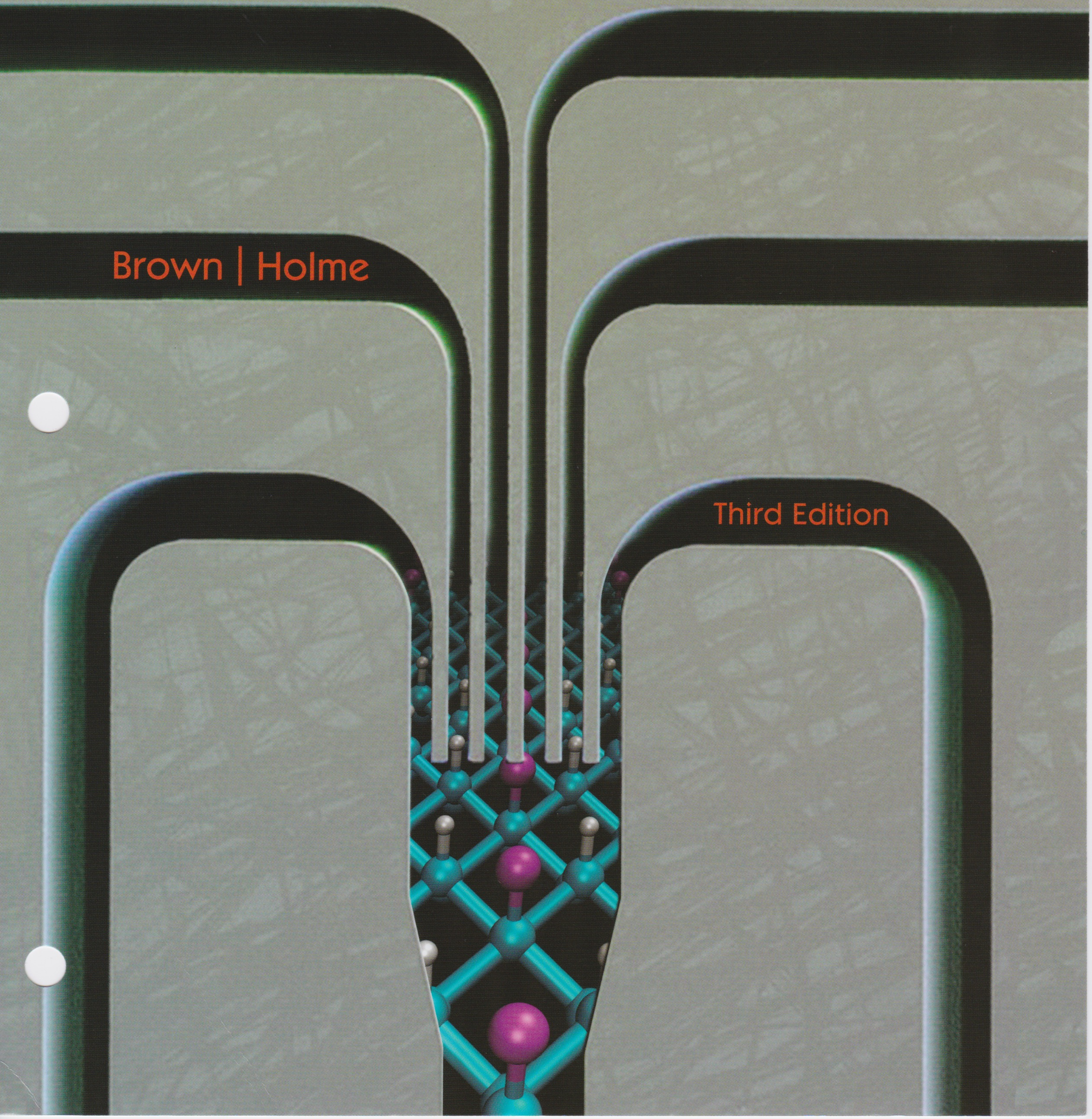
# Chemistry

## For Engineering Students



Brown | Holme

Third Edition

## SOME USEFUL CONSTANTS

(a more complete list appears in Appendix B)

| | |
|---|---|
| Atomic mass unit | 1 amu = $1.6606 \times 10^{-24}$ g |
| Avogadro's number | $N = 6.02214179 \times 10^{23}$ particles/mol |
| Electronic charge | $e = 1.60218 \times 10^{-19}$ coulombs |
| Faraday constant | $F = 96{,}485.3399$ coulombs/mol $e^-$ |
| Gas constant | $R = 0.08206 \frac{\text{L atm}}{\text{mol K}} = 1.987 \frac{\text{cal}}{\text{mol K}}$ $= 8.314472 \frac{\text{J}}{\text{mol K}} = 8.314472 \frac{\text{kPa dm}^3}{\text{mol K}}$ |
| Pi | $\pi = 3.1415927$ |
| Planck's constant | $h = 6.62606896 \times 10^{-34}$ J s |
| Speed of light (in vacuum) | $c = 2.99792458 \times 10^8$ m/s |

## SOME USEFUL RELATIONSHIPS

### Mass and Weight

SI Base Unit: Kilogram (kg)

1 kilogram = 1000 grams = 2.205 pounds
1 gram = 1000 milligrams
1 pound = 453.59 grams
1 amu = $1.6606 \times 10^{-24}$ grams
1 gram = $6.022 \times 10^{23}$ amu
1 ton = 2000 pounds

