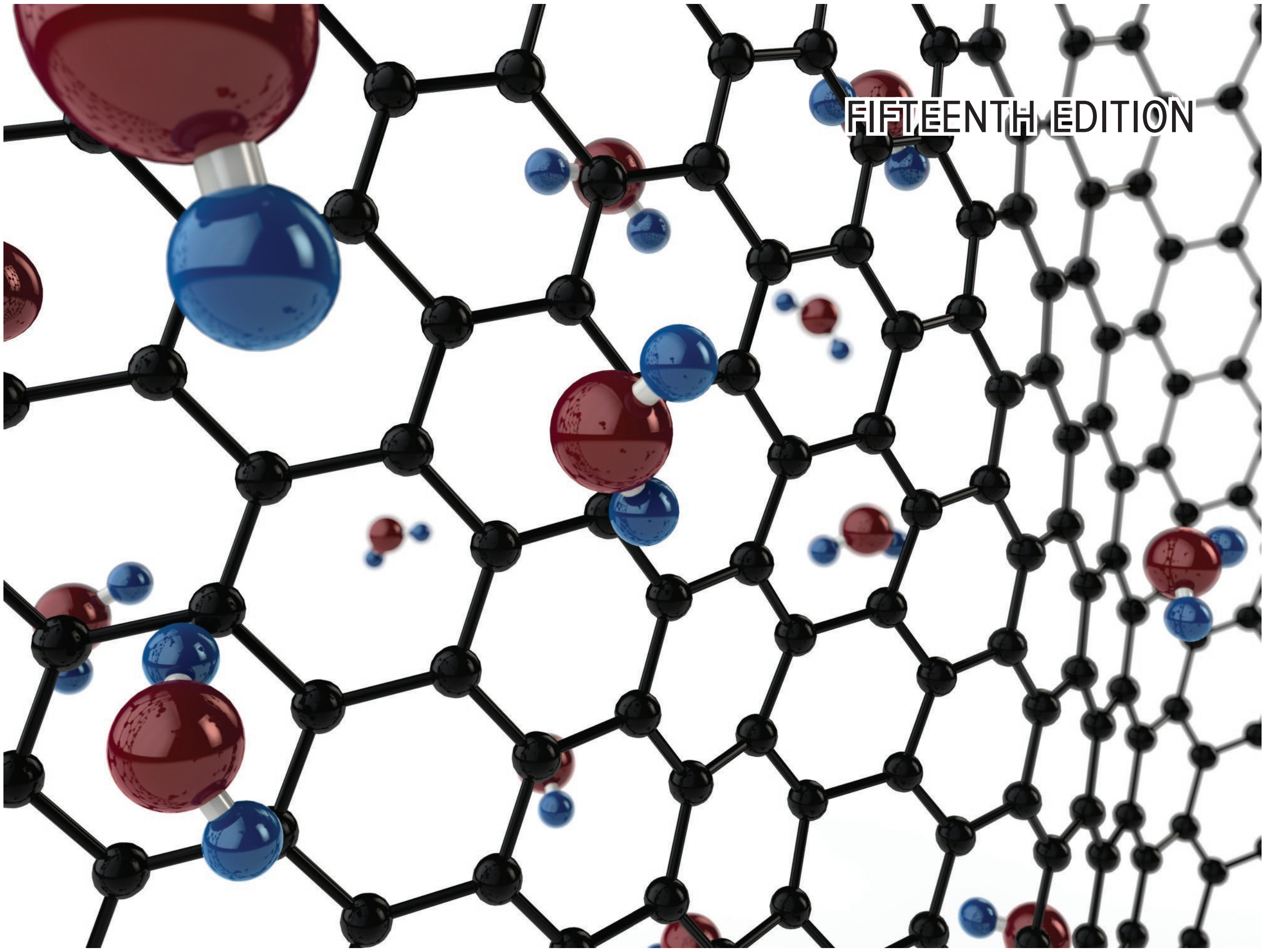
Chemistry



FIFTEENTH EDITION

Jason Overby

College of Charleston

Mc Graw Hill

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About the Author

Jason Overby/McGraw Hill

Jason Overby was born in Bowling Green, Kentucky, and raised in Clarksville, Tennessee. He received his B.S. in chemistry and political science from the University of Tennessee at Martin. After obtaining his Ph.D. in inorganic chemistry from Vanderbilt University, Jason conducted postdoctoral research at Dartmouth College.

