW! Prerequisite Science Skill Tutorials

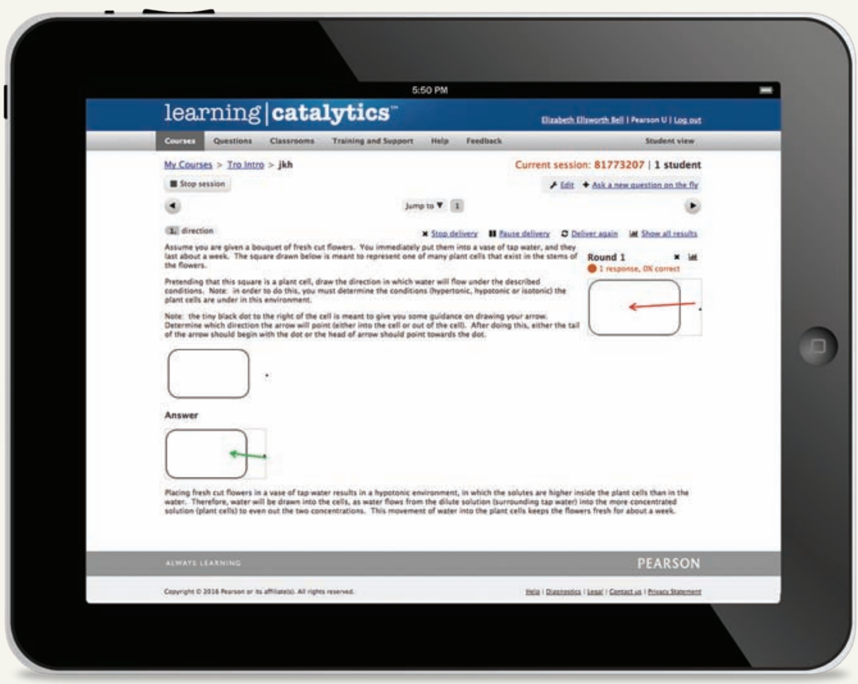
Bringing the aforementioned interlude to life, Video Tutor Solutions cover topics of measurements, significant digits, rounding off nonsignificant digits, adding and subtracting measurements, multiplying and dividing measurements, exponential numbers, and scientific notation from the popular Prerequisite Science Skills section of the book.

with MasteringChemistry™

DURING CLASS

Learning Catalytics™ generates class discussion, can help to guide your lecture, and promotes peer-to-peer learning with real-time analytics. MasteringChemistry with eText now includes Learning Catalytics, an interactive student response tool that uses students' smartphones, tablets, or laptops to engage them in more sophisticated tasks and thinking. Instructors can:

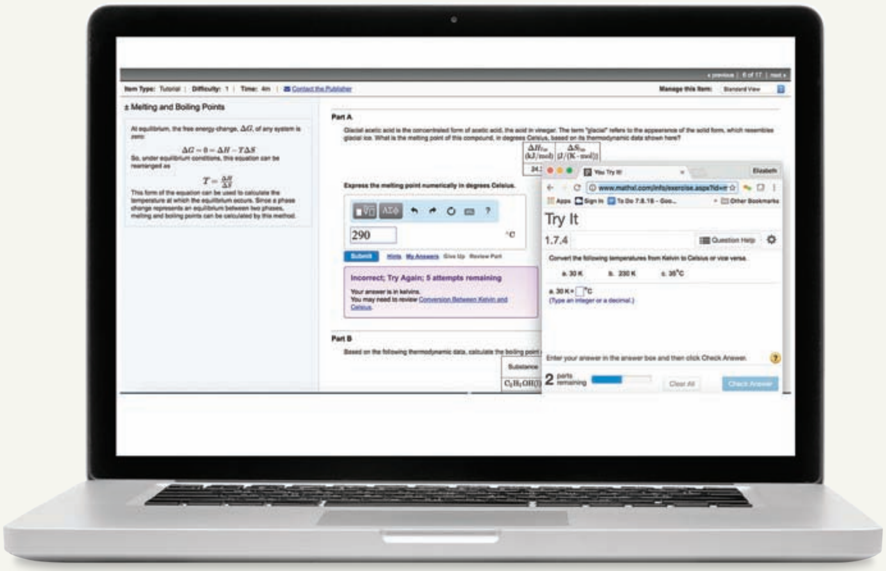
- **NEW!** upload a full PowerPoint® deck for easy creation of slide questions
- **HELP** students develop critical thinking skills
- **MONITOR** responses to find out where students are struggling
- **RELY** on real-time data to adjust a teaching strategy
- **GROUP** students automatically for discussion, teamwork, and peer-to-peer learning



Close the learning loop with after-class assignments

AFTER CLASS

Assignable, in-depth tutorials guide students through the toughest topics in chemistry with individualized coaching. These self-paced tutorials aid students with hints and feedback specific to individual misconceptions. Tutorials respond, at any step, to a wide variety of typical wrong answers that students enter, and offer hints, allowing students to choose specific help when they need it.



Math Remediation links in selected tutorials launch algorithmically generated math exercises that give students unlimited practice on prerequisite skills, freeing 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.