### Volume

SI Base Unit: Cubic Meter ($m^3$)

1 liter = 0.001 cubic meter
1 liter = 1000 cubic centimeters = 1000 mL
1 liter = 1.056 quarts
1 quart = 0.9463 liter
1 milliliter = 0.001 liter = 1 cubic centimeter
cubic foot = 7.475 gallons = 28.316 liters
1 gallon = 4 quarts

### Pressure

SI Base Unit: Pascal (Pa)

$$1 \text{ pascal} = \frac{\text{kg}}{\text{m s}^2} = 1 \text{ Newton/m}^2$$

1 atmosphere = 760 torr
= 760 millimeters of mercury
= $1.01325 \times 10^5$ pascals
= 1.01325 bar
= 14.70 pounds per square inch
1 torr = 1 millimeter of mercury

### Length

SI Base Unit: Meter (m)

1 inch = 2.54 centimeters (exactly)
1 meter = 100 centimeters = 39.37 inches
1 yard = 0.9144 meter
1 mile = 1.609 kilometers
1 kilometer = 1000 meters = 0.6215 mile
1 Ångstrom = $1.0 \times 10^{-10}$ meters = $1.0 \times 10^{-8}$ centimeters

### Energy

SI Base Unit: Joule (J)

1 calorie = 4.184 joules = $4.129 \times 10^{-2}$ L atm

$$1 \text{ joule} = 1 \frac{\text{kg m}^2}{\text{s}^2} = 0.23901 \text{ calorie}$$

1 joule = $1 \times 10^7$ ergs
1 electron volt = $1.6022 \times 10^{-19}$ joule
1 electron volt = 96.485 kJ/mol
1 L atm = 24.217 calories = 101.325 joules

### Temperature

SI Base Unit: Kelvin (K)

$0\text{ K} = -273.15°\text{C}$
$\text{K} = °\text{C} + 273.15°$
$°\text{F} = 1.8(°\text{C}) + 32°$

$$°\text{C} = \frac{°\text{F} - 32°}{1.8°}$$

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# INTERNATIONAL TABLE OF ATOMIC WEIGHTS

| Atomic Number | Symbol | Name | Atomic Weight | Atomic Number | Symbol | Name | Atomic Weight |
|---|---|---|---|---|---|---|---|
| 89 | Ac | Actinium | [227] | 60 | Nd | Neodymium | 144.242 |
| 13 | Al | Aluminum | 26.9815386 | 10 | Ne | Neon | 20.1797 |
| 95 | Am | Americium | [243] | 3 | Np | Neptunium | [237] |
| 51 | Sb | Antimony | 121.760 | 28 | Ni | Nickel | 58.6934 |
| 18 | Ar | Argon | 39.948 | 41 | Nb | Niobium | 92.90638 |
| 33 | As | Arsenic | 74.92160 | 7 | N | Nitrogen | 14.0067 |
| 85 | At | Astatine | [210] | 102 | No | Nobelium | [259] |
| 56 | Ba | Barium | 137.327 | 76 | Os | Osmium | 190.23 |
| 97 | Bk | Berkelium | [247] | 8 | O | Oxygen | 15.9994 |
| 4 | Be | Beryllium | 9.012182 | 46 | Pd | Palladium | 106.42 |
| 83 | Bi | Bismuth | 208.98040 | 15 | P | Phosphorus | 30.973762 |
| 107 | Bh | Bohrium | [272] | 78 | Pt | Platinum | 195.084 |
| 5 | B | Boron | 10.811 | 94 | Pu | Plutonium | [244] |
| 35 | Br | Bromine | 79.904 | 84 | Po | Polonium | [209] |
| 48 | Cd | Cadmium | 112.411 | 19 | K | Potassium | 39.0983 |
| 55 | Cs | Cesium | 132.9054519 | 59 | Pr | Praseodymium | 140.90765 |
| 20 | Ca | Calcium | 40.078 | 61 | Pm | Promethium | [145] |
| 98 | Cf | Californium | [251] | 91 | Pa | Protactinium | 231.03588 |
| 6 | C | Carbon | 12.0107 | 88 | Ra | Radium | [226] |
| 58 | Ce | Cerium | 140.116 | 86 | Rn | Radon | [222] |
| 17 | Cl | Chlorine | 35.453 | 75 | Re | Rhenium | 186.207 |
| 24 | Cr | Chromium | 51.9961 | 45 | Rh | Rhodium | 102.90550 |
| 27 | Co | Cobalt | 58.933195 | 111 | Rg | Roentgenium | [280] |
| 29 | Cu | Copper | 63.546 | 37 | Rb | Rubidium | 85.4678 |
| 96 | Cm | Curium | [247] | 44 | Ru | Ruthenium | 101.07 |
| 110 | Ds | Darmstadtium | [281] | 104 | Rf | Rutherfordium | [267] |
| 105 | Db | Dubnium | [268] | 62 | Sm | Samarium | 150.36 |
| 66 | Dy | Dysprosium | 162.500 | 21 | Sc | Scandium | 44.955912 |
| 99 | Es | Einsteinium | [252] | 106 | Sg | Seaborgium | [271] |
| 68 | Er | Erbium | 167.259 | 34 | Se | Selenium | 78.96 |
| 63 | Eu | Europium | 151.964 | 14 | Si | Silicon | 28.0855 |
| 100 | Fm | Fermium | [257] | 47 | Ag | Silver | 107.8682 |
| 9 | F | Fluorine | 18.9984032 | 11 | Na | Sodium | 22.98976928 |
| 87 | Fr | Francium | [223] | 38 | Sr | Strontium | 87.62 |
| 64 | Gd | Gadolinium | 157.25 | 16 | S | Sulfur | 32.065 |
| 31 | Ga | Gallium | 69.723 | 73 | Ta | Tantalum | 180.94788 |
| 32 | Ge | Germanium | 72.64 | 43 | Tc | Technetium | [98] |
| 79 | Au | Gold | 196.966569 | 52 | Te | Tellurium | 127.60 |
| 72 | Hf | Hafnium | 178.49 | 65 | Tb | Terbium | 158.92535 |
| 108 | Hs | Hassium | [270] | 81 | Tl | Thallium | 204.3833 |
| 2 | He | Helium | 4.002602 | 90 | Th | Thorium | 232.03806 |
| 67 | Ho | Holmium | 164.93032 | 69 | Tm | Thulium | 168.93421 |
| 1 | H | Hydrogen | 1.00794 | 50 | Sn | Tin | 118.710 |
| 49 | In | Indium | 114.818 | 22 | Ti | Titanium | 47.867 |
| 53 | I | Iodine | 126.90447 | 74 | W | Tungsten | 183.84 |
| 77 | Ir | Iridium | 192.217 | 112 | Uub | Ununbium | [285] |
| 6 | Fe | Iron | 55.845 | 116 | Uuh | Ununhexium | [293] |
| 36 | Kr | Krypton | 83.798 | 118 | Uuo | Ununoctium | [294] |
| 57 | La | Lanthanum | 138.90547 | 115 | Uup | Ununpentium | [288] |
| 103 | Lr | Lawrencium | [262] | 114 | Uuq | Ununquadium | [289] |
| 82 | Pb | Lead | 207.2 | 113 | Uut | Ununtrium | [284] |
| 3 | Li | Lithium | 6.941 | 92 | U | Uranium | 238.02891 |
| 71 | Lu | Lutetium | 174.9668 | 23 | V | Vanadium | 50.9415 |
| 12 | Mg | Magnesium | 24.3050 | 54 | Xe | Xenon | 131.293 |
| 25 | Mn | Manganese | 54.938045 | 70 | Yb | Ytterbium | 173.054 |
| 109 | Mt | Meitnerium | [276] | 39 | Y | Yttrium | 88.90585 |
| 101 | Md | Mendelevium | [258] | 30 | Zn | Zinc | 65.38 |
| 80 | Hg | Mercury | 200.59 | 40 | Zr | Zirconium | 91.224 |
| 42 | Mo | Molybdenum | 95.96 | | | | |