Since joining the Department of Chemistry and Biochemistry at the College of Charleston, South Carolina, Jason has taught a variety of courses ranging from general chemistry to advanced inorganic chemistry. He is also interested in the integration of technology into the classroom, with a particular focus on adaptive learning. Additionally, he conducts research with undergraduates in inorganic and organic synthetic chemistry as well as computational organometallic chemistry.

In his free time, he enjoys boating, bowling, and cooking. He is also involved with USA Swimming as a nationally certified official. He lives in South Carolina with his wife Robin and two daughters, Emma and Sarah.

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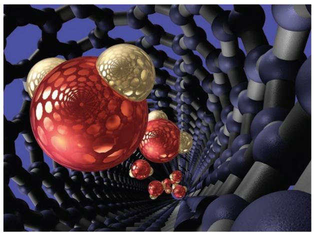

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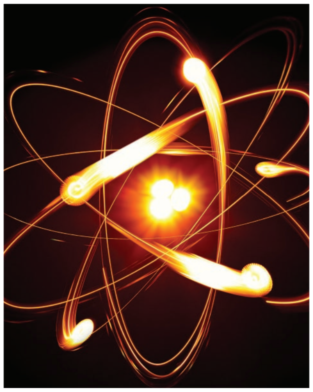

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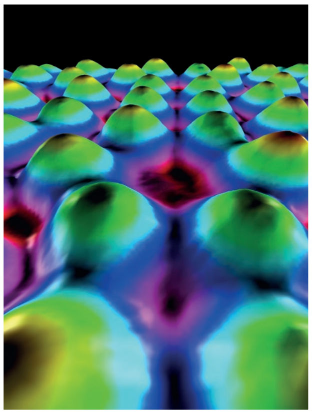

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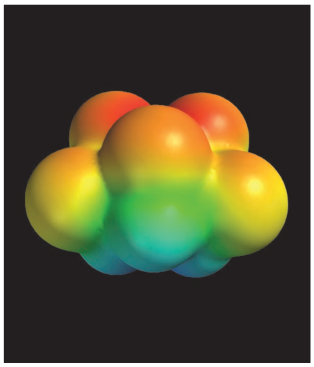
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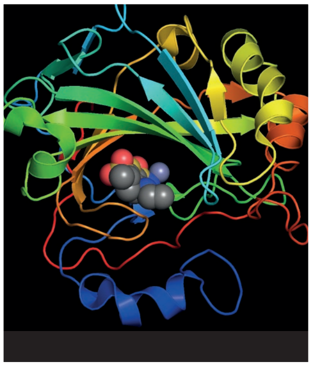

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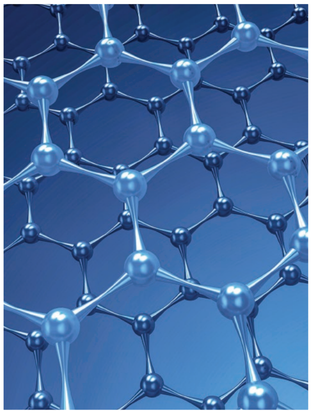

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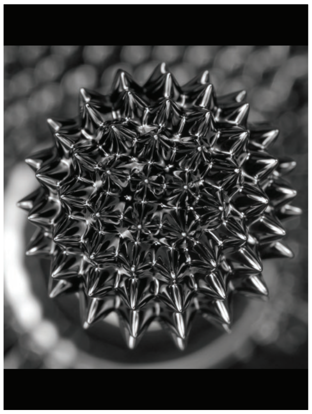

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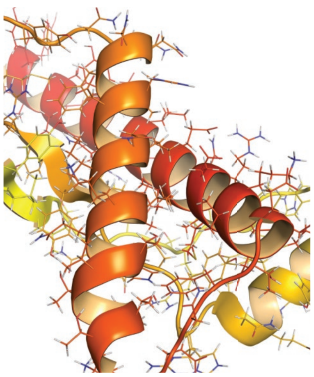

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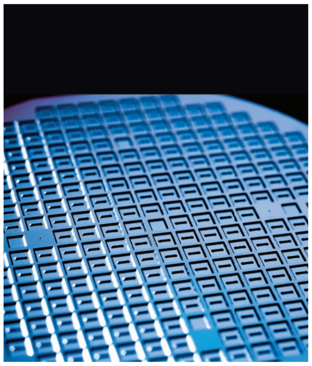

