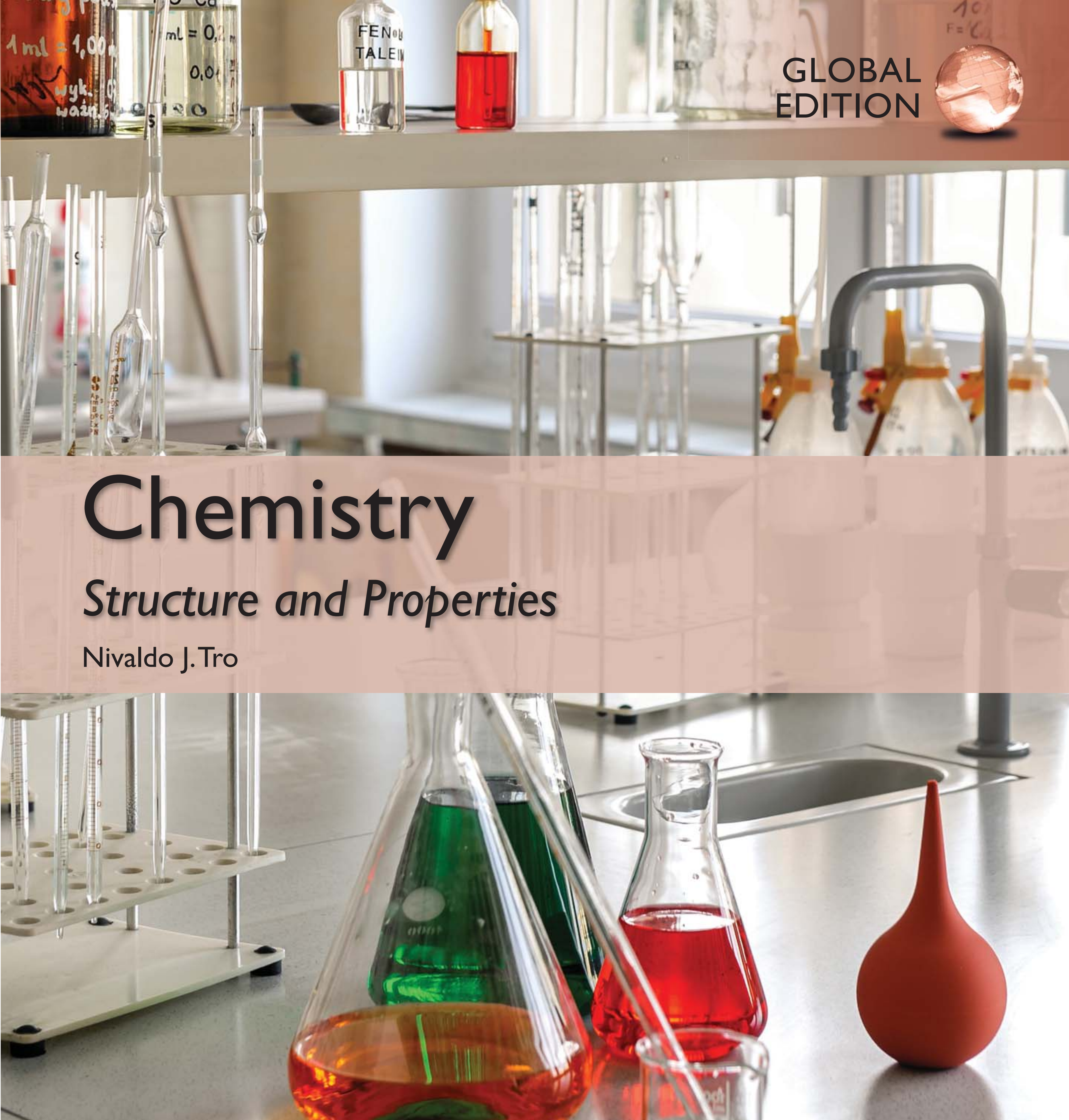

GLOBAL EDITION

Chemistry

Structure and Properties

Nivaldo J. Tro

ALWAYS LEARNING

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Metals | Metalloids | Nonmetals

Period	Main groups 1A[a] 1	2A 2	Transition metals 3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	8B 9	8B 10	1B 11	2B 12	Main groups 3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.94	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.97	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** [98]	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** [208.98]	85 **At** [209.99]	86 **Rn** [222.02]
7	87 **Fr** [223.02]	88 **Ra** [226.03]	89 **Ac** [227.03]	104 **Rf** [261.11]	105 **Db** [262.11]	106 **Sg** [266.12]	107 **Bh** [264.12]	108 **Hs** [269.13]	109 **Mt** [268.14]	110 **Ds** [271]	111 **Rg** [272]	112 **Cn** [285]	113	114 **Fl** [289]	115	116 **Lv** [292]	117*	118

Lanthanide series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** [145]	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
Actinide series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** [237.05]	94 **Pu** [244.06]	95 **Am** [243.06]	96 **Cm** [247.07]	97 **Bk** [247.07]	98 **Cf** [251.08]	99 **Es** [252.08]	100 **Fm** [257.10]	101 **Md** [258.10]	102 **No** [259.10]	103 **Lr** [262.11]

[a] The labels on top (1A, 2A, etc.) are common American usage. The labels below these (1, 2, etc.) are those recommended by the International Union of Pure and Applied Chemistry.
Atomic masses in brackets are the masses of the longest-lived or most important isotope of radioactive elements.
*Element 117 is currently under review by IUPAC.

List of Elements with Their Symbols and Atomic Masses

Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	227.03[a]
Aluminum	Al	13	26.98
Americium	Am	95	243.06[a]
Antimony	Sb	51	121.76
Argon	Ar	18	39.95
Arsenic	As	33	74.92
Astatine	At	85	209.99[a]
Barium	Ba	56	137.33
Berkelium	Bk	97	247.07[a]
Beryllium	Be	4	9.012
Bismuth	Bi	83	208.98
Bohrium	Bh	107	264.12[a]
Boron	B	5	10.81
Bromine	Br	35	79.90
Cadmium	Cd	48	112.41
Calcium	Ca	20	40.08
Californium	Cf	98	251.08[a]
Carbon	C	6	12.01
Cerium	Ce	58	140.12
Cesium	Cs	55	132.91
Chlorine	Cl	17	35.45
Chromium	Cr	24	52.00
Cobalt	Co	27	58.93
Copernicium	Cn	112	285[a]
Copper	Cu	29	63.55
Curium	Cm	96	247.07[a]
Darmstadtium	Ds	110	271[a]
Dubnium	Db	105	262.11[a]
Dysprosium	Dy	66	162.50
Einsteinium	Es	99	252.08[a]
Erbium	Er	68	167.26
Europium	Eu	63	151.96
Fermium	Fm	100	257.10[a]
Flerovium	Fl	114	289[a]
Fluorine	F	9	19.00
Francium	Fr	87	223.02[a]
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.72
Germanium	Ge	32	72.63
Gold	Au	79	196.97
Hafnium	Hf	72	178.49
Hassium	Hs	108	269.13[a]
Helium	He	2	4.003
Holmium	Ho	67	164.93
Hydrogen	H	1	1.008
Indium	In	49	114.82
Iodine	I	53	126.90
Iridium	Ir	77	192.22
Iron	Fe	26	55.85
Krypton	Kr	36	83.80
Lanthanum	La	57	138.91
Lawrencium	Lr	103	262.11[a]
Lead	Pb	82	207.2
Lithium	Li	3	6.94
Livermorium	Lv	116	292[a]
Lutetium	Lu	71	174.97
Magnesium	Mg	12	24.31
Manganese	Mn	25	54.94

