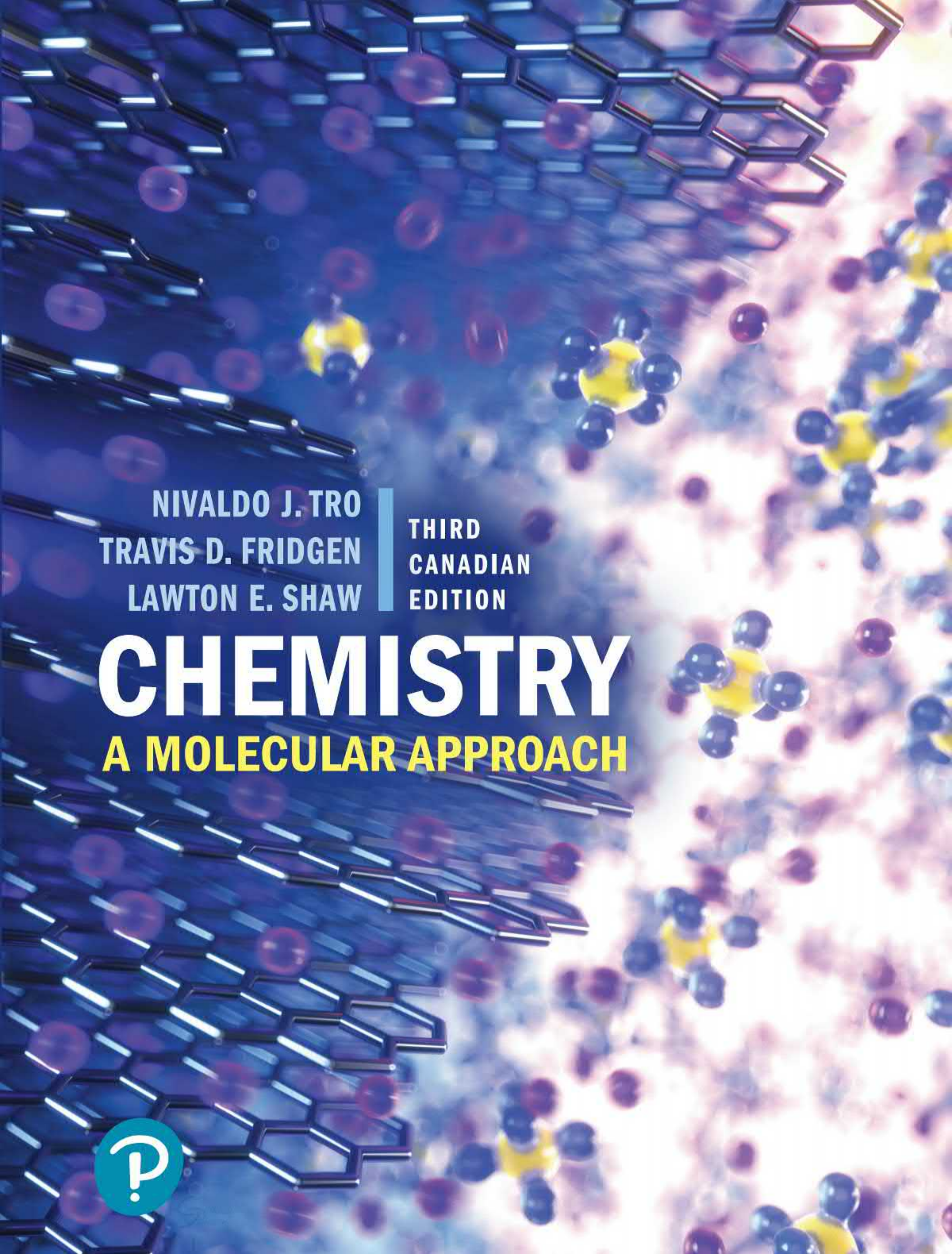