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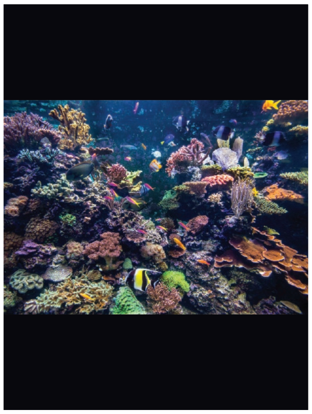
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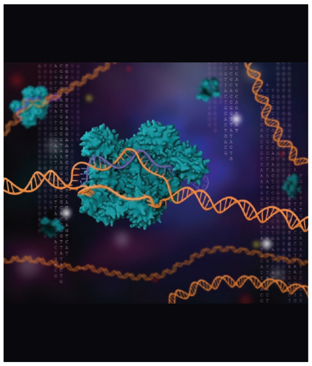
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List of Applications

The opening sentence of this text is, "Chemistry is an active, evolving science that has vital importance to our world, in both the realm of nature and the realm of society." Throughout the text, Chemistry in Action boxes and Chemical Mysteries (digital only) give specific examples of chemistry as active and evolving in all facets of our lives.

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Chemical Mystery (digital only)

The Disappearance of the Dinosaurs
Who Killed Napoleon?
Out of Oxygen
The Exploding Tire
Discovery of Helium and the Rise and Fall of Coronium
The Wrong Knife
Decaying Papers
A Hard-Boiled Snack
Tainted Water
The Art Forgery of the Twentieth Century
The Disappearing Fingerprints
A Story That Will Curl Your Hair

List of Videos

The following videos are correlated to *Chemistry*. Within the chapter are icons letting the student and instructor know that a video is available for a specific topic. Videos can be found in the eBook.

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Ionic vs. Covalent Bonding (9.4)
Le Châtelier's Principle (14.5)
Limiting Reactants (3.9)
Line Spectra (7.3)
Millikan Oil Drop (2.2)
Molecular Shape and Orbital Hybridization (10.4)
Neutralization Reactions (4.3)
Nuclear Fission (19.5)
Operation of a Voltaic Cell (18.2)
Orientation of Collision (13.4)
Osmosis (12.6)
Oxidation-Reduction Reactions (4.4)
Packing Spheres (11.4)
Phase Diagrams and the States of Matter (11.9)
Polarity of Molecules (10.2)
Properties of Buffers (16.2)
Radioactive Decay (19.3)
Reaction of Cu with $AgNO_3$ (4.4)
Reactions of Magnesium and Oxygen (9.2)
Resonance (9.8)
Rutherford's Experiment (2.2)
Sigma and Pi Bonds (10.5)
Strong Electrolytes, Weak Electrolytes, and Nonelectrolytes (4.1)
VSEPR (10.1)
VSEPR Theory (10.1)

Preface

In the fifteenth edition of *Chemistry,* the long history of focusing on a solid background of chemical concepts while providing an appreciation of the importance of chemistry in our daily lives continues unabated. Helping both instructors and students in attaining these goals requires a solid logical flow of material, so we believe that it is our duty to present a wide range of chemical topics with consistent presentation. We focus on balancing theory with application by demonstrating various principles with useful examples whenever possible.

As in earlier editions, we strive to present a text with clear and concise explanations that clarify difficult concepts but are detailed enough that students will gain a solid foundation as they progress through the chemistry curriculum. We always encourage feedback from all instructors and students.

ALEKS Data Parity with *Chemistry,* 15th Edition

A major source of frustration for instructors and students alike over the past two decades has been the lack of data coordination between a print text, eBook, and an online resource. Often it is not clear what is a true accepted value for an important chemical item (e.g., standard enthalpy of formation, acid ionization constant, or standard electrode potential for a half-reaction) as different sources often give a multitude of differing numbers. With the fifteenth edition of *Chemistry*, no longer will students be confused about which particular chemical value to employ in a calculation when using ALEKS. The data between the print text, eBook, and ALEKS are now parallel with one another. Numerous tables, figures, and problems throughout the text have been updated to mirror the data in ALEKS, thereby presenting unified chemical data.

Learning Objectives and Summary of Concepts and Facts

In the previous edition, a new listing of Learning Objectives was added to each chapter. To better help instructors and students focus on relevant topics and ideas in a given section, we are providing Learning Objectives at the beginning of each section followed by a Summary of Concepts & Facts at the end of each section. We believe that this perfectly introduces the pertinent idea(s) to be covered and finishes with a reinforcement of those ideas at the end of a section.

13.2 Rate Laws

Learning Objectives

- Summarize reaction order and provide examples of a zeroth-, first-, and second-order reaction rate law.
- Write the rate law of a reaction given experimental data.
- Express the units of the rate constant k for a reaction.