# Chemistry for Engineering Students

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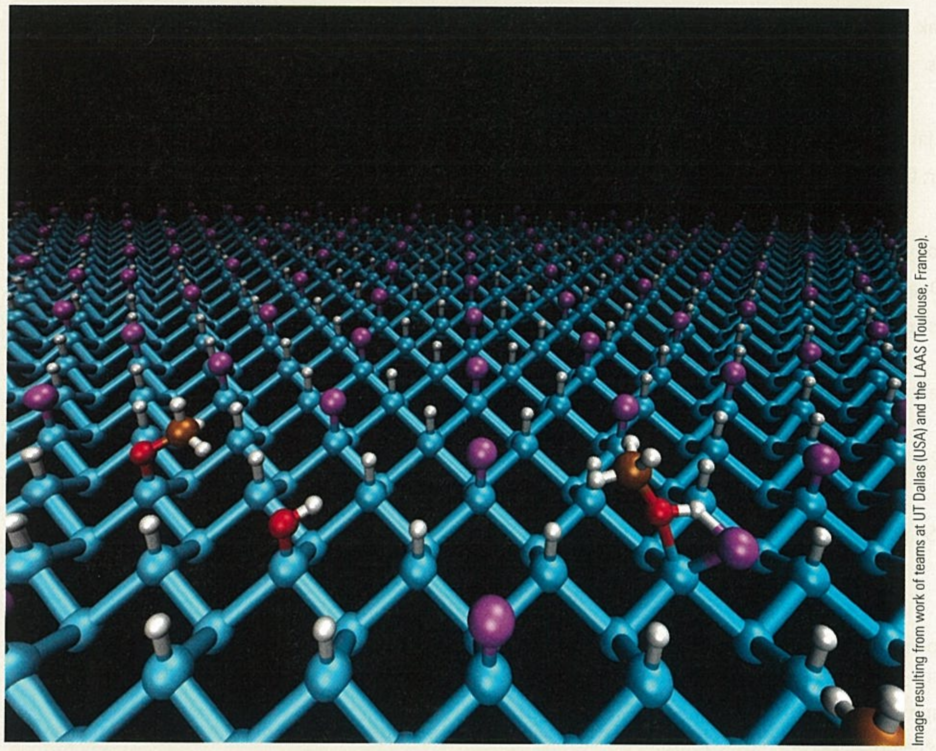


The cover image shows a portion of a microelectromechanical system, or MEMS, along with a representation of the surface of silicon. MEMS devices such as this one can be used to process or analyze samples of DNA or other biochemical molecules, and provide an excellent example of the interface between chemistry and engineering.