Etext 2.0

NEW! eText 2.0 brings the text to life with new and enhanced features:

- **Full eReader functionality** includes page navigation, search, glossary, highlighting, note taking, annotations, and more.
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- **In-context glossary** offers students instant access to definitions by simply hovering over key terms.
- **Seamlessly integrated videos and activities** allow students to watch and practice key concepts within the eText learning experience.
- **Accessible** (screen-reader ready).
- **Configurable reading settings**, including resizable type and night reading mode.

Instructor and student supplements

Instructor Resource Center

This lecture resource contains selected art from the textbook, three pre-built PowerPoint® presentations, animations, interactive activities, the Instructor's Manual lecture outlines in Word® format, and the Test Bank in Word® format.

Instructor Manual and Test Bank

Written by Charles H. Corwin, the Instructor Manual provides complete solutions to all even-numbered exercises in the textbook, lists learning objectives for course planning, recommends media resources, and suggests chemical demonstrations. It also includes the Test Bank with over 3000 class-tested questions that have undergone item analysis and address each topic in the textbook.

Student Study Guide & Selected Solutions Manual

Also written by the author, this printed study aid includes diagnostic test questions for each topic covered in the text, crossword puzzles using key terms, and complete solutions to all odd-numbered exercises.

Resources in Print and Online

Name of Supplement	Available in Print	Available Online	Instructor or Student Supplement	Description
MasteringChemistry®—for Introductory Chemistry: Concepts and Critical Thinking, 8/e 0134555015 / 9780134555010		✓	Supplement for Instructors and Students	The Mastering platform is the most effective and widely used online homework, tutorial, and assessment system for the sciences. It delivers self-paced tutorials that focus on your course objectives, provide individualized coaching, and respond to each student's progress. The Mastering system helps instructors maximize class time with easy-to-assign, customizable, and automatically graded assessments that motivate students to learn outside of class and arrive prepared for lecture or lab.
Study Guide & Selected Solutions Manual for Introductory Chemistry: Concepts and Critical Thinking, 8/e 0134580281 / 9780134580289	✓		Supplement for Students	Written by the author, Charles H. Corwin, this study aid includes diagnostic test questions for each topic covered in the text, crossword puzzles using key terms, and complete solutions to all odd-numbered exercises.
Instructor Manual and Test Bank for Introductory Chemistry: Concepts and Critical Thinking, 8/e 0134580265 / 9780134580265		✓	Supplement for Instructors	The manual features a list of all chapter learning objectives and complete solutions to the even-numbered chapter exercises. This has been updated to reflect the revisions in this text and contains questions in a bank of more than 4,000 multiple-choice questions.
Instructor Resource Materials for Introductory Chemistry: Concepts and Critical Thinking, 8/e 0134580257 / 9780134580258		✓	Supplement for Instructors	This lecture resource contains all art and images from the textbook, three pre built PowerPoint® presentations, animations, interactive activities, the Instructor's Manual in PDF format, and the test item file in Word® format.
Laboratory Manual for Introductory Chemistry: Concepts and Critical Thinking, 6/e 0321750942/9780321750945	✓		Supplement for Laboratory	Emphasizing environmental considerations, Corwin's acclaimed lab manual offers a proven format of a prelaboratory assignment, a stepwise procedure, and a postlaboratory assignment. More than 300,000 students to date in introductory chemistry, preparatory chemistry, and allied health chemistry have used these "bulletproof" experiments successfully. The *Sixth Edition* features environmental icons to alert students to recycle chemical waste, updated prelabs and postlabs, new experimental procedures, a new experiment (Experiment 25), and a new appendix on how to keep a laboratory notebook. Corwin's lab manual can be packaged with any Pearson intro prep chemistry book.