Element	Symbol	Atomic Number	Atomic Mass
Meitnerium	Mt	109	268.14[a]
Mendelevium	Md	101	258.10[a]
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.95
Neodymium	Nd	60	144.24
Neon	Ne	10	20.18
Neptunium	Np	93	237.05[a]
Nickel	Ni	28	58.69
Niobium	Nb	41	92.91
Nitrogen	N	7	14.01
Nobelium	No	102	259.10[a]
Osmium	Os	76	190.23
Oxygen	O	8	16.00
Palladium	Pd	46	106.42
Phosphorus	P	15	30.97
Platinum	Pt	78	195.08
Plutonium	Pu	94	244.06[a]
Polonium	Po	84	208.98[a]
Potassium	K	19	39.10
Praseodymium	Pr	59	140.91
Promethium	Pm	61	145[a]
Protactinium	Pa	91	231.04
Radium	Ra	88	226.03[a]
Radon	Rn	86	222.02[a]
Rhenium	Re	75	186.21
Rhodium	Rh	45	102.91
Roentgenium	Rg	111	272[a]
Rubidium	Rb	37	85.47
Ruthenium	Ru	44	101.07
Rutherfordium	Rf	104	261.11[a]
Samarium	Sm	62	150.36
Scandium	Sc	21	44.96
Seaborgium	Sg	106	266.12[a]
Selenium	Se	34	78.97
Silicon	Si	14	28.09
Silver	Ag	47	107.87
Sodium	Na	11	22.99
Strontium	Sr	38	87.62
Sulfur	S	16	32.06
Tantalum	Ta	73	180.95
Technetium	Tc	43	98[a]
Tellurium	Te	52	127.60
Terbium	Tb	65	158.93
Thallium	Tl	81	204.38
Thorium	Th	90	232.04
Thulium	Tm	69	168.93
Tin	Sn	50	118.71
Titanium	Ti	22	47.87
Tungsten	W	74	183.84
Uranium	U	92	238.03
Vanadium	V	23	50.94
Xenon	Xe	54	131.293
Ytterbium	Yb	70	173.05
Yttrium	Y	39	88.91
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.22
*[b]		113	284[a]
*[b]		115	288[a]

[a]Mass of longest-lived or most important isotope.

[b]The names of these elements have not yet been decided.

CHEMISTRY

STRUCTURE AND PROPERTIES

Global Edition

Nivaldo J. Tro

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Nivaldo Tro is a professor of chemistry at Westmont College in Santa Barbara, California, where he has been a faculty member since 1990. He received his Ph.D. in chemistry from Stanford University for work on developing and using optical techniques to study the adsorption and desorption of molecules to and from surfaces in ultrahigh vacuum. He then went on to the University of California at Berkeley, where he did postdoctoral research on ultrafast reaction dynamics in solution. Since coming to Westmont, Professor Tro has been awarded grants from the American Chemical Society Petroleum Research Fund, from the Research Corporation, and from the National Science Foundation to study the dynamics of various processes occurring in thin adlayer films adsorbed on dielectric surfaces. He has been honored as Westmont's outstanding teacher of the year three times and has also received the college's outstanding researcher of the year award. Professor Tro lives in Santa Barbara with his wife, Ann, and their four children, Michael, Ali, Kyle, and Kaden. In his leisure time, Professor Tro enjoys mountain biking, surfing, reading to his children, and being outdoors with his family.

To Ann, Michael, Ali, Kyle, and Kaden

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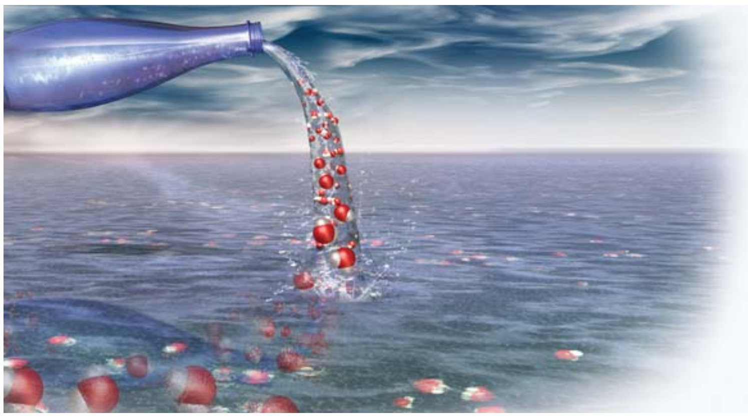

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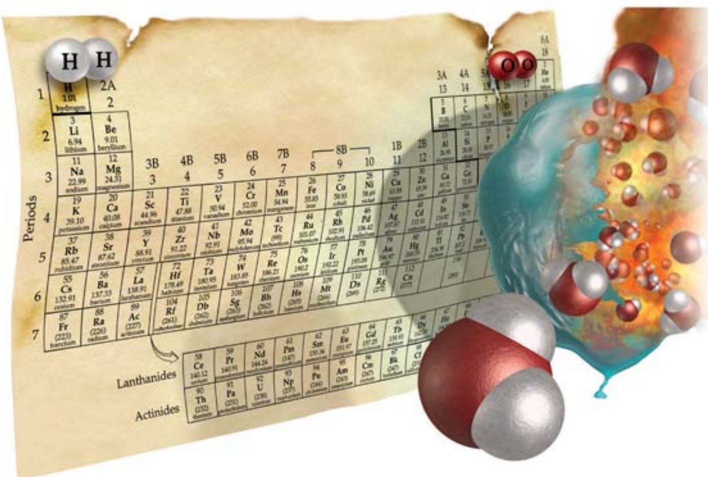

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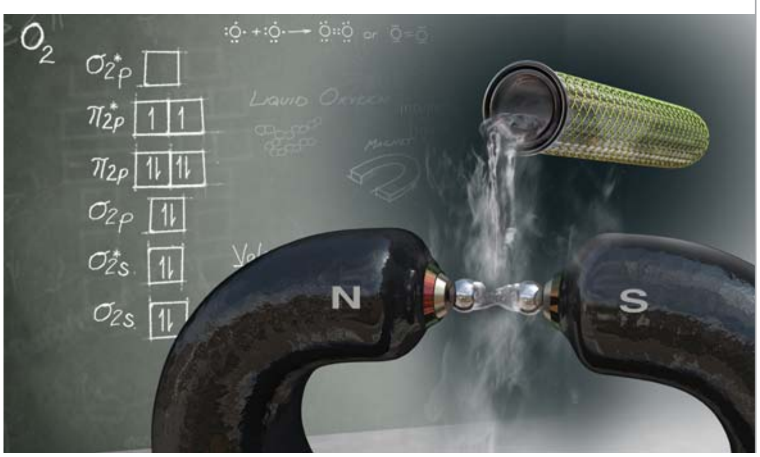

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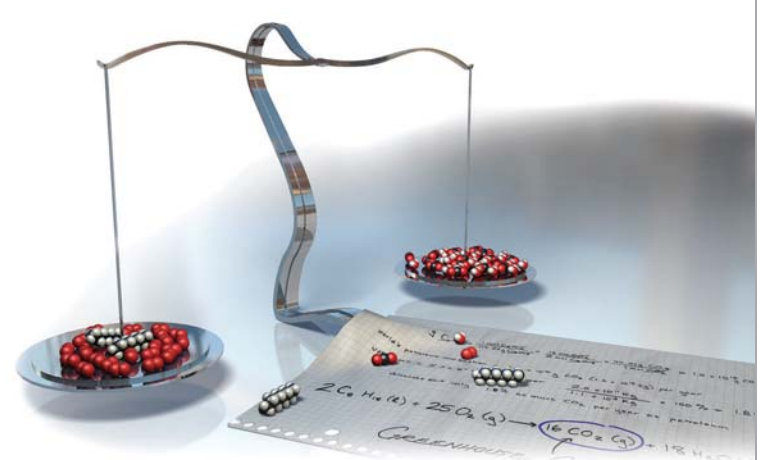

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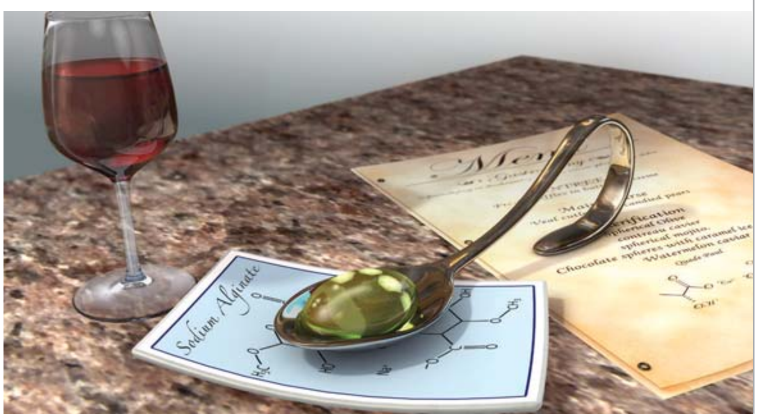