**THIRD EDITION**

**Lawrence S. Brown**

*Texas A&M University*

**Thomas A. Holme**

*Iowa State University*

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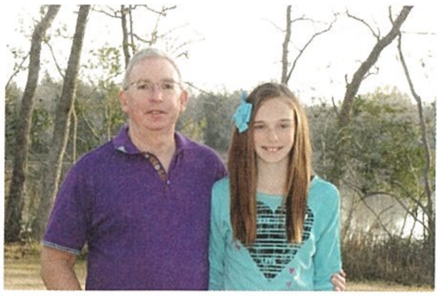


Courtesy of Lawrence Brown/photo by Sherry Yennello

**Larry Brown** has been a faculty member at Texas A&M University since 1988, and in 2013 he was named Presidential Professor for Teaching Excellence. He received his B.S. in 1981 from Rensselaer Polytechnic Institute, and his M.A. in 1983 and Ph.D. in 1986 from Princeton University. During his graduate studies, Larry spent a year working in what was then West Germany. He was a Postdoctoral Fellow at the University of Chicago for two years before moving to Texas A&M. Over the years, he has taught more than 14,000 general chemistry students, most of them engineering majors. Larry's excellence in teaching has been recognized by awards from the Association of Former Students at Texas A&M at both the College of Science and University levels. A version of his class has been broadcast on KAMU-TV, College Station's PBS affiliate and is currently available on iTunesU. From 2001 to 2004, Larry served as a Program Officer for Education and Interdisciplinary Research in the Physics Division of the National Science Foundation. He also coordinates chemistry courses for Texas A&M's engineering program in Doha, Qatar. When not teaching chemistry, he enjoys road bicycling and playing soccer with his daughter Stephanie.

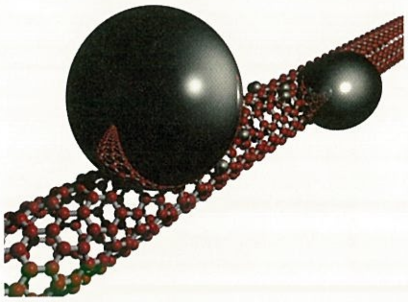
Courtesy of Thomas Holme/photo by Dennis Salisbury

**Tom Holme** is a Professor of Chemistry at Iowa State University and Director of the ACS Examinations Institute. He received his B.S. in 1983 from Loras College, and his Ph.D. in 1987 from Rice University. He began his teaching career as a Fulbright Scholar in Zambia, Africa and has also lived in Jerusalem, Israel and Suwon, South Korea. He is a fellow of the American Chemical Society and the American Association for the Advancement of Science. His research interests lie in computational chemistry, particularly as applied to understanding processes important for plant growth. He is also active chemical education research and has been involved with the general chemistry for engineers course at both Iowa State University and at the University of Wisconsin–Milwaukee where he was a member of the Chemistry and Biochemistry Department. He has received several grants from the National Science Foundation for work in assessment methods for chemistry, and the "*Focus on Problem Solving*" feature in this textbook grew out of one of these projects. He served as an Associate Editor on the encyclopedia "*Chemistry Foundations and Applications*." He was the lead editor of the laboratory manual for the new AP chemistry curriculum. In 1999 Tom won the ACS's Helen Free Award for Public Outreach for his efforts doing chemical demonstrations on live television in the Milwaukee area.

# Brief Contents

# Contents





Courtesy of Zettl Research Group, Lawrence Berkeley National Laboratory, and the University of California at Berkeley

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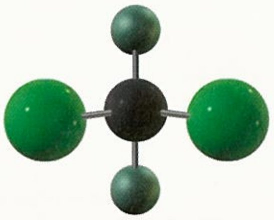

Freon-12, $CF_2Cl_2$

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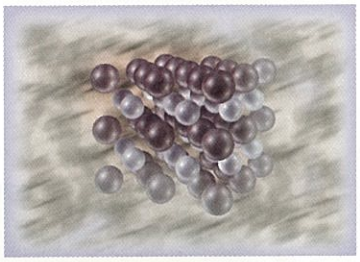

Original illustration courtesy of Raymond Schaak

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Thomas A. Holme



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National Park Service


Thomas A. Holme


Lawrence S. Brown



## Appendixes

# Preface

## The Genesis of This Text

As chemists, we see connections between our subject and virtually everything. So the idea that engineering students should learn chemistry strikes most chemists as self-evident. But chemistry is only one of many sciences with which a practicing engineer must be familiar, and the undergraduate curriculum must find room for many topics. Hence, engineering curricula at more and more universities are shifting from the traditional year long general chemistry sequence to a single semester. And in most cases, these schools are offering a separate one-term course designed specifically for their engineering students. When schools—including our own—originally began offering these courses, there was no text on the market for them, so content from two-semester texts had to be heavily modified to fit the course. Although it is possible to do this, it is far from ideal. It became apparent that a book specifically geared for this shorter course was necessary. ***We have written this book to fill this need.***

Our goal is to instill an appreciation for the role of chemistry in many areas of engineering and technology and of the interplay between chemistry and engineering in a variety of modern technologies. For most engineering students, the chemistry course is primarily a prerequisite for courses involving materials properties. These courses usually take a phenomenological approach to materials rather than emphasizing the chemist's molecular perspective. Thus one aim of this text is to provide knowledge of and appreciation for the chemical principles of structure and bonding that underpin materials science. This does *not* mean that we have written the book as a materials science text, but rather that the text is intended to prepare students for subsequent study in that area.