Summary of Concepts & Facts

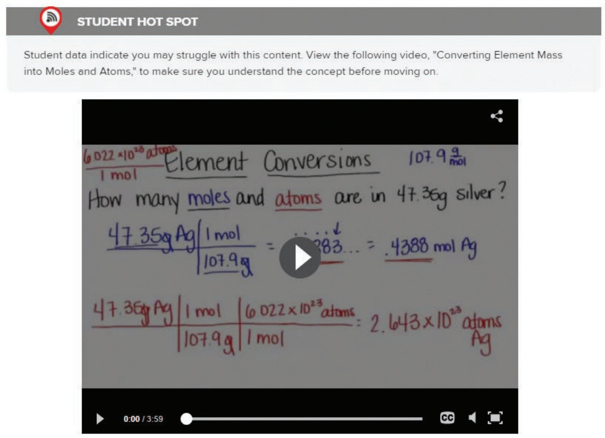
- The rate law expresses the relationship of the rate of a reaction to the rate constant and the concentrations of the reactants raised to appropriate powers. The rate constant k for a given reaction changes only with temperature.
- Reaction order is the power to which the concentration of a given reactant is raised in the rate law. Overall reaction order is the sum of the powers to which reactant concentrations are raised in the rate law. The rate law and the reaction order cannot be determined from the stoichiometry of the overall equation for a reaction; they must be determined by experiment. For a zero-order reaction, the reaction rate is equal to the rate constant.

Student Hot Spots

In the electronic version of this text, all the learning resources for the Student Hot Spots are readily available.

Student Hot Spot

Student data indicate you may struggle with significant figures. Access your eBook for additional Learning Resources on this topic.



Further, access to student results has guided the editing of content in many chapters. While many of the changes are subtle, some are more comprehensive. The ability to edit based on real-time assessment data from students is the new paradigm for textbook authoring. Undoubtedly this changes how we provide and enhance learning materials for our students in the future!

Chapter Summary

A Chapter Summary is provided at the end of every chapter with a succinct overview of all sections in the chapter.

These are intended to be a reinforcement of the important ideas a student will have seen in the chapter. These can easily be used as study guides as well.

Chapter Summary

Molecular Geometry Molecular geometry refers to the three-dimensional arrangement of atoms in a molecule. For relatively small molecules, in which the central atom contains two to six bonds, geometries can be reliably predicted by the valence-shell electron-pair repulsion (VSEPR) model. This model is based on the assumption that chemical bonds and lone pairs tend to remain as far apart as possible to minimize repulsion. (Section 10.1)

Dipole Moments In a diatomic molecule, the difference in the electronegativities of bonding atoms results in a polar bond and a dipole moment. The dipole moment of a molecule made up of three or more atoms depends on both the polarity of the bonds and molecular geometry. Dipole moment measurements can help us distinguish between different possible geometries of a molecule. (Section 10.2)

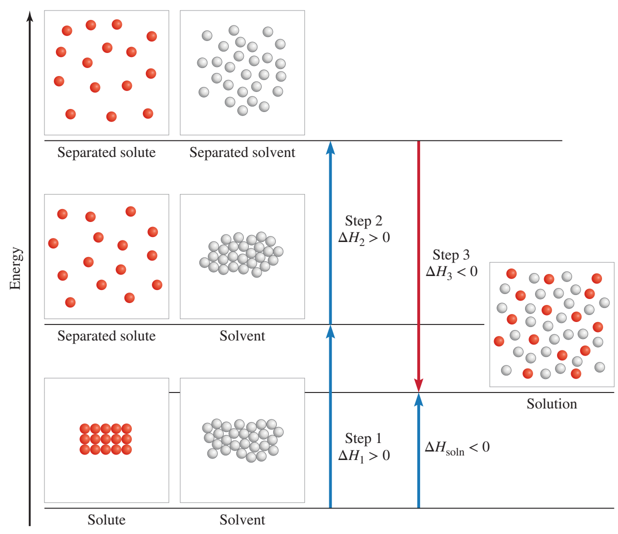
Valence Bond Theory Valence bond theory is a quantum mechanical description of bonding that assumes electrons in a molecule occupy atomic orbitals of the individual atoms and these atomic orbitals overlap to form a covalent bond. Valence bond theory states that stable molecules form when the potential energy of the system of atoms has decreased to a minimum. Diatomic molecules can be easily explained by this minimization of potential energy with changes in distance between reacting atoms. (Section 10.3)

Hybridization of Atomic Orbitals Hybridization is the quantum mechanical description of chemical bonding. Atomic orbitals are hybridized, or mixed, to form hybrid orbitals. These orbitals then interact with other atomic orbitals to form chemical bonds. Various molecular geometries can be generated by different hybridizations. The hybridization concept accounts for the exception to the octet rule and also explains the formation of double and triple bonds. (Sections 10.4, 10.5)