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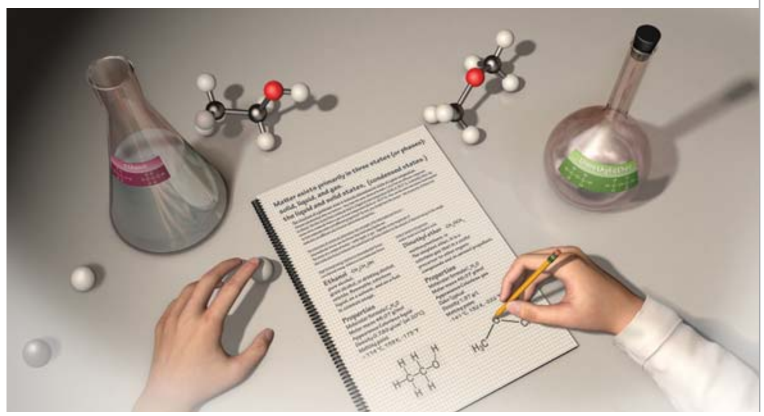

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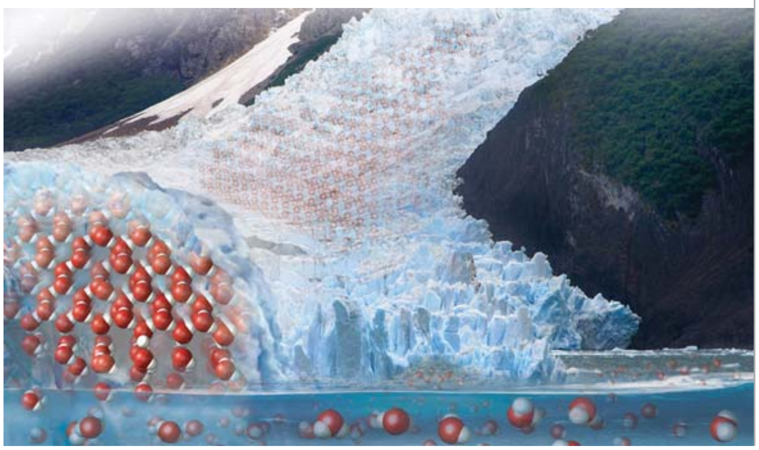

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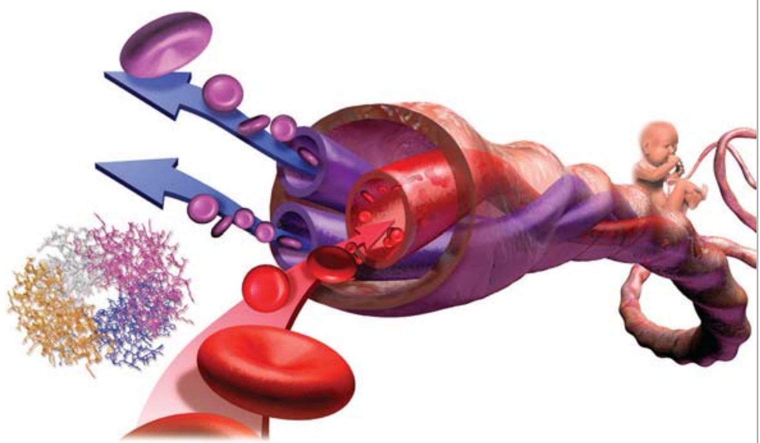

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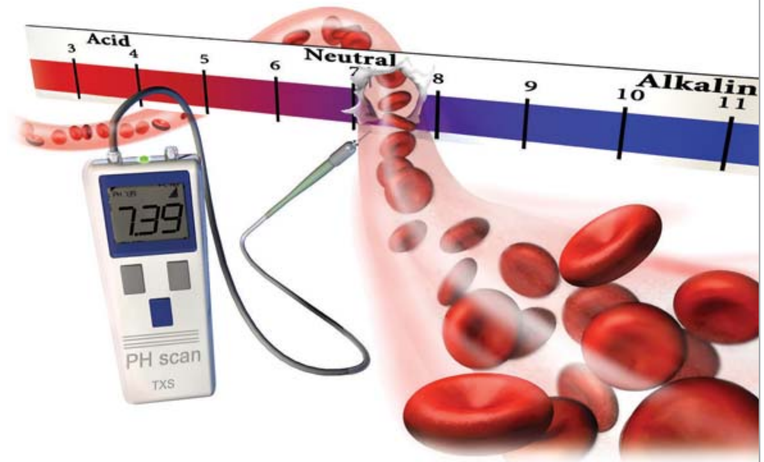

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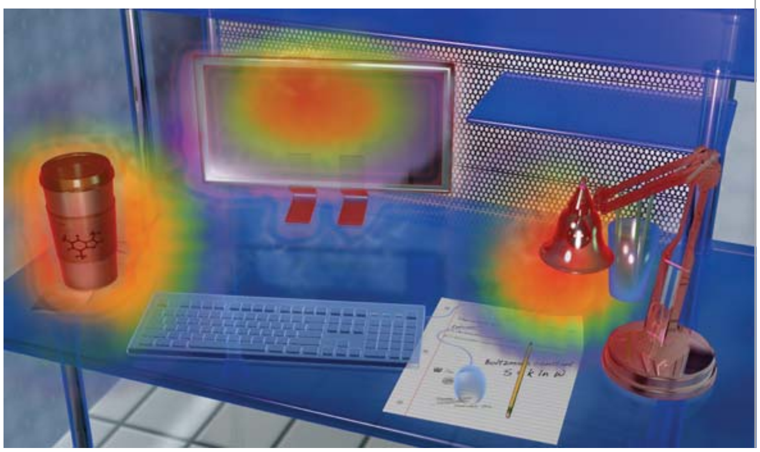

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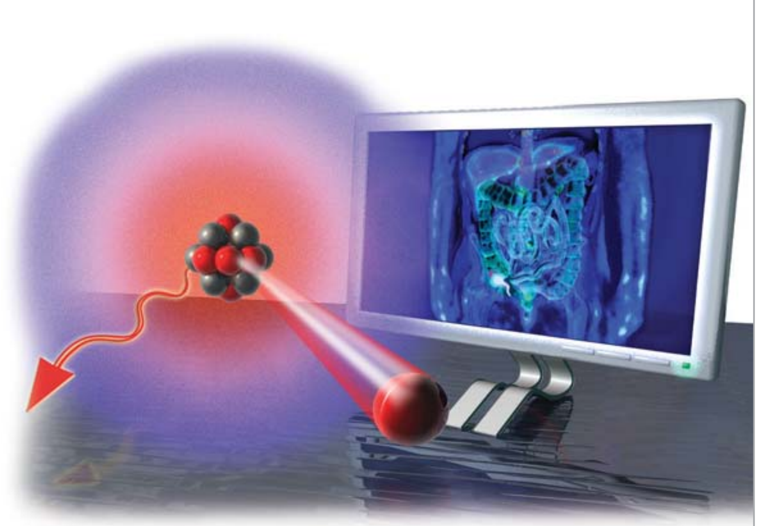

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Preface

To the Student

In this book, I tell the story of chemistry, a field of science that has not only revolutionized how we live (think of drugs designed to cure diseases or fertilizers that help feed the world), but also helps us to understand virtually everything that happens all around us all the time. The core of the story is simple: Matter is composed of particles, and the structure of those particles determines the properties of matter. Although these ideas may seem familiar to you as a 21st-century student, they were not so obvious as recently as 200 years ago. Yet, they are among the most powerful ideas in all of science. You need not look any further than the advances in biology over the last half-century to see how the particulate view of matter drives understanding. In that time, we have learned how even living things derive much of what they are from the particles (especially proteins and DNA) that compose them. I invite you to join the story as you read this book. Your part in its unfolding is yet to be determined, but I wish you the best as you start your journey.

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To the Professor

In recent years, some chemistry professors have begun teaching their General Chemistry courses with what is now called an *atoms-first* approach. In a practical sense, the main thrust of this approach is a reordering of topics so that atomic theory and bonding models come much earlier than in the traditional approach. A primary rationale for this approach is that students should understand the theory and framework behind the chemical "facts" they are learning. For example, in the traditional approach students learn early that magnesium atoms tend to form ions with a charge of 2+. However, they don't understand *why* until much later (when they get to quantum theory). In an *atoms-first* approach, students learn quantum theory first and understand immediately why magnesium atoms form ions with a charge of 2+. In this way, students see chemistry as a more coherent picture and not just a jumble of disjointed facts.