The book also provides sufficient background in the science of chemistry for a technically educated professional. Engineering, after all, is the creative and practical application of a broad array of scientific principles, so its practitioners should have a broad base in the natural sciences.

## Content and Organization

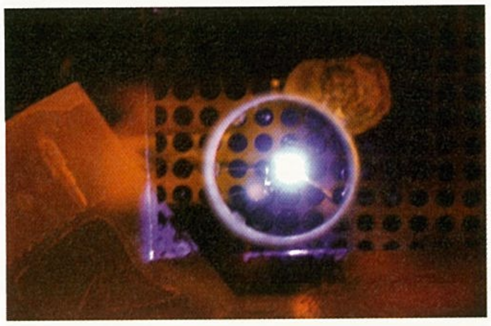
The full scope of the traditional general chemistry course cannot be taught meaningfully in one semester or one or two quarters, so we have had to decide what content to include. There are basically two models used to condense the general chemistry curriculum. The first is to take the approach of an "essentials" book and reduce the depth of coverage and the number of examples but retain nearly all of the traditional topics. The second is to make more difficult and fundamental decisions as to what chemistry topics are proper and relevant to the audience, in this case future engineers. We chose the latter approach and built a 14-chapter book from the ground up to satisfy what we think are the goals of the course:

- Provide a concise but thorough introduction to the science of chemistry.
- Give students a firm foundation in the principles of structure and bonding as a foundation for further study of materials science.

- Show the connection between molecular behavior and observable physical properties.
- Show the connections between chemistry and the other subjects studied by engineering students, especially mathematics and physics.

Taken together, the 14 chapters in this book probably represent somewhat more material than can comfortably fit into a standard semester course. Thus departments or individual instructors will need to make some further choices as to the content that is most suitable for their own students. We suspect that many instructors will not choose to include all of the material on equilibrium in Chapter 12, for example. Similarly, we have included more topics in Chapter 8, on condensed phases, than we expect most faculty will include in their courses.

## Topic Coverage



Courtesy of the U.S. Department of Energy's Ames Laboratory

The coverage of topics in this text reflects the fact that chemists constantly use multiple concepts to understand their field, often using more than one model simultaneously. Thus the study of chemistry we present here can be viewed from multiple perspectives: macroscopic, microscopic, and symbolic. The latter two perspectives are emphasized in Chapters 2 and 3 on atoms, molecules, and reactions. In Chapters 4 and 5, we establish more of the connection between microscopic and macroscopic in our treatment of stoichiometry and gases. We return to the microscopic perspective to cover more details of atomic structure and chemical bonding in Chapters 6 through 8. The energetic aspects of chemistry, including important macroscopic consequences, are considered in Chapters 9 and 10, and kinetics and equilibrium are treated in Chapters 11 and 12, respectively. Chapter 13 deals with electrochemistry and corrosion, an important chemistry application for many engineering disciplines. Finally, we conclude with a discussion of nuclear chemistry.

## Specific Content Coverage

We know that there are specific topics in general chemistry that are vital to future engineers. We've chosen to treat them in the following ways.

***Organic Chemistry:*** Organic chemistry is important in many areas of engineering, particularly as related to the properties of polymers. Rather than using a single organic chapter, we integrate our organic chemistry coverage over the entire text, focusing on polymers. We introduce organic polymers in Section 2.1 and use polymers and their monomers in many examples in this chapter. Chapter 2 also contains a rich discussion of organic line structures and functional groups and ends with a section on the synthesis, structure, and properties of polyethylene. Chapter 4 opens and ends with discussions of fuels, a topic to which we return in Chapter 9. Chapter 8 contains more on carbon and polymers, and the recycling of polymers provides the context for consideration of the second law of thermodynamics in Chapter 10.

***Acid–Base Chemistry:*** Acid–base reactions represent another important area of chemistry with applications in engineering, and again we have integrated our coverage into appropriate areas of the text. Initially, we define acids and bases in conjunction with the introduction to solutions in Chapter 3. Simple solution stoichiometry is presented in Chapter 4. Finally, a more detailed treatment of acid–base chemistry is presented in the context of equilibria in Chapter 12.

***Nuclear Chemistry:*** A chapter dealing with nuclear chemistry is included for those wishing to teach that topic. Coverage in this chapter includes fundamentals of nuclear reactions, nuclear stability and radioactivity, decay kinetics, and the energetic consequences of nuclear processes.

***Mathematics:*** The math skills of students entering engineering majors generally are stronger than those in the student body at large, and most of the students taking a course of the type for which this book is intended will be concurrently enrolled in an introductory calculus course. In light of this, we include references to the role of calculus where appropriate via our **MathConnections** boxes. These essays expand and review math concepts as they pertain to the particular topic being studied, and appear wherever the links between the topic at hand and mathematics seems especially strong. These boxes are intended to be unobtrusive, so those students taking a precalculus math course will not be adversely affected. The point of including calculus is not to raise the level of material being presented, but rather to show the natural connections between the various subjects students are studying.

## Connections between Chemistry and Engineering


Lawrence S. Brown

Because this book is intended for courses designed for engineering majors, we strive to present chemistry in contexts that we feel will appeal to the interests of such students. Links between chemistry and engineering are central to the structure of the text. Each chapter begins and ends with a section called ***INSIGHT INTO*** . . . , which introduces a template or theme showing the interplay between chemistry and engineering. These sections are only the beginning of the connections, and the theme introduced in the initial *Insight* appears regularly throughout that chapter.