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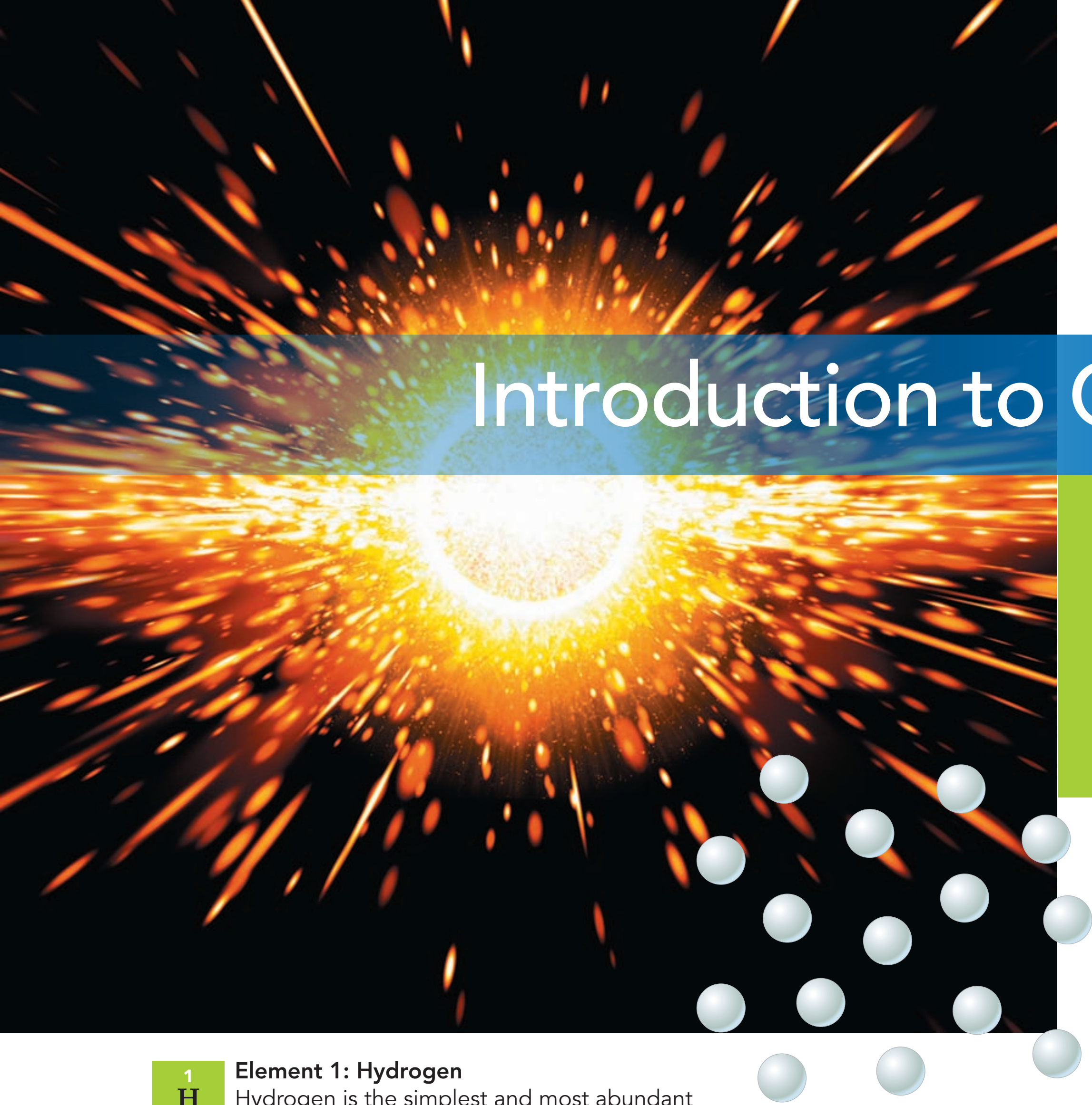
CHAPTER 1

Introduction to Chemistry



"All our dreams can come true—if we have the courage to pursue them."

Walt Disney, Disneyland Creator (1901–1966)

1 H hydrogen

Element 1: Hydrogen
Hydrogen is the simplest and most abundant element in the universe. Beginning with the Big Bang 14 billion years ago, hydrogen atoms were scattered throughout the universe. Subsequently, two hydrogen atoms fused to produce the second element, helium, which in turn fused with another hydrogen atom to give the third element, lithium. Thus, each of the elements evolved beginning with hydrogen.

In the United States, Canada, and other developed countries, we enjoy a standard of living that could not have been imagined a century ago. Owing to the evolution of science and technology, we have abundant harvests; live in comfortable, climate-controlled buildings; and travel the world via automobiles and airplanes. We also have extended life spans free of many diseases that previously ravaged humanity.

The development of technology has provided machinery and equipment to perform tedious tasks, which gives us time for more interesting activities. The arrival of the computer chip has given us electronic appliances that afford ready convenience and dazzling entertainment. We can select from a multitude of audio and video resources that offer remarkable sound and brilliant color. We can access these audio and video resources from the Internet, satellite, a compact disc, or a smartphone that can communicate wirelessly while surfing the Internet (Figure 1.1).

Our present standard of living requires scientists and technicians with educational training in chemistry. The health sciences as well as the life sciences, physical sciences, and earth sciences demand an understanding of chemical principles. In fact, chemistry is sometimes referred to as the central science because it stands at the crossroads of biology, physics, geology, and medicine. Just as personal computers and smartphones are indispensable in our everyday activities, chemistry plays an essential role in our daily lives.

▲ **Figure 1.1 Smartphone**
A typical smartphone has Internet access and cloud connectivity.

1.1 Evolution of Chemistry

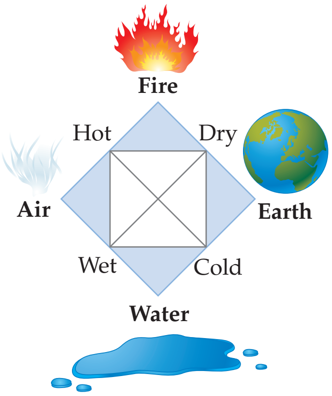
LEARNING OBJECTIVES

- Describe the early practice of chemistry.
- Identify the three steps in the scientific method.

The earliest concept of science began with the ancient Chinese, Egyptian, and Greek civilizations. The Chinese believed that the universe was created from the interaction of two forces. Yin, the feminine force, was manifested in darkness, cold, and wetness. Yang, the masculine force, was manifested in light, heat, and dryness. When the yin and yang forces interacted, they brought the earthly world into existence and were responsible for everything in nature.