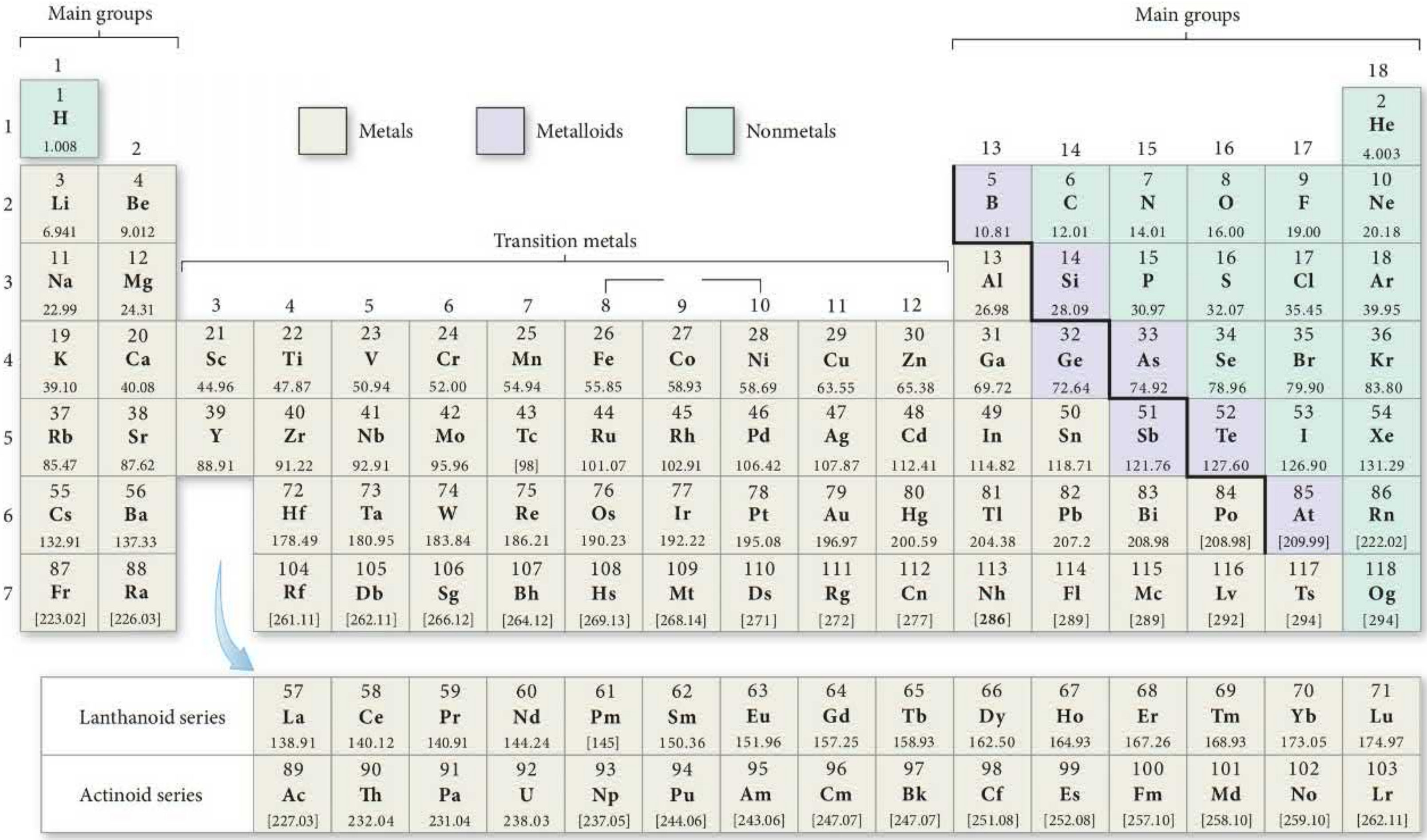