We opt for currency in our engineering applications wherever possible, so throughout the book, we discuss recent key innovations in various fields. For example, Chapter 3 includes a discussion of the chemistry and engineering involved in the conversion of biomass to biofuels. In Chapter 7, we describe mesoporous silicon nanoparticles, a front-line research topic that may have important applications in biomedical engineering in the future. Chapter 8 closes with a discussion of the fabrication of micro-electrical-mechanical systems (MEMS).

## Approach to Problem Solving

Problem solving is a key part of college chemistry courses and is especially important as a broadly transferable skill for engineering students. Accordingly, this text includes worked problems throughout. All of our Example Problems include a *Strategy* section immediately following the problem statement, in which we emphasize the concepts and relationships that must be considered to work the problem. After the solution, we often include a section called *Analyze Your Answer* that is designed to help students learn to estimate whether or not the answer they have obtained is reasonable. In many examples, we also include *Discussion* sections that help explain the importance of a problem solving concept or point out common pitfalls to be avoided. Finally, each example closes with a *Check Your Understanding* problem or question to help the student to generalize or extend what's been learned in the example problem.

We believe that the general chemistry experience should help engineering students develop improved problem solving skills. Moreover, we feel that those skills should be transferable to other subjects in the engineering curriculum even though chemistry content may not be involved. Accordingly, we include a unique feature at the end of each chapter called **FOCUS ON PROBLEM SOLVING**. In these sections, the questions posed do not require a numerical answer, but rather ask the student to identify the strategy or reasoning to be used in the problem and often require them to identify missing information for the problem. In most cases, it is not possible to arrive at a final numerical answer using the information provided, so students are forced to focus on developing a solution rather than just identifying and executing an algorithm. In this third edition, we have emphasized the use of graphical problem-solving strategies in some of these features. The end-of-chapter exercises include additional problems of this nature so the *Focus on Problem Solving* can be fully incorporated into the course. This feature grew out of an NSF-funded project on assessing problem solving in chemistry classes.

## Text Features

We employ a number of features, some of which we referred to earlier, to help students see the utility of chemistry and understand the connections to engineering.

***INSIGHT INTO*** **Sections** Each chapter is built around a template called *Insights Into* . . . . These themes, which both open and close each chapter, have been chosen to showcase connections between engineering and chemistry. In addition to the chapter opening and closing sections, the template themes are woven throughout the chapter, frequently providing the context for points of discussion or example problems. This special *Insight* icon is used throughout the book to identify places where ideas presented in the chapter opening section are revisited in the narrative.

**FOCUS ON PROBLEM SOLVING Sections** Engineering faculties unanimously say that freshman engineering students need practice in solving problems. However, it is important to make a distinction here between problems and exercises. Exercises provide a chance to practice a narrow skill, whereas problems require multiple steps and thinking outside the context of the information given. *Focus on Problem Solving* offers students the chance to develop and practice true problem solving skills. These sections, which appear at the end of every chapter, include a mix of quantitative and qualitative questions that focus on the *process* of finding a solution to a problem, not the solution itself. We support these by including additional similar problems in the end-of-chapter material.

**MathConnections** In our experience, one trait that distinguishes engineering students from other general chemistry students is a higher level of comfort with mathematics. Typically, most students who take a class of the sort for which this book has been written will also be taking a course in calculus. Thus it seems natural to us to point out the mathematical underpinnings of several of the chemistry concepts presented in the text because this should help students forge mental connections between their courses. At the same time, we recognize that a student taking a precalculus math course should not be precluded from taking chemistry. To balance these concerns, we have placed any advanced mathematics into special *MathConnections* sections, which are set off from the body of the text. Our hope is that those students familiar with the mathematics involved will benefit from seeing the origin of things such as integrated rate laws, whereas those students with a less extensive background in math will still be able to read the text and master the chemistry presented.

**Example Problems** Our examples are designed to illustrate good problem solving practices by first focusing on the reasoning behind the solution before moving into any needed calculations. We emphasize this "think first" approach by beginning with a *Strategy* section, which outlines a plan of attack for the problem. We find that many students are too quick to accept whatever answer their calculator might display. To combat this, we follow most solutions with an *Analyze Your Answer* section, which uses estimation and other strategies to walk students through a double check of their answers. Every example closes with a *Check Your Understanding* exercise to allow students to practice or extend the skill they have just learned. Answers to these additional exercises are included in Appendix J at the end of the book.

**End-of-Chapter Features** Each chapter concludes with a chapter summary, outlining the main points of the chapter, and a list of key terms, each of which includes the section number where the term first appeared. Definitions for all key terms appear in the Glossary.

**Problem Sets** Each chapter includes roughly 100 problems and exercises, spanning a wide range of difficulty. Most of these exercises are identified with specific sections to provide the practice that students need to master material from that section. Each chapter also includes a number of *Additional Problems*, which are not tied to any particular section and which may incorporate ideas from multiple sections. *Focus on Problem Solving* exercises follow, as described earlier. The problems for most chapters conclude with *Cumulative Problems*, which ask students to synthesize information from the current chapter with what they've learned from previous chapters to form answers. For the third edition, we have added a number of more challenging problems in several chapters. Answers for all odd-numbered problems appear at the end of the book in Appendix K.

**Margin Notes** Margin notes in the text point out additional facts, further emphasize points, or point to related discussion either earlier or later in the book. Margin Notes are denoted with an ◀ⓘ icon that is also placed in the narrative and links the margin note with the relevant passage in the text.