As early as 600 B.C., the Greeks began to speculate that the universe was composed of a single element. Thales, the founder of Greek science, mathematics, and philosophy, suggested that water was the single element. He claimed that Earth was a dense, flat disc floating in a universe of water. He also believed that air and space were less dense forms of water.

A few years later, another Greek philosopher proposed that air was the basic element. This theory was followed by the proposals that fire, and later earth, was the basic element. About 450 B.C., the Greek philosopher Empedocles observed that when wood burned, smoke was released (air), followed by a flame (fire). He also noticed that a cool surface held over a fire collected moisture (water) and that the only remains were ashes (earth). Empedocles interpreted his observations as evidence for air, fire, water, and earth as basic elements. The conclusion was logical based on his observations and he further speculated other substances were examples of these four elements combined in varying proportions, as illustrated in Figure 1.2.



▲ **Figure 1.2 The Four Greek Elements** The four elements proposed by the Greeks: air, earth, fire, and water. Notice the properties hot, cold, wet, and dry associated with each element.

In about 350 B.C., Aristotle adopted the idea that air, earth, fire, and water were basic elements. In addition, he added a fifth element, ether, that he believed filled all space. Aristotle's influence was so great that his opinions dominated other Greek philosophers and shaped our understanding of nature for nearly 2,000 years.

The Scientific Method

In 1661, the English scientist Robert Boyle (1627–1691) published *The Sceptical Chymist*. In his classic book, Boyle stated that theoretical speculation was worthless unless it was supported by experimental evidence. This principle led to the development of the scientific method, which marked a turning point in scientific inquiry and the beginning of modern science.

Science can be defined as the methodical exploration of nature followed by a logical explanation of the observations. The practice of science entails planning an investigation, carefully recording observations, gathering data, and analyzing the results. In an **experiment**, scientists explore nature according to a planned strategy and make observations under controlled conditions.

▲ **Robert Boyle** Boyle performed experiments with the vacuum pump, and wrote the classic textbook, *The Skeptical Chymist*, which laid the foundation for the scientific method.

The **scientific method** is a systematic investigation of nature and requires proposing an explanation for the results of an experiment in the form of a general principle. The initial, tentative proposal of a scientific principle is called a **hypothesis**.

After further experimentation, the initial hypothesis may be rejected, modified, or elevated to the status of a scientific principle. However, for a hypothesis to become a scientific principle, many additional experiments must support and verify the original proposal. Only after there is sufficient evidence does a hypothesis rise to the level of a **scientific theory**. We can summarize the three steps in the scientific method as follows:

Applying the Scientific Method

Step 1: Perform a planned experiment, make observations, and record data.

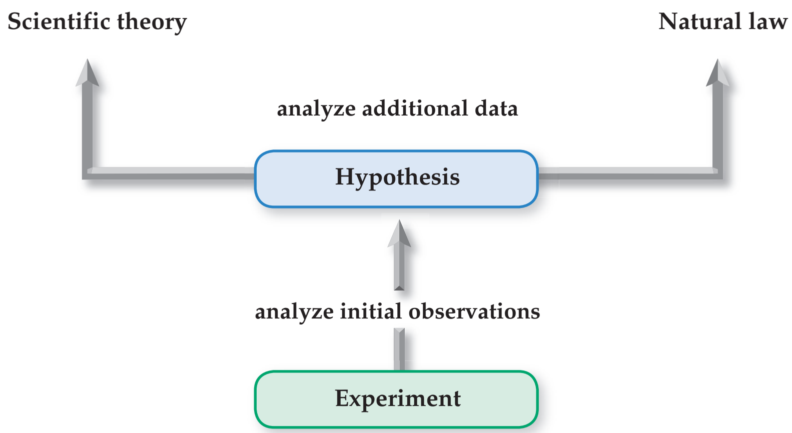
Step 2: Analyze the data and propose a tentative hypothesis to explain the experimental observations.

Step 3: Conduct additional experiments to test the hypothesis. If the evidence supports the initial proposal, the hypothesis may become a scientific theory.

We should note that scientists exercise caution before accepting a theory. Experience has shown that nature reveals its secrets slowly and only after considerable probing. A scientific theory is not accepted until rigorous testing has established that the hypothesis is a valid interpretation of the evidence. For example, in 1803, John Dalton (1766–1844) proposed that all matter was composed of small, indivisible particles called atoms. However, it took nearly 100 years of gathering additional evidence before his proposal was universally accepted and elevated to the status of the atomic theory.

Although the terms *theory* and *law* are related, there is a distinction between the two terms. A theory is a model that explains the behavior of nature. A **natural law** does not explain behavior, but rather states a measurable relationship. To illustrate, it is a *law* that heat flows from a hotter object to a cooler one because we can measure experimentally the change in temperature if we drop an ice cube into water. It is a *theory* that the transfer of heat is due to changes in the motion of molecules in the ice and water.

We can distinguish between a theory and a law by simply asking the question, "Is the proposal measurable?" If the answer is yes, the statement is a law; otherwise, the statement is a theory. Figure 1.3 summarizes the relationship of a hypothesis, a scientific theory, and a natural law.