NIVALDO J. TRO
TRAVIS D. FRIDGEN
LAWTON E. SHAW

THIRD
CANADIAN
EDITION

CHEMISTRY

A MOLECULAR APPROACH



Metals

Metalloids

Nonmetals

	Main groups		Transition metals										Main groups					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.941	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** 32.07	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** 72.64	33 **As** 74.92	34 **Se** 78.96	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** 95.96	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		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]		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** [277]	113 **Nh** [286]	114 **Fl** [289]	115 **Mc** [289]	116 **Lv** [292]	117 **Ts** [294]	118 **Og** [294]

Lanthanoid series	57 **La** 138.91	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
Actinoid series	89 **Ac** [227.03]	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]

Atomic masses in brackets are the masses of the longest-lived or most important isotope of radioactive elements.

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	277[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	72.64
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	6.941
Livermorium	Lv	116	292[a]
Lutetium	Lu	71	174.97
Magnesium	Mg	12	24.31
Manganese	Mn	25	54.94
Meitnerium	Mt	109	268.14[a]
Mendelevium	Md	101	258.10[a]
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.96
Moscovium	Mc	115	289
Neodymium	Nd	60	144.24
Neon	Ne	10	20.18
Neptunium	Np	93	237.05[a]
Nickel	Ni	28	58.69
Nihonium	Nh	113	284
Niobium	Nb	41	92.91
Nitrogen	N	7	14.01
Nobelium	No	102	259.10[a]
Oganesson	Og	118	294
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	78.96
Silicon	Si	14	28.09
Silver	Ag	47	107.87
Sodium	Na	11	22.99
Strontium	Sr	38	87.62
Sulfur	S	16	32.07
Tantalum	Ta	73	180.95
Technetium	Tc	43	98[a]
Tellurium	Te	52	127.60
Tennessine	Ts	117	294
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

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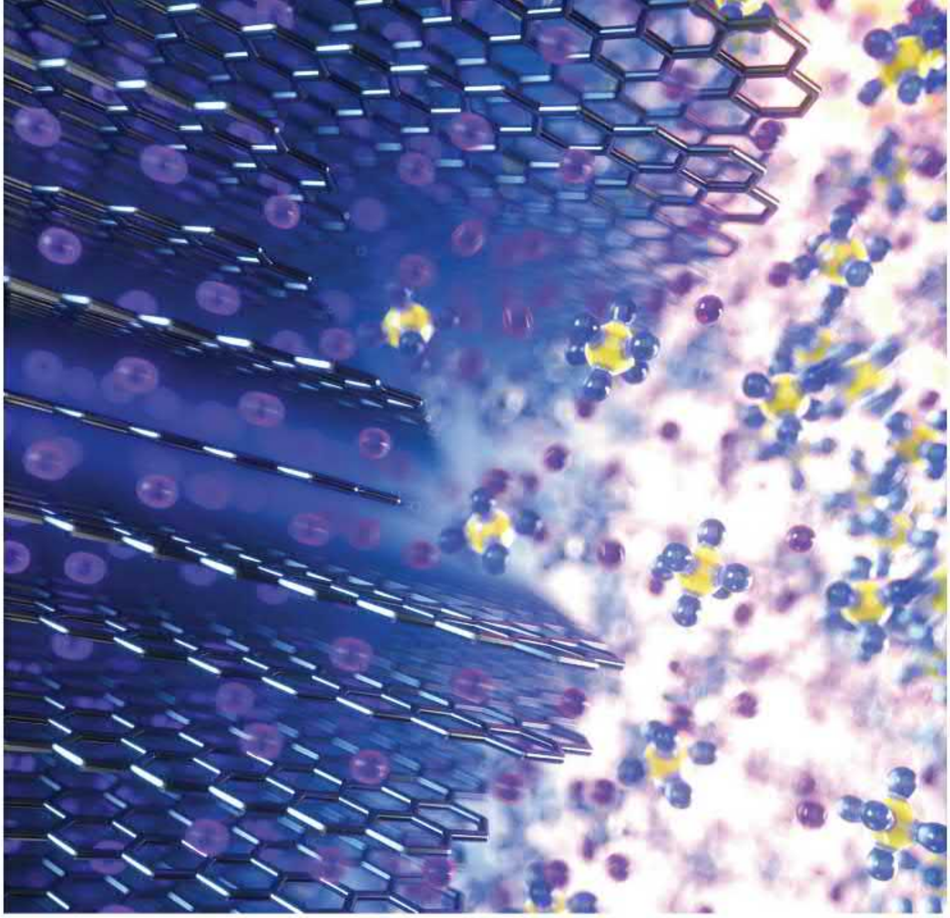
[a] Mass of longest-lived or most important isotope.