From my perspective, the *atoms-first* movement is better understood—not in terms of topic order—but in terms of emphasis. Professors who teach with an *atoms-first* approach generally emphasize: (1) the particulate nature of matter; and (2) the connection between the *structure* of atoms and molecules and their *properties* (or their function). The result of this emphasis is that the topic order is rearranged to make these connections earlier, stronger, and more often than is possible with the traditional approach. Consequently, I have chosen to name this book *Chemistry*: *Structure and Properties*, and I have not included the phrase a*toms-first* in the title. From my perspective, the topic order grows out of the particulate emphasis, not the other way around.

In addition, by making the relationship between structure and properties the emphasis of the book, I extend that emphasis beyond just the topic order in the first half of the book. For example, in the chapter on acids and bases, a more traditional approach puts the relationship between the structure of an acid and its acidity toward the end of the chapter, and many professors even skip this material. In contrast, in this book, I cover this relationship early in the chapter, and I emphasize its importance in the continuing story of structure and properties. Similarly, in the chapter on free energy and thermodynamics, a traditional approach does not put much emphasis on the relationship between molecular structure and entropy. In this book, however, I emphasize this relationship and use it to tell the overall story of entropy and its ultimate importance in determining the direction of chemical reactions.

Throughout the course of writing this book and in conversations with many of my colleagues, I have also come to realize that the *atoms-first* approach has some unique challenges. For example, how do you teach quantum theory and bonding (with topics like bond energies) when you have not covered thermochemistry? Or how do you find laboratory activities for the first few weeks if you have not covered chemical quantities and stoichiometry? I have sought to develop solutions to these challenges in this book. For example, I have included a section on energy and its units in Chapter 2. This section introduces changes in energy and the concepts of exothermicity and endothermicity. These topics are therefore in place when you need them to discuss the energies of orbitals and spectroscopy in Chapter 3 and bond energies in Chapter 6. Similarly, I have introduced the mole concept in Chapter 2; this placement allows not only for a more even distribution of quantitative homework problems, but also for laboratory exercises that require the use of the mole concept. In addition, because I strongly support the efforts of my colleagues at the Examinations Institute of the American Chemical Society, and because I have sat on several committees that write the ACS General Chemistry exam, I have ordered the chapters in this book so that they can be used with those exams in their present form. The end result is a table of contents that emphasizes structure and properties, while still maintaining the overall traditional division of first- and second-semester topics.

For those of you who have used my other General Chemistry book (*Chemistry: A Molecular Approach*), you will find that this book is a bit shorter and more focused and streamlined. I have shortened some chapters, divided others in half, and completely eliminated three chapters (Biochemistry, Chemistry of the Nonmetals, and Metals and Metallurgy). These topics are simply not being taught much in most General Chemistry courses. *Chemistry: Structure and Properties* is a leaner and more efficient book that fits well with current trends that emphasize depth over breadth. Nonetheless, the main features that have made *Chemistry: A Molecular Approach* a success continue in this book. For example, strong problem-solving pedagogy, clear and concise writing, mathematical and chemical rigor, and dynamic art are all vital components of this book.

I hope that this book supports you in your vocation of teaching students chemistry. I am increasingly convinced of the importance of our task. Please feel free to e-mail me with any questions or comments about the book.

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The Development Story

A great textbook starts with an author's vision, but that vision and its implementation must be continuously tested and refined to ensure that the book meets its primary goal—to teach the material in new ways that result in improved student learning. The development of a first edition textbook is an arduous process, typically spanning several years. This process is necessary to ensure that the content and pedagogical framework meet the educational needs of those who are in the classroom: *both* instructors and students.

The development of Dr. Tro's *Structure and Properties* was accomplished through a series of interlocking feedback loops. Each chapter was drafted by the author and subjected to an initial round of internal developmental editing, with a focus on making sure that the author's goal of "emphasizing the particulate nature of matter" was executed in a clear and concise way.

The chapters were then revised by the author and exposed to intensive reviewer scrutiny. We asked over 150 reviewers across the country to define what teaching with an *atoms-first* approach meant to them and to focus on how that philosophy was executed in *Chemistry: Structure and Properties*. They were also asked to analyze the table of contents and to read each chapter carefully. We asked them to evaluate the breadth and depth of coverage, the execution of the art program, the worked examples, and the overall pedagogical effectiveness of each chapter. The author and the development editor then worked closely together to analyze the feedback and determine which changes were necessary to improve each chapter.

In addition to reviews, we hosted six focus groups where professors scrutinized the details of several chapters and participated in candid group discussions with the author and editorial team. These group meetings not only focused on the content within the book, but also provided the author and participants with an opportunity to discuss the challenges they face each day in the classroom and what the author and the publisher could do to address these concerns in the book and within our media products. These sessions generated valuable insights that would have been difficult to obtain in any other way and were the inspiration for some significant ideas and improvements.

Class-Tested and Approved

General Chemistry students across the country also contributed to the development of *Chemistry: Structure and Properties.* Over 2000 students provided feedback through extensive class testing prior to publication. We asked students to use the chapters in place of, or alongside, their current textbook during their course. We then asked them to evaluate numerous aspects of the text, including how it explains difficult topics; how clear and understandable the writing style is; if the text helped them to see the "big picture" of chemistry through its macroscopic-to-microscopic organization of the material; and how well the Interactive Worked Examples helped them further understand the examples in the book. Through these student reviews, the strengths of *Chemistry: Structure and Properties* were put to the test, and it passed. Overwhelmingly, the majority of students who class tested would prefer to use *Chemistry: Structure and Properties* over their current textbook in their General Chemistry course!

In addition, our market development team interviewed over 75 General Chemistry instructors, gathering feedback on how well the *atoms-first* approach is carried out throughout the text; how well the text builds conceptual understanding; and how effective the end-of-chapter and practice material is. The team also reported on the accuracy and depth of the content overall. All comments, suggestions, and corrections were provided to the author and editorial team to analyze and address prior to publication.

ACKNOWLEDGMENTS

The book you hold in your hands bears my name on the cover, but I am really only one member of a large team that carefully crafted this book. Most importantly, I thank my editor, Terry Haugen. Terry is a great editor and friend who really gets the *atoms-first* approach. He gives me the right balance of freedom and direction and always supports my efforts. Thanks, Terry, for all you have done for me and for the progression of the *atoms-first* movement throughout the world. I am also grateful for my project editor, Jessica Moro, who gave birth to her baby girl at about the same time that we gave birth to this book. Thanks Jessica for your hard labor on this project and congratulations on your beautiful baby! Thanks also to Coleen Morrison who capably filled in while Jessica was on maternity leave.

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Dear Colleague:

In recent years, many chemistry professors have begun teaching their General Chemistry courses with what is now called an *atoms-first* approach. On the surface, this approach may seem like a mere reordering of topics, so that atomic theory and bonding theories come much earlier than in the traditional approach. A rationale for this reordering is that students should understand the theory and framework behind the chemical "facts" they are learning. For example, in the traditional approach students learn early that magnesium atoms tend to form ions with a charge of 2+. However, they don't understand why until much later (when they get to quantum theory). In an atoms-first approach, students learn quantum theory first and understand immediately why magnesium atoms form ions with a charge of 2+. In this way, students see chemistry as a more coherent picture and not just a jumble of disjointed facts.

From my perspective, however, the *atoms-first* movement is much more than just a reordering or topics. To me, the *atoms-first* movement is a result of the growing emphasis in chemistry courses on the two main ideas of chemistry: a) *that matter is particulate*, and b) *that the structure of those particles determines the properties of matter.* In other words, the atoms-first movement is—at its core—an attempt to tell the story of chemistry in a more unified and thematic way. As a result, an atoms-first textbook must be more than a rearrangement of topics: it must tell the story of chemistry through the lens of the particulate model of matter. That is the book that I present to you here. The table of contents reflects the ordering of an atoms-first approach, but more importantly, the entire book is written and organized so that the theme—*structure determines properties*—unifies and animates the content. My hope is that students will see the power and beauty of the simple ideas that lie at the core of chemistry, and that they may learn to apply them to see and understand the world around them in new ways.

> **"My hope is that students will see the power and beauty of the simple ideas that lie at the core of chemistry."**
>
> **Niva**

Nivaldo J. Tro

150 **Peer reviewers**

who scrutinized each chapter and provided feedback on everything from content and organization to art and pedagogy.

75 **Instructors**

who tested chapters in their own classrooms and advised how students interacted with and learned from the content.

50 **Focus Group Participants**

who joined Dr. Tro and the editorial team for in-person candid discussions on the challenges they face in their classrooms and how we could address those challenges in the book and within our media products.