◀ **Figure 1.3 The Scientific Method** The initial observations from an experiment are analyzed and formulated into a hypothesis. Next, additional data is collected from experiments conducted under various conditions and the data is analyzed. If the additional data supports the initial proposal, the hypothesis may be elevated to a scientific theory or a natural law.

1.2 Modern Chemistry

LEARNING OBJECTIVE

- Describe the modern practice of chemistry.

In the A.D. eighth century, the Arabs introduced the pseudoscience of **alchemy**. Alchemists conducted simple experiments and believed in the existence of a magic potion that had miraculous healing powers and could transmute lead into gold. Although alchemy did not withstand the test of time, it preceded the planned, systematic, scientific experiments that are the cornerstone of modern chemical research.

In the late eighteenth century, the French chemist Antoine Lavoisier (1743–1794) organized chemistry and wrote two important textbooks. Lavoisier also built a magnificent laboratory and invited scientists from around the world to view it; his many visitors included Benjamin Franklin and Thomas Jefferson. Lavoisier was a prolific experimenter and published his work in several languages. For his numerous contributions, he is considered the founder of modern chemistry.

Today, we define **chemistry** as the science that studies the composition of matter and its properties. Chemists have accumulated so much information during the past two centuries that we now divide the subject into several branches or specialties. The branch of chemistry that studies substances containing the element carbon is called **organic chemistry**. The study of all other substances, those that do not contain the element carbon, is called **inorganic chemistry**.

▲ **Antoine Lavoisier** In addition to writing two textbooks on chemistry, Lavoisier established a magnificent eighteenth-century laboratory that attracted scientists from around the world.

The branch of chemistry that studies substances derived from plants and animals is **biochemistry**. Another branch, analytical chemistry, includes qualitative analysis (what substances are present in a sample) and quantitative analysis (how much of each substance is present). Physical chemistry is a specialty that proposes theoretical and mathematical explanations for chemical behavior. Recently, environmental chemistry has become an important specialty that focuses on the safe disposal of chemical waste. **Green chemistry**, also termed *sustainable chemistry*, refers to the design of chemical products and processes that reduce or eliminate hazardous substances.

Chemistry plays a meaningful role in medicine, especially in the dispensing of pharmaceutical prescriptions. Chemists help ensure agricultural harvests by formulating fertilizers and pesticides. Chemistry is indispensable to many industries including the manufacture of automobiles, electronic components, aluminum, steel, paper, and plastics. One of the largest industries is the petrochemical industry. Petrochemicals are chemicals derived from petroleum and natural gas. They can be used to manufacture a wide assortment of consumer products including paints, plastics, rubber, textiles, dyes, and detergents.

In every chapter you will have example exercises that put learning into action. Each example exercise poses a question and shows the solution. There is also a practice exercise and a concept exercise to further your understanding. Example Exercise 1.1 illustrates a question, practice exercise, and concept exercise.

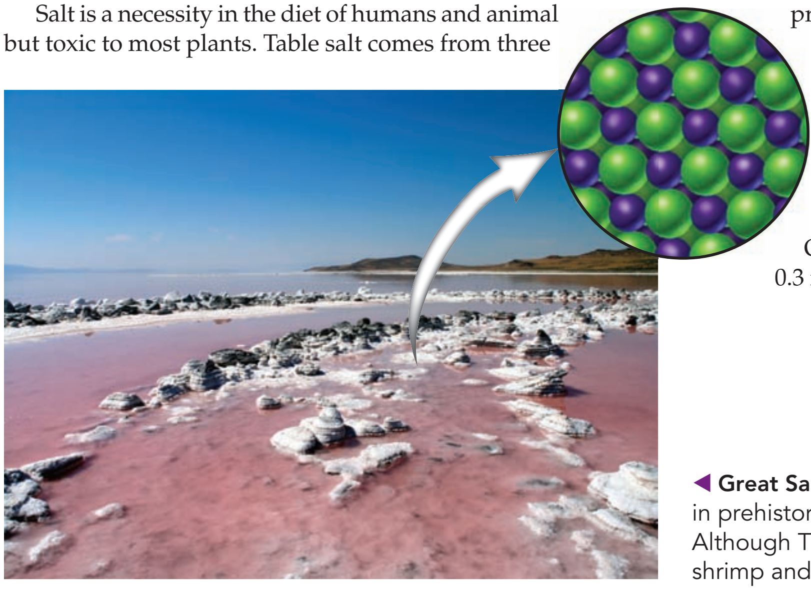
A CLOSER LOOK Watch Your Salt Intake!

Q: How much salt is too much?

The many uses for salt predate modern history. In the ancient world, towns and settlements were near salt reservoirs, because salt was a dietary necessity and a food preservative. Hippocrates, the Greek founder of medicine, urged physicians to soak their patients in salt water as treatment for various ailments. Because most natural salt was not suitable for ingestion, pure salt was a rare and valuable commodity. So-called "salt roads" were used by caravans of camels to transport salt long distances in trade for gold and textiles.

Salt is a necessity in the diet of humans and animal but toxic to most plants. Table salt comes from three sources: salt mining, solution mining, and evaporation of salt water. The United States and Canada have extensive deposits of salt, and the Great Salt Lake in Utah is so concentrated and dense that humans can easily float in the salt water.