## New in this Edition

There are several important changes in this third edition of the textbook. As we did for the second edition, we have replaced a number of the "Insight Into. . ." sections to make them more current and to try to include topics that will appeal to a wider range of student interests. Thus, we have introduced two new topics for the chapter-opening insights: Biomass and Biofuel Engineering in Chapter 3 and Trace Analysis in Chapter 6. Both of these themes are more readily connected to engineering applications than those that they replaced. The closing insight sections for Chapters 3, 8, 9, 12, and 13 have also been rewritten to highlight topics with more current relevance. A detailed list of specific changes is given below.

| Chapter | Summary of Changes |
|---|---|
| 1 | • Updated references to contexts used throughout the book, because several of these contexts have changed.<br>• Improved artwork showing particulate nature of matter and phases.<br>• Cleaned up usage of margin notes throughout.<br>• Added end-of-chapter problems. |
| 2 | • Added a section to the text about the newly approved IUPAC atomic masses and explained how the issue of what atomic mass to use in calculations is handled in this book. This change includes a table with the new approved ranges and references to aspects of scientific investigations, such as climate change, that rely on this level of information.<br>• Added end-of-chapter problems that build on connection between isotopes and mass spectroscopy.<br>• Cleaned up usage of margin notes throughout.<br>• Cleaned up artwork for several figures. |

| Chapter | Summary of Changes |
|---|---|
| 3 | Major Change<br>• Changed the context for the entire chapter from explosions to biofuels.<br>  ○ Includes new opening insight<br>  ○ Includes changes in several example problems<br>  ○ Includes changes at several points in the text where references to context are made<br>  ○ Includes changes for several figures (3.1, 3.2, 3.10)<br>  ○ Includes changes to end-of-chapter problems related to the context theme<br>Other changes<br>• Changed Closing Insight section from explosive and green chemistry to carbon sequestration.<br>• Cleaned up usage of margin notes throughout. |
| 4 | • Cleaned up usage of margin notes throughout.<br>• Replaced "Focus on Problem Solving" with a new style of problem for this feature that includes graphical reasoning.<br>• Replaced several end-of-chapter problems and added several end-of-chapter problems. |
| 5 | • Cleaned up usage of margin notes throughout.<br>• Added several end-of-chapter problems. |
| 6 | Major Change<br>• Changed the context for the entire chapter from light bulbs to trace analysis.<br>  ○ Includes new opening insight<br>  ○ Includes changes in several example problems<br>  ○ Includes changes at several points in the text where references to context are made.<br>  ○ Includes changes for several figures (6.1, 6.2, 6.10, which replaces what was 6.16)<br>  ○ Includes changes to end-of-chapter problems related to the context theme<br>Other changes<br>• Correction made in Math Connections feature.<br>• Cleaned up usage of margin notes throughout.<br>• Corrected artwork in Figure 6.20 to reflect accurate values of atomic radii.<br>• Changed wording in the introductory paragraph of the closing insight so it is not dependent on the now-removed context. |
| 7 | • Cleaned up usage of margin notes throughout.<br>• Cleaned-up artwork for several figures.<br>• Added several end-of-chapter problems.<br>• Corrected quantitative information on atomic radii in Figure 7.1.<br>• Removed mentions of $sp^3d$ and $sp^3d^2$ hybridization to reflect current best understanding of their non-utility in describing bonding. |
| 8 | • Cleaned up usage of margin notes throughout.<br>• Cleaned-up artwork for several figures.<br>  ○ Includes replacing Figures 8.1 and 8.24 to get the science depiction to be more accurate<br>• Added several end-of-chapter problems.<br>• Replaced closing insight section on the invention of new materials with one on micro-electrical-mechanical systems (with references to new cover art included) |
| 9 | • Cleaned up usage of margin notes throughout.<br>• Added several end-of-chapter problems.<br>• Replaced closing insight section on batteries with one on power distribution and the electrical grid with specific references to computer science demands.<br>  ○ Some of the more important concepts related to batteries were moved to the section in Chapter 13 on batteries.<br>• Updated artwork that had dated information.<br>• Updated several end-of-chapter problems to reflect content changes in the chapter. |

| Chapter | Summary of Changes |
| --- | --- |
| 10 | • Cleaned up usage of margin notes throughout.<br>• Cleaned up artwork for several figures.<br>• Reworked Carnot cycle description of entropy.<br>• Replaced the final two paragraphs of the closing insight section to include the role of plastics in marine environments—includes adding a new figure in addition to text content.<br>• Fixed factual errors in one end-of-chapter problem and added new end-of-chapter problems. |
| 11 | • Cleaned up usage of margin notes throughout.<br>• Cleaned up artwork for several figures, including updates on artwork that has data from specific years.<br>• Replaced "Focus on Problem Solving" with a new style of problem for this feature that includes graphical reasoning. |
| 12 | • Cleaned up usage of margin notes throughout.<br>• Cleaned up numerical information related to equilibrium constant for a few reactions in the text and appendixes.<br>• Added several end-of-chapter problems and cleaned up sub-headings used in the end-of-chapter problems.<br>• Replaced closing insight section on borates and boric acid with one on bendable concrete. |
| 13 | • Cleaned up usage of margin notes throughout.<br>• Added material about cathodic protection to Section 13-3.<br>• Revised information about batteries, changing examples, in Section 13-5.<br>   ◦ Includes moving materials on primary vs. secondary batteries from Chapter 9 to here<br>   ◦ Includes moving information about energy density of batteries from Chapter 9 to here<br>• Replaced closing insight on corrosion prevention with a new closing insight on lithium-ion batteries and their use in aerospace engineering.<br>• Replaced end-of-chapter problems with new ones appropriate for the new materials added. |
| 14 | • Cleaned up usage of margin notes throughout.<br>• Added a several paragraph description within Section 14-6 about the Fukushima reactor accident and the release of radioactivity from it.<br>• Added a large number of additional end-of-chapter problems. |

## Supporting Material

Please visit www.cengage.com/chemistry/brownholme/chemengineer3e for more information about student and instructor resources for this text.