Structure and Properties was developed with the goal of presenting the story of chemistry in a unified way. To ensure that the book consistently emphasizes the theme—s*tructure determines properties*—Dr. Tro consulted a community of general chemistry instructors teaching with an atoms-first approach.

What Instructors are Saying:

This book is exactly what I have been looking for in a book. It has what I would consider the perfect order of topics. It has a true atoms-first approach.

Ken Friedrich — Portland Community College

Chemistry: Structures and Properties is a student-friendly text, offering a pedagogically sound treatment of an atoms first approach to chemistry. With its well-written text, supporting figures and worked examples, students have access to a text possessing the potential to maximize their learning.

Christine Mina Kelly — University of Colorado

It is an outstanding, very well written text that nails the "atoms-first" approach. The book is clear, concise and entertaining to read.

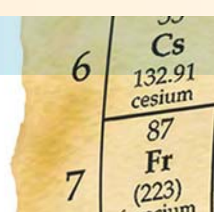
Richard Mullins — Xavier University

Dr. Tro takes excellent artwork, excellent worked examples, and excellent explanations and combines them in an Atoms First General Chemistry book that raises the bar for others to follow.

John Kiser — Western Piedmont Community College

Niva Tro presents the science of chemistry using a very warm writing style and approach that connects well with both the student and scientist reader.

Amina El-Ashwamy/Collin County CC



2,000

Student Class Testers

In addition to peer reviews, general chemistry students across the country also contributed to the development of *Chemistry: Structure and Properties*.
Students were asked to use chapters in place of, or alongside, their current textbook during their course and provide feedback to the author and editorial team.

What Students are Saying:

"This sample is really unlike any chemistry book I've ever seen. The examples and breakdowns of problems were awesome. The concepts are clear and down to earth. This book just makes it seem like the author really wants you to get it."

Kenneth Bell — Colorado School of Mines

"It is the best text I've read that clearly and concisely presents chemistry concepts in a fun and organized way!"

Peter Inirio — Marywood University

"I think that sometimes in chemistry, it's very hard to see the "big picture." I thought that this textbook did a great job with that by organizing the material and making me think about how it relates to real life."

Megan Little — University of Massachusetts Lowell

"I really enjoyed how this chapter/author doesn't assume your knowledge of prerequisite material. Going from macro to micro allows the reader/student to truly conceptualize all aspects of the material. The organization and step-by-step approach delivers the chapter in a simple yet thorough manner. This booklet helped me tremendously, thank you."

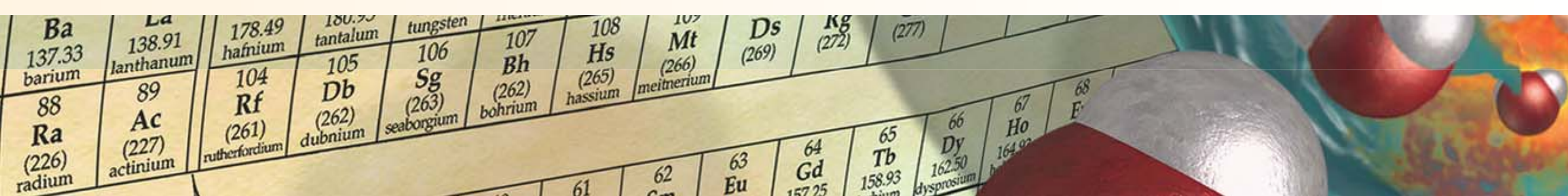
Meghan Berthold — Collin County Community College

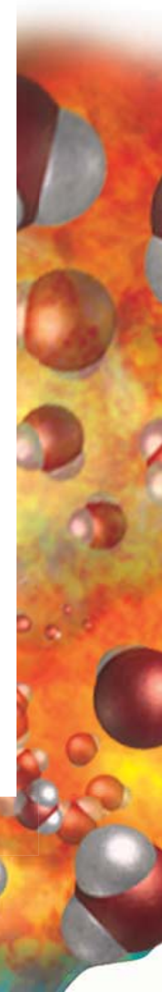
"Students need to learn chemistry in a way that is not intimidating. My current textbook had language that was too advanced for a beginner. This book was a fresh breath of air that made me relax and understand the topics better than ever before."

Megan Van Doren — Bloomsburg University

"It was very similar to a classroom format, giving me the confidence to solve problems on my own."

Zachary Ghalayini — University of South Florida





Unifying Theme of Structure and Properties

Section 1.1 – Introduction to the theme

1.1 A Particulate View of the World: Structure Determines Properties

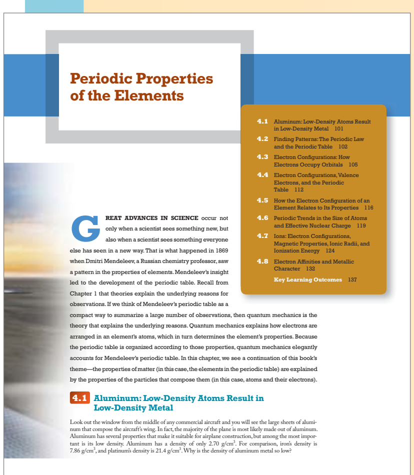
A good novel usually has a strong *premise*—a short statement that describes the central idea of the story. The story of chemistry as described in this book also has a strong premise, which consists of two simple statements:

1. Matter is particulate—it is composed of particles.
2. The structure of those particles determines the properties of matter.

Matter is anything that occupies space and has mass. Most things you can think of—such as this book, your desk, and even your body—are composed of matter. The particulate nature of matter—first

Section 4.1 – How the structure of Al atoms determines the density of aluminum metal

The densities of elements and the radii of their atoms are examples of *periodic properties*. A **periodic property** is one that is generally predictable based on an element's position within the periodic table. In this chapter, we examine several periodic properties of elements, including atomic radius, ionization energy, and electron affinity. As we do, we will see that these properties—as well as the overall arrangement of the periodic table—are explained by quantum-mechanical theory, which we first examined in Chapter 3. *Quantum-mechanical theory explains the electronic structure of atoms—this in turn determines the properties of those atoms*.



Periodic Properties of the Elements

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Key Learning Outcomes 137

GREAT ADVANCES IN SCIENCE occur not only when a scientist sees something new, but also when a scientist sees something everyone else has seen in a new way. That is what happened in 1869 when Dmitri Mendeleev, a Russian chemistry professor, saw a pattern in the properties of elements. Mendeleev's insight led to the development of the periodic table. Recall from Chapter 1 that theories explain the underlying reasons for observations. If we think of Mendeleev's periodic table as a compact way to summarize a large number of observations, then quantum mechanics is the theory that explains the underlying reasons. Quantum mechanics explains how electrons are arranged in an element's atoms, which in turn determines the element's properties. Because the periodic table is organized according to those properties, quantum mechanics elegantly accounts for Mendeleev's periodic table. In this chapter, we see a continuation of this book's theme—the properties of matter (in this case, the elements in the periodic table) are explained by the properties of the particles that compose them (in this case, atoms and their electrons).

4.1 Aluminum: Low-Density Atoms Result in Low-Density Metal

Look out the window from the middle of any commercial aircraft and you will see the large sheets of aluminum that compose the aircraft's wing. In fact, the majority of the plane is most likely made out of aluminum. Aluminum has several properties that make it suitable for airplane construction, but among the most important is its low density. Aluminum has a density of only 2.70 g/cm^3. For comparison, iron's density is 7.86 g/cm^3, and platinum's density is 21.4 g/cm^3. Why is the density of aluminum metal so low?