Table salt (sodium chloride) is necessary in the human diet; however, too much sodium has been linked to high blood pressure that can lead to diabetes and heart problems. The recommended daily allowance (RDA) of table salt is a teaspoon, which contains approximately 2300 mg of sodium. Surprisingly, most salt in the human diet does not come from table salt, but from processed foods, for example, ketchup, pickles, and snack foods. Table salt contains iodine in the form of potassium iodide. Humans require iodine in small quantities for proper function of the thyroid gland. The hormone thyroxine, which contains iodine, is largely responsible for maintaining our metabolic rate. One teaspoon of iodized table salt contains about 0.3 milligram of iodine, which is twice the RDA.



◀ **Great Salt Lake** The Great Salt Lake in Utah was created in prehistoric times and contains more salt than seawater. Although The Great Salt Lake provides habitat for brine shrimp and aquatic birds, it is called "America's Dead Sea."

A: The RDA for sodium is 2300 mg; about 1 teaspoon of table salt.

EXAMPLE EXERCISE 1.1 Introduction to Chemistry

What is the difference between ancient chemistry and modern chemistry?

Solution

The principal difference is that modern chemistry is founded on the scientific method. Ancient chemistry was based on speculation, whereas modern chemistry is based on planned experiments.

Practice Exercise

What question can we ask to distinguish a scientific theory from a natural law?

Answer: We can distinguish a theory from a law by asking the question, "Is the proposed statement measurable?" If we take measurements and verify a relationship by a mathematical equation, the statement is a law; if not, it is a theory.

Concept Exercise

Alchemists believed in a magic potion that had what miraculous power?

Answer: See Appendix G, 1.1.

CHEMISTRY CONNECTION A Student Success Story

Q: Which common inexpensive metal was more valuable than gold in the nineteenth century?

In 1885, Charles Martin Hall (1863–1914) was a 22-year-old student at Oberlin College in Ohio. One day his chemistry teacher told the class that anyone who could discover an inexpensive way to produce aluminum metal would become rich and benefit humanity. At the time, aluminum was a rare and expensive metal. In fact, Napoleon III, a nephew of Napoleon Bonaparte, entertained his most honored guests with utensils made from aluminum while other guests dined with utensils of silver and gold. Although aluminum is the most abundant metal in Earth's crust, it is not found free in nature; it is usually found combined with oxygen in minerals such as bauxite.

After graduation, Charles Hall set up a laboratory in a woodshed behind his father's church in Oberlin, Ohio. Using homemade batteries, he devised a simple method for producing aluminum by passing electricity through a molten mixture of minerals. After only 8 months of experimenting, he invented a successful method for reducing an aluminum mineral to aluminum metal. In February 1886, Charles Hall walked into his former teacher's office with a handful of metallic aluminum globules.

Just as his chemistry teacher had predicted, within a short period of time, Hall became rich and famous. In 1911, he received the Perkin Medal for achievement in chemistry, and in his will, he donated \$5 million to Oberlin College. He also helped to establish the Aluminum Company of America (ALCOA), and the process for making aluminum metal gave rise to a huge industry. Aluminum is now second only to steel as a construction metal.

It is an interesting coincidence that the French chemist Paul Hèroult, without knowledge of Hall's work, made a similar discovery at the same time. Thus, the industrial method for obtaining aluminum metal is referred to as the Hall–Hèroult process. In 1886, owing to the discovery of this process, the price of aluminum plummeted dramatically. Today, the price of aluminum is less than \$1 a pound.

▲ **Aluminum Globules** The notebook of Charles Hall along with globules of aluminum.

A: Before 1886, aluminum was an extremely rare and expensive metal.

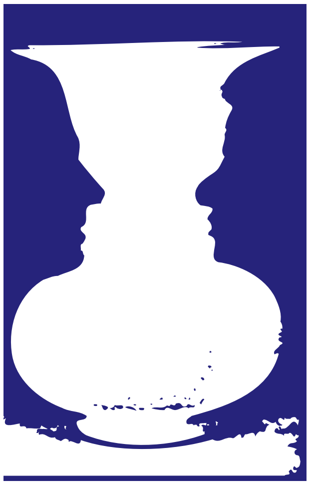
LEARNING OBJECTIVE

- Conclude that chemistry is very relevant in our daily life.

1.3 Learning Chemistry

In a survey published by the American Chemical Society, entering college students were asked to express their attitudes about science courses. The students rated chemistry as the most relevant science course, and as highly relevant to their daily lives. Unfortunately, 83% of the students thought chemistry was a difficult subject. In view of the results of the student survey, perhaps we should take a moment to consider perceptions in general, and attitudes about chemistry in particular.

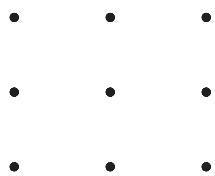
You are probably familiar with the expression that some people see a glass of water as half full, while others see the same glass as half empty. This expression implies that different people can respond to the same experience with optimism or pessimism. Moreover, experimental psychologists have found that they can use abstract visual images to discover underlying attitudes regarding a particular perception. A practical lesson involving two perceptions obtained from the same image is revealed by the following picture.