CHEMISTRY

A MOLECULAR APPROACH

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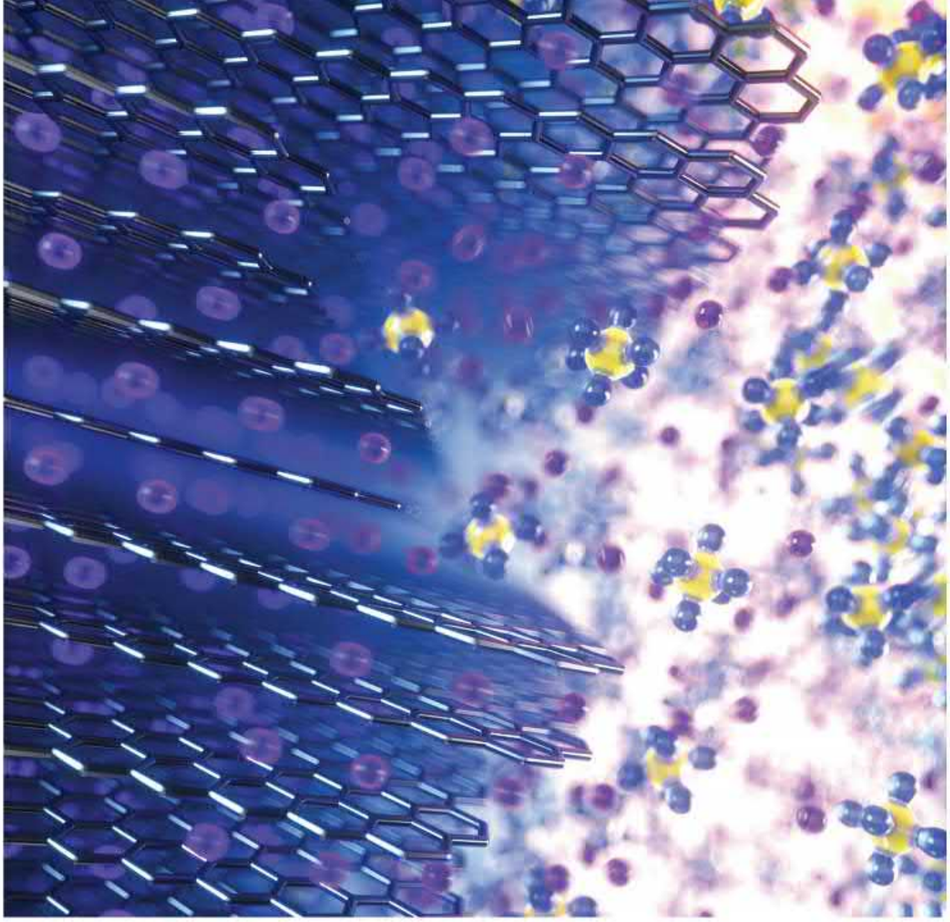

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Pearson

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978-0-13-475538-0

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Library and Archives Canada Cataloguing in Publication
Tro, Nivaldo J., author
Chemistry : a molecular approach / Nivaldo J. Tro, Westmont College,
Travis D. Fridgen, Memorial University, Lawton E. Shaw, Athabasca
University. — Third Canadian edition.

Issued in print and electronic formats.
ISBN 978-0-13-475538-0 (hardcover).—ISBN 978-0-13-489482-9 (looseleaf).—ISBN 978-0-13-499409-3 (HTML)

1. Chemistry, Physical and theoretical—Textbooks. 2. Textbooks.
I. Fridgen, Travis D. (Travis David), 1970-, author II. Shaw, Lawton, 1972-,
author III. Title.

QD453.3.T76 2019 541 C2018-905951-6
C2018-905952-4

Pearson

To Michael, Ali, Kyle, and Kaden
—Nivaldo Tro

To Cailyn, Carter, Colton, and Chloe
—Travis Fridgen

To Calvin, Nathan, Alexis, and Andrew
—Lawton Shaw

About the Authors

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 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 honoured 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.

Travis Fridgen is currently Associate Dean of Science and Professor of Chemistry at Memorial University in St. John's, Newfoundland and Labrador. His research group studies the energetics, reactions, and structures of gaseous self-assembled complexes composed of metal ions and biologically relevant molecules such as DNA bases, amino acids, and peptides using a combination of mass spectrometry, tunable infrared lasers, and computational chemistry. Their research is aimed at answering fundamental questions such as why K^+ is associated with guanine quadruplexes such as telomeric DNA. He graduated with a B.Sc. (Hons) in chemistry from Trent University and a B.Ed. from Queen's University. His Ph.D. in physical chemistry is from Trent and Queen's Universities, where he studied the spectroscopy of reactive species in a cryogenic matrix environment. During his postdoctoral fellowship at the University of Waterloo, he first began conducting research using mass spectrometric methods. During a brief period as an assistant professor at Wilfrid Laurier University, he initiated a collaboration with a group of researchers from France to spectroscopically determine structures of gas phase proton-bound dimer ions. He has taught physical chemistry courses at all levels, but mostly enjoys teaching first year. He was recently awarded the inaugural Distinguished Teaching Award by the Faculty of Science at Memorial University. He lives in Mount Pearl, Newfoundland and Labrador, with his wife, Lisa; their four children, Cailyn, Carter, Colton, and Chloe; and their three Shih Tzus, Kobe, Jacky, and Joey. They are all avid fans of the Ottawa Senators and enjoy busy, active lives that include outdoor activities such as shovelling snow (good old Newfoundland!).