Molecular Orbital Theory Molecular orbital theory describes bonding in terms of the combination of atomic orbitals to form orbitals that are associated with the molecule as a whole. Molecules are stable if the number of electrons in bonding molecular orbitals is greater than that in antibonding molecular orbitals. We write electron configurations for molecular orbitals as we do for atomic orbitals, using the Pauli exclusion principle and Hund's rule. (Sections 10.6, 10.7, 10.8)

Art Program and Design

For this edition, the art program was further revised to impart a more modern look and enhance visibility as well as provide better ADA compliance for vision-impaired students. Clear graphics are a vital component of the student learning process and as such, all molecular models, graphs, periodic tables, and other figures have been updated with a new look and color scheme. In some instances, illustrations have been replaced with scientifically accurate photographs for enhanced chemical context. Many chapter-opening photographs have been updated for new insights into various chemical topics and applications.



Problem Solving

The development of problem-solving skills has always been a major objective of this text. The two major categories of learning are shown next.

Worked examples follow a proven step-by-step strategy and solution.

- **Problem statement** is the reporting of the facts needed to solve the problem based on the question posed.
- **Strategy** is a carefully thought-out plan or method to serve as an important function of learning.
- **Solution** is the process of solving a problem given in a stepwise manner.
- **Check** enables the student to compare and verify with the source information to make sure the answer is reasonable.
- **Practice Exercise** provides the opportunity to solve a similar problem to become proficient in this problem type. The margin note lists additional similar problems to work in the end-of-chapter problem section.

End-of-Chapter Problems are organized in various ways. Each section under a topic heading begins with Concept Review questions followed by Problems. The Additional Problems section provides more problems not organized by section, followed by the problem type Interpreting, Modeling, & Estimating.

Many of the examples and end-of-chapter problems present extra tidbits of knowledge and enable the student to solve a chemical problem that a chemist would solve. The examples and problems show students the real world of chemistry and applications to everyday life situations.

Visualization

Graphs and Flow Charts are important in science. In *Chemistry,* flow charts show the thought process of a concept and graphs present data to comprehend the concept. A significant number of Problems and Review of Concepts & Facts, including many new to this edition, include graphical data.

Molecular art appears in various formats to serve different needs. Molecular models help to visualize the three-dimensional arrangement of atoms in a molecule. Electrostatic potential maps illustrate the electron density distribution in molecules. Finally, there is the macroscopic to microscopic art helping students understand processes at the molecular level.

Photos are used to help students become familiar with chemicals and understand how chemical reactions appear in reality.

Figures of apparatus enable the student to visualize the practical arrangement in a chemistry laboratory.

Study Aids

Setting the Stage

Each chapter starts with the Chapter Outline and a brief opening discussion of the chapter.

Chapter Outline enables the student to see at a glance the big picture and focus on the main ideas of the chapter.

Tools to Use for Studying

Useful aids for studying are plentiful in *Chemistry* and should be used constantly to reinforce the comprehension of chemical concepts.

Worked Examples along with the accompanying Practice Exercises are very important tools for learning and mastering chemistry. The problem-solving steps guide the student through the critical thinking necessary for succeeding in chemistry. Similar problems in the end-of-chapter problems section are listed at the end of the examples, enabling the student to apply new skill to other problems of the same type. Answers to the Practice Exercises are listed at the end of the chapter problems in the print text, or immediately following the Practice Exercises in the eBook.

Key Equations are highlighted within the chapter, drawing the student's eye to material that needs to be understood and retained. The key equations are also presented in the chapter summary materials for easy access in review and study.

Chapter Summary provides a quick review of concepts presented and discussed in detail within the chapter.

Key Words are a list of all important terms to help the student understand the language of chemistry.

Testing Your Knowledge

Review of Concepts & Facts lets students pause and check to see if they understand the concept presented and discussed in the section. Answers to the Review of Concepts can be found in the Student Solution Manual.