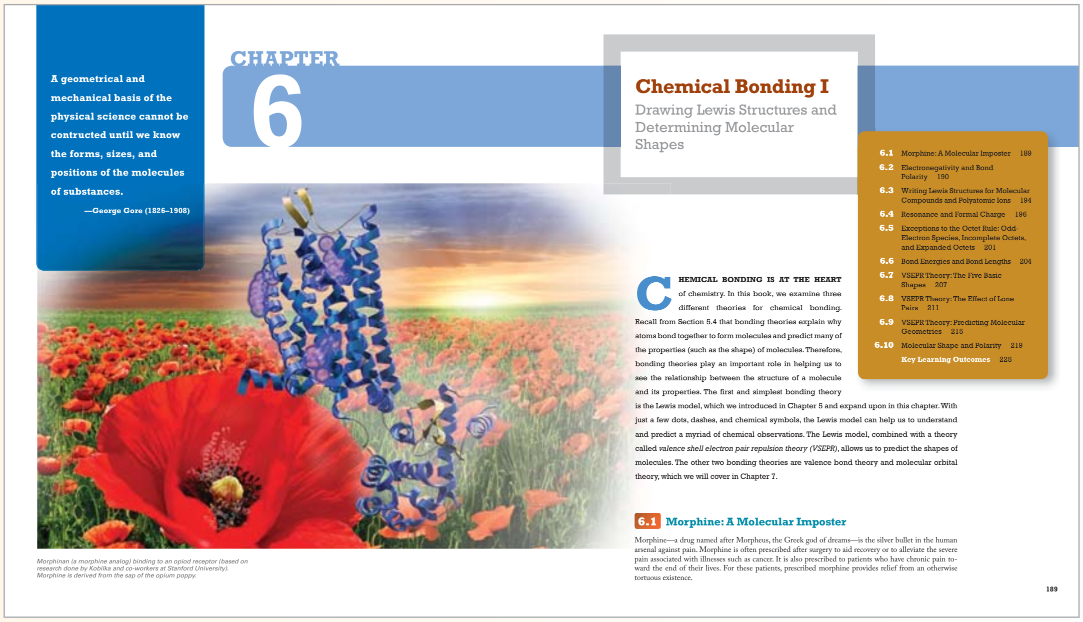
Section 4.5 – How atomic structure determines the properties of the elements

4.5 How the Electron Configuration of an Element Relates to Its Properties

As we discussed in Section 4.4, *the chemical properties of elements are largely determined by the number of valence electrons they contain*. The properties of elements are periodic because the number of valence electrons is periodic. Mendeleev grouped elements into families (or columns) based on observations about their properties. We now know that elements in a family have the same number of valence electrons. In other words, elements in a family have similar properties because they have the same number of valence electrons.

Section 6.1 – How the structure of morphine allows it to be a molecular imposter for the body's natural endorphins

Morphine binds to opioid receptors because it fits into a special pocket (called the active site) on the opioid receptor protein (just as a key fits into a lock) that normally binds endorphins. Certain parts of the morphine molecule have a similar enough shape to endorphins that they fit the lock (even though they are not the original key). In other words, morphine is a *molecular imposter*, mimicking the action of endorphins because of similarities in shape.



A geometrical and mechanical basis of the physical science cannot be contructed until we know the forms, sizes, and positions of the molecules of substances.

—George Gore (1826–1908)

CHAPTER 6

Chemical Bonding I

Drawing Lewis Structures and Determining Molecular Shapes

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CHEMICAL BONDING IS AT THE HEART of chemistry. In this book, we examine three different theories for chemical bonding. Recall from Section 5.4 that bonding theories explain why atoms bond together to form molecules and predict many of the properties (such as the shape) of molecules. Therefore, bonding theories play an important role in helping us to see the relationship between the structure of a molecule and its properties. The first and simplest bonding theory is the Lewis model, which we introduced in Chapter 5 and expand upon in this chapter. With just a few dots, dashes, and chemical symbols, the Lewis model can help us to understand and predict a myriad of chemical observations. The Lewis model, combined with a theory called *valence shell electron pair repulsion theory (VSEPR)*, allows us to predict the shapes of molecules. The other two bonding theories are valence bond theory and molecular orbital theory, which we will cover in Chapter 7.

6.1 Morphine: A Molecular Imposter

Morphine—a drug named after Morpheus, the Greek god of dreams—is the silver bullet in the human arsenal against pain. Morphine is often prescribed after surgery to aid recovery or to alleviate the severe pain associated with illnesses such as cancer. It is also prescribed to patients who have chronic pain toward the end of their lives. For these patients, prescribed morphine provides relief from an otherwise tortuous existence.

Morphinan (a morphine analog) binding to an opiod receptor (based on research done by Kobilka and co-workers at Stanford University). Morphine is derived from the sap of the opium poppy.

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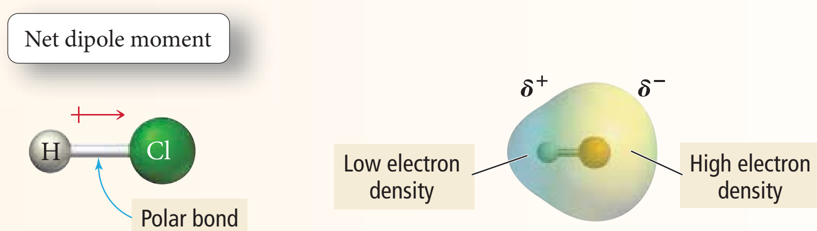
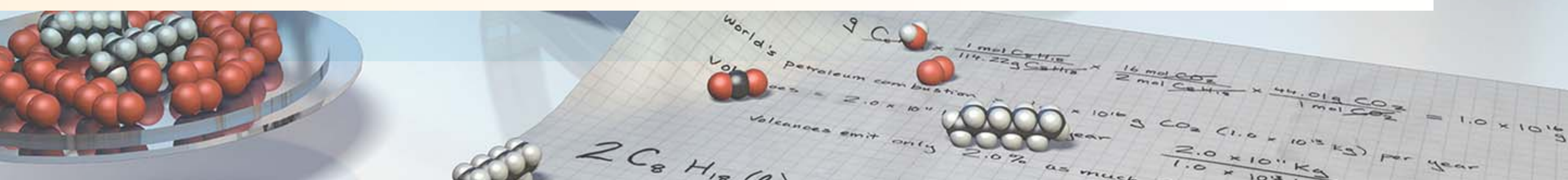
Section 6.10 – How molecular structure determines whether a substance is polar or nonpolar

6.10 Molecular Shape and Polarity

In Section 6.2, we discussed polar bonds. Entire molecules can also be polar, depending on their shape and the nature of their bonds. For example, if a diatomic molecule has a polar bond, the molecule as a whole will be polar.



In the figure shown here the image to the right is an electrostatic potential map of HCl. In these maps, red areas indicate electron-rich regions in the molecule and the blue areas indicate electron-poor regions. Yellow indicates moderate electron density. Notice that the region around the more

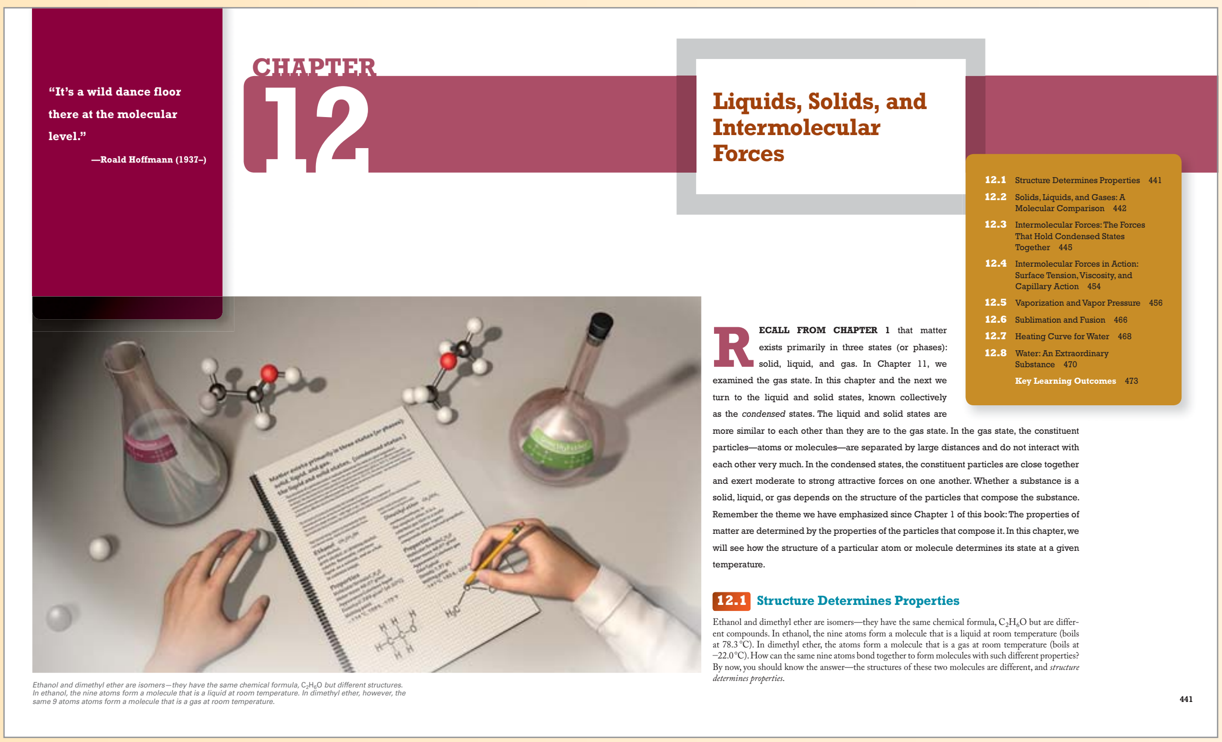


Structure and Properties: Unified Theme Carries through the Second Semester

Section 12.1 – How ethanol and dimethyl ether are composed of exactly the same atoms, but their different structures result in different properties