## Acknowledgments

We are very excited to see this book move forward in this third edition, and we are grateful for the help and support we have enjoyed from a large and talented team of professionals. There are many people without whom we never could have done this. But foremost among them are our families, to whom this book is again dedicated.

The origin of this text can be traced back many years, and as we move into the third edition we would like once more to thank a few people who were instrumental in getting this project started. Jennifer Laugier first brought the two of us together to work on a book for engineering students. Jay Campbell's work as developmental editor for the first edition was tremendous, and without his efforts the book may never have been published. When Jay became involved, the project had been languishing for some time, and the subsequent gains in momentum were clearly not coincidental. The editorial leadership team at that time, consisting of Michelle Julet, David Harris, and Lisa Lockwood, was also crucial in seeing this project come to fruition. The decision to launch a book in a market segment that has not really existed was clearly not an easy one, and we appreciate the confidence that everyone at what was then Brooks/Cole placed in us.

In the development of this third edition, our Cengage Learning team includes a mix of the familiar and the new. We would like to thank our product manager, Lisa Lockwood, whose continued support is always appreciated. Our new Content Developer for this edition is Alyssa White, and both Lisa and Alyssa contributed greatly to discussions on where to focus our efforts in this revision. Alyssa has guided us through the entire revision process, and showed wonderful flexibility when we had trouble keeping up with the original production schedule. Media Editor Maureen Ross is coordinating work on the new MindTap electronic version of the text. Assistant Editor Brendan Killion is overseeing revisions to ancillary materials. Carol Samet at Cengage and Teresa Christie at MPS Limited have overseen all aspects of the actual production process. Richard Camp as copy editor has helped us to be much more consistent in our handling of a number of style issues, and Jill Reichenbach provided photo research. David Shinn has helped us check the page proofs, providing many valuable comments that have improved the accuracy of the text. The book in your hands truly reflects the best efforts of many hard-working professionals, and we are grateful to all of them for their roles in this project.

It has been nearly eight years since the first edition was published, and throughout that time we have received useful feedback from numerous students and colleagues. Much of that feedback is informal, including e-mail from students or faculty members pointing out errors they have found or letting us know about sections they really liked. Although there is no way to list all of the people who have contributed in this way, we do sincerely thank you all.

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**Tom Holme**
*March, 2013*

# Student Introduction

## Chemistry and Engineering

As you begin this chemistry course, odds are that you may be wondering "Why do I have to take chemistry anyway? I'll never really need to know any of this to be an engineer." So we'd like to begin by offering just a few examples of the many links between our chosen field of chemistry and the various branches of engineering. The most obvious examples, of course, might come from chemical engineering. Many chemical engineers are involved with the design or optimization of processes in the chemical industry, so it is clear that they would be dealing with concepts from chemistry on a daily basis. Similarly, civil or environmental engineers working on environmental protection or remediation might spend a lot of time thinking about chemical reactions taking place in the water supply or the air. But what about other engineering fields?

Much of modern electrical engineering relies on solid-state devices whose properties can be tailored by carefully controlling their chemical compositions. And although most electrical engineers do not regularly make their own chips, an understanding of how those chips operate on an atomic scale is certainly helpful. As the push for ever smaller circuit components continues, the ties between chemistry and electrical engineering will grow tighter. From organic light-emitting diodes (OLEDs) to single molecule transistors, new developments will continue to move out of the chemistry lab and into working devices at an impressive pace.

Some applications of chemistry in engineering are much less obvious. At 1483 feet, the Petronas Towers in Kuala Lumpur, Malaysia, were the tallest buildings in the world when they were completed in 1998. Steel was in short supply in Malaysia, so the towers' architects decided to build the structures out of something the country had an abundance of and local engineers were familiar with: concrete. But the impressive height of the towers required exceptionally strong concrete. The engineers eventually settled on a material that has come to be known as high-strength concrete, in which chemical reactions between silica fume and Portland cement produce a stronger material, more resistant to compression. This example illustrates the relevance of chemistry even to very traditional fields of engineering, and we will discuss some aspects of the chemistry of concrete in Chapter 12, including the development of novel bendable concrete.

## About This Text

Both of us have taught general chemistry for many years, and we are familiar with the difficulties that students may encounter with the subject. Perhaps more importantly, for the past several years, we've each been teaching engineering students in the type of one-semester course for which this text is designed. The approach to subjects presented in this text draws from both levels of experience.

We've worked hard to make this text as readable and student friendly as possible. One feature that makes this book different from any other text you could have used for this course is that we incorporate connections between chemistry and engineering as a fundamental component of each chapter. You will notice that each chapter begins and ends with a section called ***INSIGHT INTO***. . . . These sections are only