Lawton Shaw received his Ph.D. in chemistry from the University of Calgary in the area of photochemical reaction mechanisms of organometallic complexes. Shortly after graduating, he joined the full-time teaching faculty at Mount Royal College in Calgary, where he developed one of the first science courses at Mount Royal delivered partially online. This work led to a serious interest in online and distance education. In 2005, he joined the Centre for Science at Athabasca University, where he teaches and coordinates distance-delivered chemistry courses. This experience led to the book *Accessible Elements: Teaching Science Online and at a Distance,* which he co-edited. His research interests are split between the realms of teaching/education and environmental chemistry. He studies the effects of pharmaceuticals and personal care products on biofilms in freshwater ecosystems. He is a former president of College Chemistry Canada. He has extensive experience with the Athabasca University Faculty Association, serving as President from 2014 to 2017. He lives in St. Albert, Alberta, with his wife, Tanya, and their four children. Their family leisure time is filled with activities such as cross-country skiing, swimming, and camping.

Brief Contents

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Preface

TO THE STUDENT

As you begin this course, think about your reasons for enrolling in it. Why are you taking general chemistry? Why are you pursuing a university or college education at all? If you are like most students taking general chemistry, part of your answer is probably that this course is required for your major or you are pursuing your education so that you can get a job some day. Although these are both good reasons, we think there is a better one. The primary reason for an education is to prepare you to *live a good life*. You should understand chemistry—not for what it can *get* you—but for what it can *do* for you. Understanding chemistry is an important source of happiness and fulfillment.

Understanding chemistry helps you to live life to its fullest for two basic reasons. The first is *intrinsic*: Through an understanding of chemistry, you gain a powerful appreciation for just how rich and extraordinary the world really is. For example, one of the most important ideas in science is that **the behaviour of matter is determined by the properties of molecules and atoms**. With this knowledge, we have been able to study the substances that compose the world around us and explain their behaviour by reference to particles so small that they can hardly be imagined. If you have never realized the remarkable sensitivity of the world we *can* see to the world we *cannot,* you have missed out on a fundamental truth about our universe. The second reason is *extrinsic*: Understanding chemistry makes you a more informed citizen—it allows you to engage with many of the issues of our day. Scientific literacy helps you understand and discuss in a meaningful way important issues from the development of the oil sands in Alberta (Chapter 6) to how the production of pharmaceuticals and personal care products affects our environment and our bodies (Chapter 12). In other words, understanding chemistry makes *you* a deeper and richer person and makes your country and the world a better place to live. These reasons have been the foundation of education from the very beginnings of civilization.

So this is why we think you should take this course and why we wish you the best as you embark on the journey to understand the world around you at the molecular level. The rewards are well worth the effort.

The Strengths of *Chemistry: A Molecular Approach*

Chemistry: A Molecular Approach is first and foremost a *student-oriented book*. The main goal of the book is to motivate students and get them to achieve at the highest possible level. As we all know, many students take general chemistry because it is a requirement; they do not see the connection between chemistry and their lives or their intended careers. *Chemistry: A Molecular Approach* strives to make those connections consistently and effectively. Unlike other books, which often teach chemistry as something that happens only in the laboratory or in industry, this book teaches chemistry in the context of relevance. It shows students *why* chemistry is important to them, to their future careers, and to their world.