12.1 Structure Determines Properties

Ethanol and dimethyl ether are isomers—they have the same chemical formula, C_2H_6O but are different compounds. In ethanol, the nine atoms form a molecule that is a liquid at room temperature (boils at 78.3 °C). In dimethyl ether, the atoms form a molecule that is a gas at room temperature (boils at −22.0 °C). How can the same nine atoms bond together to form molecules with such different properties? By now, you should know the answer—the structures of these two molecules are different, and *structure determines properties*.



"It's a wild dance floor there at the molecular level."

—Roald Hoffmann (1937–)

CHAPTER 12

Liquids, Solids, and Intermolecular Forces

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Ethanol and dimethyl ether are isomers—they have the same chemical formula, C_2H_6O but different structures. In ethanol, the nine atoms form a molecule that is a liquid at room temperature. In dimethyl ether, however, the same 9 atoms atoms form a molecule that is a gas at room temperature.

RECALL FROM CHAPTER 1 that matter exists primarily in three states (or phases): solid, liquid, and gas. In Chapter 11, we examined the gas state. In this chapter and the next we turn to the liquid and solid states, known collectively as the *condensed* states. The liquid and solid states are more similar to each other than they are to the gas state. In the gas state, the constituent particles—atoms or molecules—are separated by large distances and do not interact with each other very much. In the condensed states, the constituent particles are close together and exert moderate to strong attractive forces on one another. Whether a substance is a solid, liquid, or gas depends on the structure of the particles that compose the substance. Remember the theme we have emphasized since Chapter 1 of this book: The properties of matter are determined by the properties of the particles that compose it. In this chapter, we will see how the structure of a particular atom or molecule determines its state at a given temperature.

12.1 Structure Determines Properties

Ethanol and dimethyl ether are isomers—they have the same chemical formula, C_2H_6O but are different compounds. In ethanol, the nine atoms form a molecule that is a liquid at room temperature (boils at 78.3 °C). In dimethyl ether, the atoms form a molecule that is a gas at room temperature (boils at −22.0 °C). How can the same nine atoms bond together to form molecules with such different properties? By now, you should know the answer—the structures of these two molecules are different, and *structure determines properties*.

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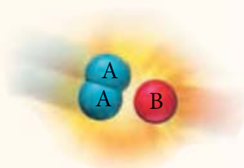
Section 15.2 – How reaction rates depend of the structure of the reacting particles

15.2 Rates of Reaction and the Particulate Nature of Matter

We have seen throughout this book that matter is composed of particles (atoms, ions, and molecules). The simplest way to begin to understand the factors that influence a reaction rate is to think of a chemical reaction as the result of a collision between these particles, which is the basis of *the collision model* (which we cover in more detail in Section 15.6). For example, consider the following simple generic reaction occurring in the gaseous state:

A¬ A + B ¡ A¬ B + A

According to the collision model, the reaction occurs as a result of a collision between A-A particles and B particles.



Section 17.4 – How the structure of an acid determines its strength

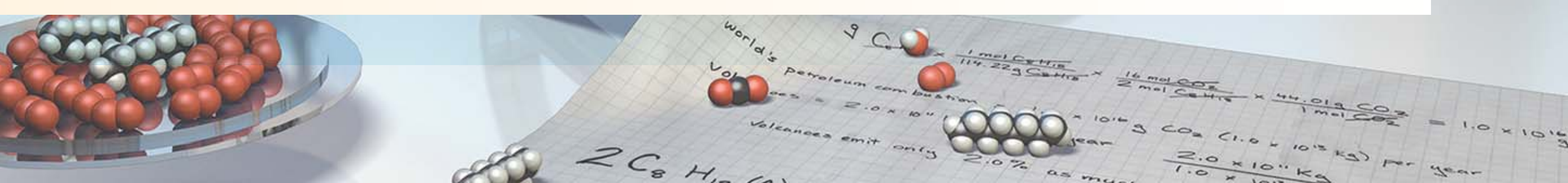
17.4 Acid Strength and Molecular Structure

We have learned that a Brønsted–Lowry acid is a proton (H^+) donor. Now we explore why some hydrogen-containing molecules act as proton donors while others do not. In other words, we want to explore *how the structure of a molecule affects its acidity*. Why is H_2S acidic while CH_4 is not? Or why is HF a weak acid while HCl is a strong acid? We divide our discussion about these issues into two categories: binary acids (those containing hydrogen and only one other element) and oxyacids (those containing hydrogen bonded to an oxygen atom that is bonded to another element).

Section 19.4 – How the structure of a molecule determines its entropy

19.4 Predicting Entropy and Entropy Changes for Chemical Reactions

We now turn our attention to predicting and quantifying entropy and entropy changes in a sample of matter. As we examine this topic, we again encounter the theme of this book: *structure determines properties.* In this case, the property we are interested in is entropy. In this section we see how the structure of the particles that compose a particular sample of matter determines the entropy that the sample possesses at a given temperature and pressure.



Key Concept Videos

Key Concept Videos and Interactive Worked Examples digitally bring Dr. Tro's award winning teaching directly to students.

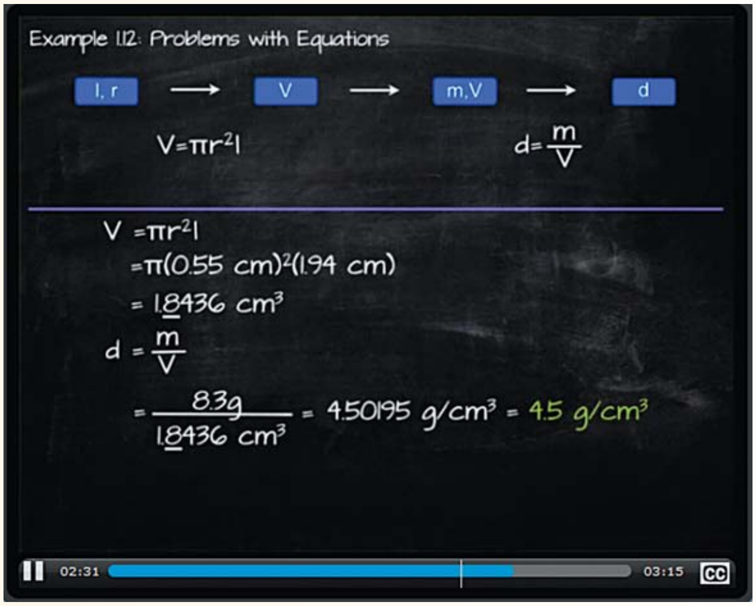
In these highly conceptual videos, the author visually explains key concepts within each chapter and engages students in the learning process by asking them to answer embedded questions.

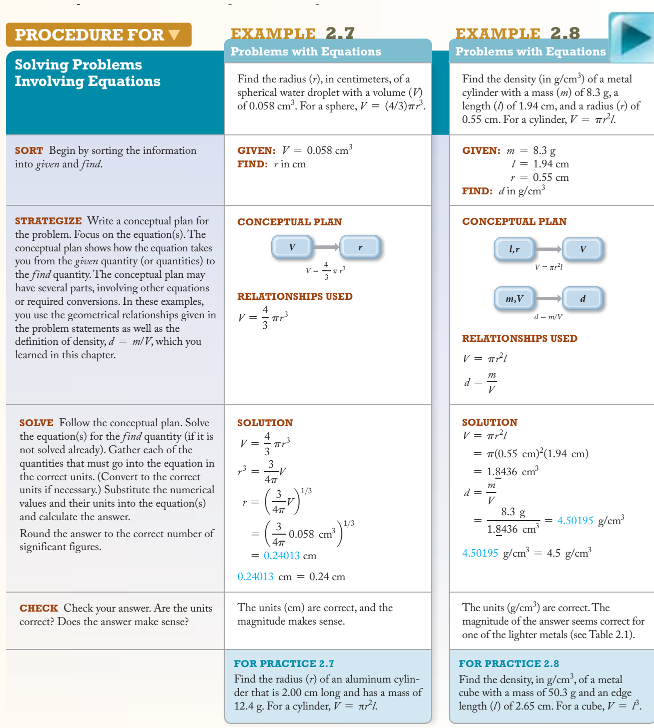
Scan this QR code (located on the back cover of the textbook) with your smartphone to access the Key Concept videos.