End-of-Chapter Problems enable the student to practice critical thinking and problem-solving skills. The problems are broken into various types:

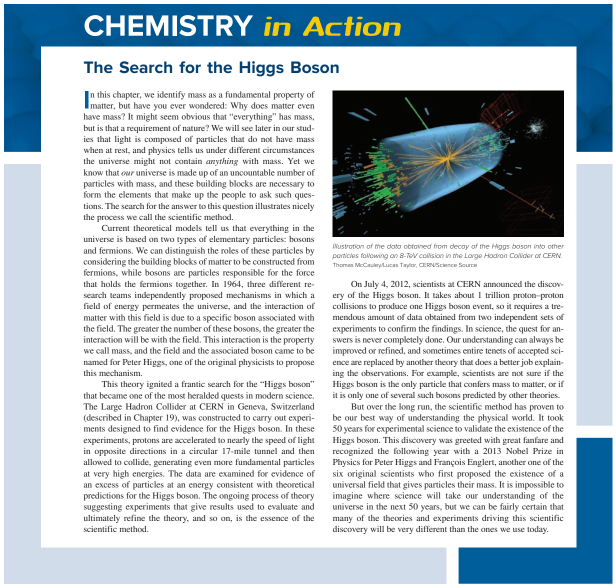
- By chapter section. Starting with Review Questions to test basic conceptual understanding, followed by Problems to test the student's skill in solving problems for that particular section of the chapter.
- Additional Problems use the knowledge gained from the various sections and/or previous chapters to solve the problem.
- Interpreting, Modeling, & Estimating problems teach students the art of formulating models and estimating ballpark answers based on appropriate assumptions.

Real-Life Relevance

Interesting examples of how chemistry applies to life are used throughout the text. Analogies are used where appropriate to help foster understanding of abstract chemical concepts.

End-of-Chapter Problems pose many relevant questions for the student to solve. Examples include: Why do swimming coaches sometimes place a drop of alcohol in a swimmer's ear to draw out water? How does one estimate the pressure in a carbonated soft drink bottle before removing the cap?

Chemistry in Action boxes appear in every chapter on a variety of topics, each with its own story of how chemistry can affect a part of life. The student can learn about the science of scuba diving and nuclear medicine, among many other interesting cases.



CHEMISTRY *in Action*

The Search for the Higgs Boson

In this chapter, we identify mass as a fundamental property of matter, but have you ever wondered: Why does matter even have mass? It might seem obvious that "everything" has mass, but is that a requirement of nature? We will see later in our studies that light is composed of particles that do not have mass when at rest, and physics tells us under different circumstances the universe might not contain *anything* with mass. Yet we know that *our* universe is made up of an uncountable number of particles with mass, and these building blocks are necessary to form the elements that make up the people to ask such questions. The search for the answer to this question illustrates nicely the process we call the scientific method.

Current theoretical models tell us that everything in the universe is based on two types of elementary particles: bosons and fermions. We can distinguish the roles of these particles by considering the building blocks of matter to be constructed from fermions, while bosons are particles responsible for the force that holds the fermions together. In 1964, three different research teams independently proposed mechanisms in which a field of energy permeates the universe, and the interaction of matter with this field is due to a specific boson associated with the field. The greater the number of these bosons, the greater the interaction will be with the field. This interaction is the property we call mass, and the field and the associated boson came to be named for Peter Higgs, one of the original physicists to propose this mechanism.

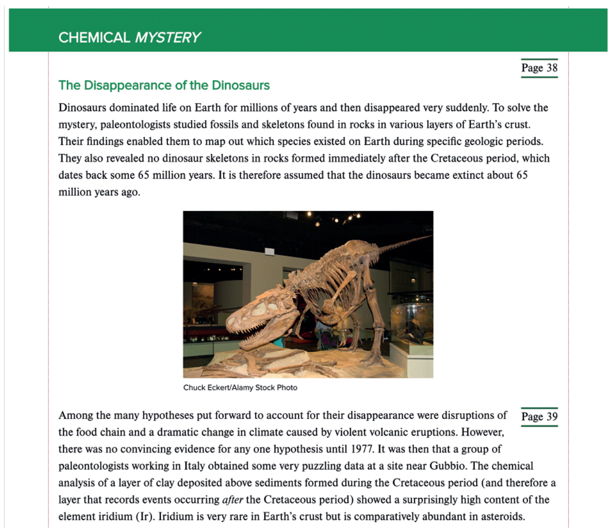
This theory ignited a frantic search for the "Higgs boson" that became one of the most heralded quests in modern science. The Large Hadron Collider at CERN in Geneva, Switzerland (described in Chapter 19), was constructed to carry out experiments designed to find evidence for the Higgs boson. In these experiments, protons are accelerated to nearly the speed of light in opposite directions in a circular 17-mile tunnel and then allowed to collide, generating even more fundamental particles at very high energies. The data are examined for evidence of an excess of particles at an energy consistent with theoretical predictions for the Higgs boson. The ongoing process of theory suggesting experiments that give results used to evaluate and ultimately refine the theory, and so on, is the essence of the scientific method.