Second, *Chemistry: A Molecular Approach* is a *pedagogically driven book*. In seeking to develop problem-solving skills, a consistent approach is applied (Sort, Strategize, Solve, and Check), usually in a two- or three-column format. In the two-column format, the left column shows the student how to analyze the problem and devise a solution strategy. It also lists the steps of the solution and explains the rationale for each one, while the right column shows the implementation of each step. In the three-column format, the left column outlines the general procedure for solving an important category of problems that is then applied to two side-by-side examples. This strategy allows students to see both the general pattern and the slightly different ways in which the procedure may be applied in differing contexts. The aim is to help students understand both the *concept of the problem* (through the formulation of an explicit conceptual plan for each problem) and the *solution to the problem.*

Third, *Chemistry: A Molecular Approach* is a *visual book.* Wherever possible, images are used to deepen the student's insight into chemistry. In developing chemical principles, multipart images help to show the connection between everyday processes visible to the unaided eye and what atoms and molecules are actually doing. Many of these images have three parts: macroscopic, molecular, and symbolic. This combination helps students to see the relationships between the formulas they write down on paper (symbolic), the world they see around them (macroscopic), and the atoms and molecules that compose that world (molecular). In addition, most figures are designed to teach rather than just to illustrate. They include annotations and labels intended to help the student grasp the most important processes and the principles that underlie them. The resulting images are rich with information but also uncommonly clear and quickly understood.

Fourth, *Chemistry: A Molecular Approach* is a *"big picture" book*. At the beginning of each chapter, a short paragraph helps students to see the key relationships between the different topics they are learning. A focused and concise narrative helps make the basic ideas of every chapter clear to the student. Interim summaries are provided at selected spots in the narrative, making it easier to grasp (and review) the main points of important discussions. And to make sure that students never lose sight of the forest for the trees, each chapter includes several *Conceptual Connections,* which ask them to think about concepts and solve problems without doing any math. The idea is for students to learn the concepts, not just plug numbers into equations to churn out the right answer.

Finally, *Chemistry: A Molecular Approach* is a book that delivers the depth of coverage faculty want and students need. We do not have to cut corners and water down the material in order to get our students interested. We simply have to meet them where they are, challenge them to the highest level of achievement, and then support them with enough pedagogy to allow them to succeed.

The Canadian Edition

Chemistry: A Molecular Approach, by Nivaldo J. Tro, is widely used in general chemistry courses at colleges and universities across North America. So, why do we need a Canadian edition? The short answer is that general chemistry courses in Canada are different from those in the United States. First-year chemistry curricula in Canada are generally at a higher level than what is seen south of the border. There is a need for a strong chemistry textbook that serves Canadian general chemistry courses.

The Canadian adaptation of *Chemistry: A Molecular Approach* drew very heavily on feedback from professors and instructors across Canada. As the Canadian authors, we took the reviews and consultations very seriously and did our best to adapt Tro's textbook accordingly. In general terms, the adaptation involved making the following changes.

International Conventions on Units, Symbols, and Nomenclature The field of chemistry is communicated according to conventions that are determined by the broader international chemistry community, through the International Union of Pure and Applied Chemistry (IUPAC). IUPAC continually releases recommendations on chemical nomenclature, definitions, symbols, and units. IUPAC recommendations are not static; they may evolve over time as new information comes to light. Although many textbooks state that they follow the recommendations of the IUPAC, you will find that the Canadian edition of *Chemistry: A Molecular Approach* scrupulously follows IUPAC recommendations for chemical names and symbols, nomenclature, and conventions for symbols and units in measurements. In the case of chemical nomenclature, there are a number of non-IUPAC chemical names that are so common that we have to include them along with the IUPAC recommended name.

S.I. units of measurement are used exclusively. Imperial units such as the gallon, pound, and the Fahrenheit scale of temperature have not been used in modern science for over a generation. IUPAC recommended defining standard pressure as 1 bar (or 100 kPa) back in 1982. This is the standard that has been adopted by chemists worldwide and is almost exclusive in second-year physical chemistry texts. Only in first-year textbooks does the atmosphere still linger as standard pressure. In this text, standard pressure is the IUPAC-recommended bar. Students will see pressure in various units, but we make little use of the atmosphere. When dealing with ideal gases, the most common value of R is 0.08314 L bar mol^{-1} K^{-1}.