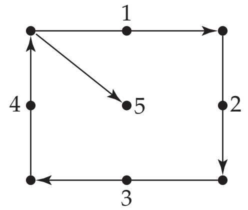
What do you see? Some students see a white vase on a dark background; others see two dark profiles facing each other. After a short period of time, one image switches to the other. If you concentrate, can you view only one of the images? Can you choose to switch the images back and forth? This exercise is an example of our brains registering dual perceptions from the same image.

Your experience of learning chemistry may be somewhat like the preceding exercise that tests your perspective. Sometimes your perception may be that chemistry is challenging, whereas a short time later your attitude may be that chemistry is easy and fun.

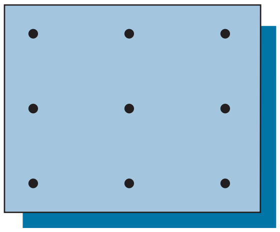
Perception is often affected by unconscious assumptions. Let's consider a type of problem that is slightly different from the vase perception. In the following problem try to connect each of the nine dots using only *four* straight, continuous lines.



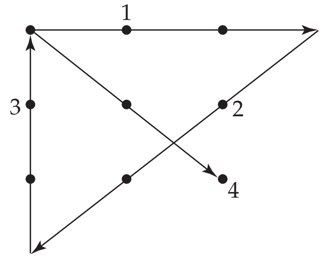
We can begin to solve the problem by experimenting. For example, let's start with the upper-left dot and draw a line to the upper-right dot. We can continue to draw straight lines as follows:



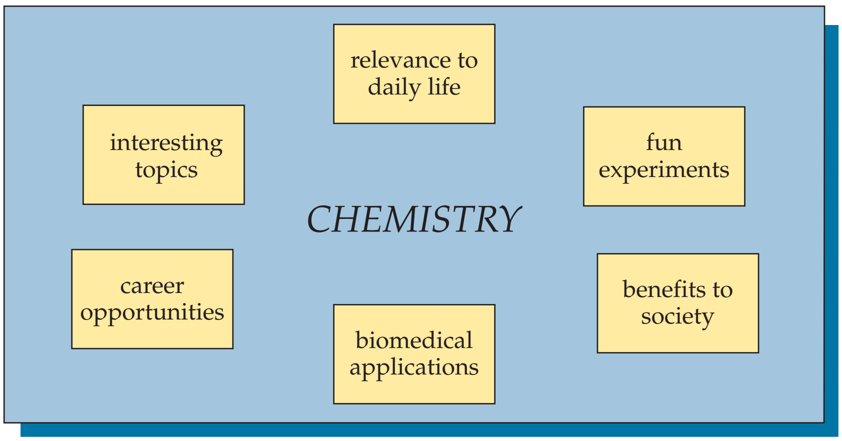
Notice that we connected the nine dots, but that it was necessary to use *five* straight, continuous lines. If we start with a different dot, we find that *five* lines are required no matter where we start. Perhaps we are bringing an underlying assumption to the nine-dot problem. That is, we may be unconsciously framing the nine dots, thus limiting the length of the four straight lines.



What will happen if we start with the upper-left dot and draw a line through the upper-right dot? If we continue, we can complete the problem with *four* straight, continuous lines as follows:



The "secret" to solving this nine-dot problem is to recognize that we may be unconsciously confining our thinking and making it impossible to solve. Similarly, we should not confine our concept of chemistry to a preconceived attitude that learning chemistry will be difficult. Or better yet, we should choose positive associations for our concept of chemistry. The following diagram illustrates a few of the positive associations for chemistry.



Helpful Hint
Studying Chemistry
It is essential to study on a regular basis. On days you lack motivation, look at the attractive art that illustrates each topic. Next, study the Example Exercises. Finally, try the odd-numbered end-of-chapter Exercises, and check your answers in Appendix I.

To prepare for a test, take the end-of-chapter Self-Test, and check your answers in Appendix J.

EXAMPLE EXERCISE 1.2 Learning Chemistry

Is it possible to have different perceptions of a single visual image?

Solution
Yes, a single image can suggest two different observations. That is, an observer may view a half glass of water as "half full" or "half empty."

Practice Exercise
Why would a student at first find a chemistry problem difficult to solve when later the solution seems easy and obvious?

Answer: If the student has an unconscious assumption that chemistry is a difficult subject, the student may assume a chemistry problem is difficult to solve.

Concept Exercise
What can a student do to eliminate an unconscious assumption regarding chemistry being a difficult subject.

Answer: See Appendix G, 1.2.