Illustration of the data obtained from decay of the Higgs boson into other particles following an 8-TeV collision in the Large Hadron Collider at CERN.
Thomas McCauley/Lucas Taylor, CERN/Science Source

On July 4, 2012, scientists at CERN announced the discovery of the Higgs boson. It takes about 1 trillion proton–proton collisions to produce one Higgs boson event, so it requires a tremendous amount of data obtained from two independent sets of experiments to confirm the findings. In science, the quest for answers is never completely done. Our understanding can always be improved or refined, and sometimes entire tenets of accepted science are replaced by another theory that does a better job explaining the observations. For example, scientists are not sure if the Higgs boson is the only particle that confers mass to matter, or if it is only one of several such bosons predicted by other theories.

But over the long run, the scientific method has proven to be our best way of understanding the physical world. It took 50 years for experimental science to validate the existence of the Higgs boson. This discovery was greeted with great fanfare and recognized the following year with a 2013 Nobel Prize in Physics for Peter Higgs and François Englert, another one of the six original scientists who first proposed the existence of a universal field that gives particles their mass. It is impossible to imagine where science will take our understanding of the universe in the next 50 years, but we can be fairly certain that many of the theories and experiments driving this scientific discovery will be very different than the ones we use today.

Chemical Mystery (eBook only) poses a mystery case to the student in online format. A series of chemical questions provide clues as to how the mystery could possibly be solved. Chemical Mystery will foster a high level of critical thinking using the basic problem-solving steps built up throughout the text.



CHEMICAL *MYSTERY*

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The Disappearance of the Dinosaurs

Dinosaurs dominated life on Earth for millions of years and then disappeared very suddenly. To solve the mystery, paleontologists studied fossils and skeletons found in rocks in various layers of Earth's crust. Their findings enabled them to map out which species existed on Earth during specific geologic periods. They also revealed no dinosaur skeletons in rocks formed immediately after the Cretaceous period, which dates back some 65 million years. It is therefore assumed that the dinosaurs became extinct about 65 million years ago.

Chuck Eckert/Alamy Stock Photo

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Among the many hypotheses put forward to account for their disappearance were disruptions of the food chain and a dramatic change in climate caused by violent volcanic eruptions. However, there was no convincing evidence for any one hypothesis until 1977. It was then that a group of paleontologists working in Italy obtained some very puzzling data at a site near Gubbio. The chemical analysis of a layer of clay deposited above sediments formed during the Cretaceous period (and therefore a layer that records events occurring *after* the Cretaceous period) showed a surprisingly high content of the element iridium (Ir). Iridium is very rare in Earth's crust but is comparatively abundant in asteroids.

Instructor and Student Resources

McGraw Hill ALEKS®

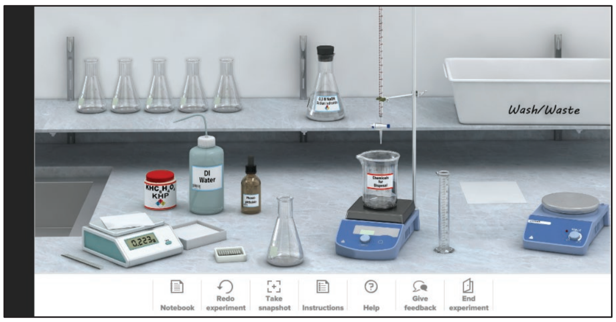
ALEKS (Assessment and LEarning in Knowledge Spaces) is a web-based system for individualized assessment and learning available 24/7 over the Internet. ALEKS uses artificial intelligence to accurately determine students' knowledge and then guides them to the material that they are most ready to learn. 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:

- **Art** Full-color digital files of all illustrations, photos, and tables in the book can be readily incorporated into lecture presentations, exams, or custom-made classroom materials. In addition, all files have been inserted into PowerPoint slides for ease of lecture preparation.
- **Animations and Videos** Numerous full-color animations and videos illustrating important concepts and processes are also provided. Harness the visual impact of concepts in motion by importing these files into classroom presentations or online course materials.
- **Accessible PowerPoint Lecture Outlines** Ready-made presentations that combine art and lecture notes are provided for each chapter of the text.
- **Computerized Test Bank** Over 3,000 test questions that accompany *Chemistry* are available for creating exams or quizzes.
- **Instructor's Solutions Manual** This supplement contains complete, worked-out solutions for *all* the end-of-chapter problems in the text.

McGraw Hill ALEKS® Virtual Labs

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, Learn-Smart Labs accomplishes it all.