Interactive Worked Examples

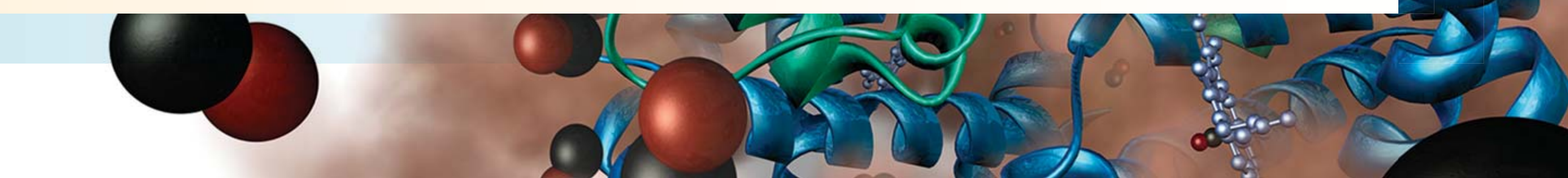
Interactive Worked Examples are digital versions of the text's worked examples that make Tro's unique problem-solving strategies interactive, bringing his award-winning teaching directly to all students using his text. In these digital versions, students are instructed how to break down problems using Tro's proven technique.

These examples and videos are often paired and can be accessed by scanning the QR code on the back cover allowing students to quickly access an office-hour type experience. These problems are incorporated into MasteringChemistry® as assignable activities, and are also available for download via the Instructor Resource Center for instructional and classroom use.





PROCEDURE FOR **Solving Problems Involving Equations**	EXAMPLE 2.7 **Problems with Equations**	EXAMPLE 2.8 **Problems with Equations**
	Find the radius (r), in centimeters, of a spherical water droplet with a volume (V) of 0.058 cm^3. For a sphere, $V = (4/3)\pi r^3$.	Find the density (in g/cm^3) of a metal cylinder with a mass (m) of 8.3 g, a length (l) of 1.94 cm, and a radius (r) of 0.55 cm. For a cylinder, $V = \pi r^2 l$.
SORT Begin by sorting the information into *given* and *find*.	**GIVEN:** $V = 0.058\ cm^3$ **FIND:** r in cm	**GIVEN:** $m = 8.3$ g $l = 1.94$ cm $r = 0.55$ cm **FIND:** d in g/cm^3
STRATEGIZE Write a conceptual plan for the problem. Focus on the equation(s). The conceptual plan shows how the equation takes you from the *given* quantity (or quantities) to the *find* quantity. The conceptual plan may have several parts, involving other equations or required conversions. In these examples, you use the geometrical relationships given in the problem statements as well as the definition of density, $d = m/V$, which you learned in this chapter.	**CONCEPTUAL PLAN** V → r $V = \frac{4}{3}\pi r^3$ **RELATIONSHIPS USED** $V = \frac{4}{3}\pi r^3$	**CONCEPTUAL PLAN** l,r → V $V = \pi r^2 l$ m,V → d $d = m/V$ **RELATIONSHIPS USED** $V = \pi r^2 l$ $d = \frac{m}{V}$
SOLVE Follow the conceptual plan. Solve the equation(s) for the *find* quantity (if it is not solved already). Gather each of the quantities that must go into the equation in the correct units. (Convert to the correct units if necessary.) Substitute the numerical values and their units into the equation(s) and calculate the answer. Round the answer to the correct number of significant figures.	**SOLUTION** $V = \frac{4}{3}\pi r^3$ $r^3 = \frac{3}{4\pi}V$ $r = \left(\frac{3}{4\pi}V\right)^{1/3}$ $= \left(\frac{3}{4\pi}0.058\ cm^3\right)^{1/3}$ $= 0.24013$ cm $0.24013\ cm = 0.24\ cm$	**SOLUTION** $V = \pi r^2 l$ $= \pi(0.55\ cm)^2(1.94\ cm)$ $= 1.8436\ cm^3$ $d = \frac{m}{V}$ $= \frac{8.3\ g}{1.8436\ cm^3} = 4.50195\ g/cm^3$ $4.50195\ g/cm^3 = 4.5\ g/cm^3$
CHECK Check your answer. Are the units correct? Does the answer make sense?	The units (cm) are correct, and the magnitude makes sense.	The units (g/cm^3) are correct. The magnitude of the answer seems correct for one of the lighter metals (see Table 2.1).
	FOR PRACTICE 2.7 Find the radius (r) of an aluminum cylinder that is 2.00 cm long and has a mass of 12.4 g. For a cylinder, $V = \pi r^2 l$.	**FOR PRACTICE 2.8** Find the density, in g/cm^3, of a metal cube with a mass of 50.3 g and an edge length (l) of 2.65 cm. For a cube, $V = l^3$.



Linking the Conceptual with the Quantitative

Self-Assessment Quizzes

Niva Tro actively participates on the ACS Exams Committee for Gen Chem I, Gen Chem II and full year exams. Tro's Self-Assessment Quizzes at the end of each chapter contain 10-15 multiple-choice questions that are similar to those found on the ACS exam and on other standardized exams. The Self-Assessment Quizzes are also assignable in MasteringChemistry®.

SELF-ASSESSMENT Quiz

1. Which wavelength of light has the highest frequency?
   a) 10 nm **b)** 10 mm **c)** 1 nm **d)** 1 mm

2. Which kind of electromagnetic radiation contains the greatest energy per photon?
   a) Microwaves **b)** Gamma rays
   c) X-rays **d)** Visible light

3. How much energy (in J) is contained in 1.00 mole of 552-nm photons?
   a) 3.60×10^{-19} J **b)** 2.17×10^{5} J
   c) 3.60×10^{-28} J **d)** 5.98×10^{-43} J

4. Light from three different lasers (A, B, and C), each with a different wavelength, is shined onto the same metal surface. Laser A produces no photoelectrons. Lasers B and C both produce photoelectrons, but the photoelectrons produced by laser B have a greater velocity than those produced by laser C. Arrange the lasers in order of increasing wavelength.
   a) $A < B < C$ **b)** $B < C < A$
   c) $C < B < A$ **d)** $A < C < B$

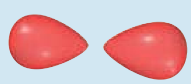
5. Calculate the frequency of an electron traveling at 1.85×10^{7} m/s.
   a) 1.31×10^{-19} s^{-1} **b)** 1.18×10^{-2} s^{-1}
   c) 3.93×10^{-11} s^{-1} **d)** 7.63×10^{18} s^{-1}

6. Which set of three quantum numbers *does not* specify an orbital in the hydrogen atom?
   a) $n = 2; l = 1; m_l = -1$ **b)** $n = 3; l = 3; m_l = -2$
   c) $n = 2; l = 0; m_l = 0$ **d)** $n = 3; l = 2; m_l = 2$

7. Calculate the wavelength of light emitted when an electron in the hydrogen makes a transition from an orbital with $n = 5$ to an orbital with $n = 3$.
   a) 1.28×10^{-6} m **b)** 6.04×10^{-7} m
   c) 2.28×10^{-6} m **d)** 1.55×10^{-19} m

8. Which electron transition produces light of the highest frequency in the hydrogen atom?
   a) $5p \longrightarrow 1s$ **b)** $4p \longrightarrow 1s$
   c) $3p \longrightarrow 1s$ **d)** $2p \longrightarrow 1s$

9. How much time (in seconds) does it take light to travel 1.00 billion km?
   a) 3.00×10^{17} s **b)** 3.33 s
   c) 3.33×10^{3} s **d)** 3.00×10^{20} s

10. Which figure represents a *d* orbital?
   a) 
   b) 
   c) 
   d) None of the above

Answers: 1:c; 2:b; 3:b; 4:b; 5:d; 6:b; 7:a; 8:a; 9:c; 10:b