Chapter Summary

Key Concepts	Learning Objectives and Related Exercises
1.1 Evolution of Chemistry This chapter traces the development of chemistry from a historical point of view. Beginning in the period 600–350 B.C., the early Greeks used reason and thoughtful mental exercises to understand the laws of nature. Although they often arrived at conclusions based on speculation, they did unveil some of nature's secrets and had a profound influence on Western civilization that lasted for 20 centuries. The term **science** implies a rigorous, systematic investigation of nature. Moreover, a scientist must accumulate significant evidence before attempting to explain the results. In the seventeenth century, Robert Boyle founded the **scientific method**, and laboratory experimentation became essential to an investigation. After an **experiment**, scientists use their observations to formulate an initial proposal, which is called a **hypothesis**. However, a hypothesis must be tested repeatedly before it is accepted as valid. After a hypothesis has withstood extensive testing, it becomes either a **scientific theory** or a **natural law**. A scientific theory is an accepted explanation for the behavior of nature, whereas a natural law states a relationship under different experimental conditions and is often expressed as a mathematical equation.	• Describe the early practice of chemistry. *Related Exercises: 1–4* • Identify the three steps in the scientific method. *Related Exercises: 5–12*
1.2 Modern Chemistry The pseudoscience of **alchemy** introduced the practice of laboratory experimentation and was the forerunner of modern **chemistry**. Today, chemistry is quite diverse and has several branches, including **inorganic chemistry**, **organic chemistry**, **green chemistry**, and **biochemistry**. The impact of chemistry is felt in medicine and agriculture, as well as in the electronics, pharmaceutical, petrochemical, and other industries.	• Describe the modern practice of chemistry. *Related Exercises: 13–16*
1.3 Learning Chemistry In this section we examined some dual perceptions and pointed out that our brains have the ability to respond to the same image in two ways. Before beginning to learn chemistry, most students have already made associations with the subject. With this knowledge, hopefully you will be able to focus on chemistry as being an interesting and relevant subject and put aside any preconceived limiting attitudes.	• Conclude that chemistry is very relevant in our daily life. *Related Exercises: 17–18*

Key Terms *Answers to Key Terms are in Appendix H.*

Select the key term that corresponds to each of the following definitions.

_____ **1.** the methodical exploration of nature and the logical explanation of the observations

_____ **2.** a scientific procedure for gathering data and recording observations under controlled conditions

_____ **3.** a systematic investigation that entails performing an experiment, proposing a hypothesis, testing the hypothesis, and stating a theory or law

_____ **4.** a tentative proposal of a scientific principle that attempts to explain the meaning of a set of data collected in an experiment

_____ **5.** an extensively tested proposal of a scientific principle that explains the behavior of nature

_____ **6.** an extensively tested proposal of a scientific principle that states a measurable relationship under different experimental conditions

_____ **7.** a pseudoscience that attempted to convert a base metal, such as lead, to gold; a medieval science that sought to discover a universal cure for disease and a magic potion for immortality

_____ **8.** the branch of science that studies the composition and properties of matter

_____ **9.** the study of chemical substances that contain the element carbon

_____ **10.** the study of chemical substances that do not contain the element carbon

_____ **11.** the study of chemical substances derived from plants and animals

_____ **12.** the design of products and processes that reduce or eliminate hazardous chemical substances

(a) alchemy (*Sec. 1.2*)
(b) biochemistry (*Sec. 1.2*)
(c) chemistry (*Sec. 1.2*)
(d) experiment (*Sec. 1.1*)
(e) green chemistry (*Sec. 1.2*)
(f) hypothesis (*Sec. 1.1*)
(g) inorganic chemistry (*Sec. 1.2*)
(h) natural law (*Sec. 1.1*)
(i) organic chemistry (*Sec. 1.2*)
(j) science (*Sec. 1.1*)
(k) scientific method (*Sec. 1.1*)
(l) scientific theory (*Sec. 1.1*)

Exercises *Answers to odd-numbered Exercises are in Appendix I.*

Evolution of Chemistry (Sec. 1.1)

1. According to ancient Chinese beliefs, what two forces were responsible for bringing the earthly world into existence?
2. According to the Greek philosopher Thales in 600 B.C., what single element composed earth, air, and space?
3. According to the Greek philosopher Empedocles in 450 B.C., what four basic elements composed everything in nature?
4. According to the Greek philosopher Aristotle in 350 B.C., what five basic elements composed everything in nature?
5. What is the first step in the scientific method?
6. What is the second step in the scientific method?
7. What is the third step in the scientific method?
8. Who is the founder of the scientific method?
9. What is the difference between a scientific theory and a natural law?
10. What is the difference between a hypothesis and a theory?
11. Which of the following statements is a natural law?
    (a) The total mass of reacting substances remains constant after reaction.
    (b) The total energy of two gas molecules remains constant after colliding.
    (c) The volumes of two gases combine in the ratio of small whole numbers.
    (d) The nucleus of an atom contains positive charges.
12. Which of the following statements is a scientific theory?
    (a) The energy in an atomic nucleus is found by $E = mc^2$.
    (b) There is the same number of molecules in equal volumes of gases.
    (c) If the temperature of a gas doubles, the pressure doubles.
    (d) The region surrounding the nucleus has negative charges.

Modern Chemistry (Sec. 1.2)

13. Why is chemistry referred to as the central science?
14. Who is the founder of modern chemistry?
15. State five professions that require a training in chemistry.
16. State five industries in which chemistry plays an important role.

Learning Chemistry (Sec. 1.3)

17. It is possible to solve the nine-dot problem with *one* straight, continuous line. Solve the problem and identify the unconscious assumption.