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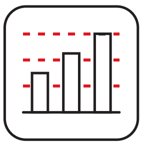
McGraw Hill ALEKS®

Break down barriers and build student knowledge

Students start your course with varying levels of preparedness. Some will get it quickly. Some won't. ALEKS is a course assistant that helps you meet each student where they are and provide the necessary building blocks to get them where they need to go. You determine the assignments and the content, and ALEKS will deliver customized practice until your students truly get it.

Experience the ALEKS Difference



Easily Identify Knowledge Gaps

Gain greater visibility into student performance so you know immediately if your lessons clicked.

- **ALEKS's "Initial Knowledge Check"** helps accurately evaluate student levels and gaps on day one, so you know precisely where students are at and where they need to go when they start your course.
- **You know when students are at risk of falling behind** through ALEKS Insights so you can remediate—be it through prep modules, practice questions, or written explanations of video tutorials.
- **Students always know where they are,** know how they are doing, and can track their own progress easily.

Gain More Flexibility and Engagement

Teach your course your way, with best-in-class content and tools to immerse students and keep them on track.

- **ALEKS gives you flexibility** to assign homework, share a vast library of curated content including videos, review progress, and provide student support, anytime anywhere.
- **You save time** otherwise spent performing tedious tasks while having more control over and impact on your students' learning process.
- **Students gain a deeper level of understanding** through interactive and hands-on assignments that go beyond multiple-choice questions.

with ALEKS® Constructive Learning Paths.

Narrow the Equity Gap

Efficiently and effectively create individual pathways for students without leaving anyone behind.

- **ALEKS creates an equitable experience for all students,** making sure they get the support they need to successfully finish the courses they start.
- **You help reduce attrition,** falling enrollment, and further widening of the learning gap.
- **Student success rates improve**—not just better grades, but better learning.

Count on Hands-on Support

A dedicated Implementation Manager will work with you to build your course exactly the way you want it and your students need it.

- **An ALEKS Implementation Manager** is with you every step of the way through the life of your course.
- **You never have to figure it out on your own** or be your student's customer service. We believe in a consultative approach and take care of all of that for you, so you can focus on your class.
- **Your students benefit** from more meaningful moments with you, while ALEKS—directed by you—does the rest.

Already benefitting from ALEKS?

Check out our New Enhancements:
mheducation.com/highered/aleks/new-releases.html

Student Solutions Manual

Students will find answers to the Practice Exercises and detailed solutions for selected problems from the text in the Student Solutions manual. In addition, there are problem-solving strategies and tutorial solutions that surround each chapter's most important topics and problem types.

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A Note to the Student

General chemistry is commonly perceived to be more difficult than most other subjects. There is some justification for this perception. For one thing, chemistry has a very specialized vocabulary. At first, studying chemistry is like learning a new language. Furthermore, some of the concepts are abstract. Nevertheless, with diligence you can complete this course successfully, and you might even enjoy it. Here are some suggestions to help you form good study habits and master the material in this text.

- Attend classes regularly and take careful notes.
- If possible, always review the topics discussed in class the same day they are covered in class. Use this book to supplement your notes.
- Think critically. Ask yourself if you really understand the meaning of a term or the use of an equation. A good way to test your understanding is to explain a concept to a classmate or some other person.
- Do not hesitate to ask your instructor or your teaching assistant for help.

The fifteenth edition tools for *Chemistry* are designed to enable you to do well in your general chemistry course. The following guide explains how to take full advantage of the text, technology, and other tools.

- Before delving into the chapter, read the chapter *outline* and the chapter *introduction* to get a sense of the important topics. Use the outline to organize your note taking in class.
- At the end of each chapter you will find a summary of facts and concepts, the key equations, and a list of key words, all of which will help you review for exams.
- Definitions of the key words can be studied in context on the pages cited in the end-of-chapter list or in the glossary at the back of the book.
- Careful study of the worked-out examples in the body of each chapter will improve your ability to analyze problems and correctly carry out the calculations needed to solve them. Also take the time to work through the practice exercise that follows each example to be sure you understand how to solve the type of problem illustrated in the example. The answers to the practice exercises appear at the end of the chapter in your print text, following the questions and problems, or immediately following the practice exercises in your eBook. For additional practice, you can turn to similar problems referred to in the margin next to the example.
- The questions and problems at the end of the chapter are organized by section.
- The appendices show a list of important figures and tables with page references. This index makes it convenient to quickly look up information when you are solving problems or studying related subjects in different chapters.

If you follow these suggestions and stay up-to-date with your assignments, you should find that chemistry is challenging, but less difficult and much more interesting than you expected.

—Jason Overby