In thermodynamics, we have adopted the recommended notation for enthalpy, entropy, and Gibbs energy changes, placing subscripts for changes after the delta sign rather than after H, S, or G. For example, the standard reaction enthalpy is expressed as $\Delta_r H^\circ$ rather than ΔH°_{rxn}. This is a subtle change that matters. The type of change (Δ) is marked on the Δ symbol (reaction, Δ_r; formation, Δ_f; and so on), rather than the type of thermodynamic quantity. We understand that this notation is not used everywhere. However, we believe that students should use standard notation throughout their education. Students who continue in chemistry or other sciences will eventually come across the standard notation in physical chemistry textbooks and in places like the *CRC Handbook of Chemistry and Physics* and the NIST Chemistry WebBook (http://webbook.nist.gov/). Furthermore, thermodynamic quantities like $\Delta_r H^\circ$ are always molar quantities and have the units kJ mol^{-1}, as recommended by IUPAC. Exclusive use of IUPAC-recommended units keeps students from getting into unit troubles when doing thermodynamic calculations.

Explicitly, we have provided the distinctions and connections between the unitless thermodynamic equilibrium constant, K_{eq} or simply K, and the phenomenological equilibrium constants, K_c and K_P, which can have units in terms of concentration and pressure, respectively, again in accordance with IUPAC recommendations. This is done in the most basic of terms, assuming that gases and solutions are ideal so that their partial pressures and concentrations are assumed to be numerically equivalent to their activities, setting up for a more rigorous treatment in second-year analytical and physical chemistry courses.

Following recommendations set out by the IUPAC ensures that we speak a common language—and teach a common language. Otherwise, students who go on in chemistry have to convert from the language learned in first year as soon as the very next year, when they take their first physical chemistry course.

Current Theories We have updated the text so that the most current, consensus scientific view is described. This is most notable in the case of bonding theory and the so-called expanded octet. In this case, evidence shows that the *d* orbitals have a negligible contribution to bonding, which means that full sp^3d and sp^3d^2 hybridizations should no longer be included in bonding theories, even though this idea continues to appear in general chemistry textbooks. This Canadian edition reflects the most current understanding of chemical phenomenon, at the first-year level.

Organic Chemistry The coverage of organic chemistry has been expanded to two chapters, reflecting the curricula in many Canadian universities, which provide additional organic chemistry coverage in first-year chemistry. The first organic chemistry chapter covers structure and bonding, stereochemistry, and structure determination. The second chapter covers organic reactivity, and it is organized according to reaction mechanisms.

Canadian Context Naturally, a Canadian edition will include Canadian examples. In some places, the Canadian content is fun, like the hockey goalie's "Quantum mechanical five hole" in Chapter 7. In other places, Canadian chemistry examples are serious and important, like the chemistry of the oil sands. Wherever Canadian content appears in this edition, it is there to promote student engagement. This book is meant for the Canadian student.

End-of-Chapter Problems One of the first things that professors consider when choosing a chemistry textbook is the quality of end-of-chapter problems. This is because, to learn chemistry, students need to work through meaningful exercises and problems. Tro's *Chemistry: A Molecular Approach* has extensive, high-quality problems.

First-year chemistry courses are perhaps the most important courses in chemistry programs, because they lay the foundation for all higher level courses. First-year courses introduce students to the language and discipline of chemistry, and some concepts are not touched on again in the entire undergraduate curriculum. Indeed, many Ph.D. comprehensive questions fall back to ideas learned in first year. This book was prepared with the full undergraduate curriculum in mind. If you are a student, we hope that the Canadian edition of *Chemistry: A Molecular Approach* helps you succeed in chemistry. We encourage you to make use of all of the features in this book that are designed to help you learn. If you are a professor, it is our hope that this textbook provides you with the strong content you need to teach first-year chemistry in a way that is true to our discipline.

Third Canadian Edition

For the third Canadian edition, we had two primary goals. Our first goal was to make focused improvements and write additional content in selected areas. Some of these are described below.

In Chapter 7, we have clarified the language and added a brief discussion of what is meant by orbital energies. We improved the discussion of electron configurations of transition metals—a topic that many students find confusing. We also added a whole new section showing the application of the Schrödinger equation to a quantum mechanical system—"the particle in a one-dimensional box." Our aim is to demystify wave functions and quantum numbers. We do this by showing that wave functions are nothing more than mathematical equations representing electrons in an atom. Furthermore, applying the Schrödinger equation to a quantum mechanical system with boundary conditions (i.e., a particle in a box or an electron in an atom) gives rise to quantum numbers.

In Chapter 9, we added a brief discussion of homolytic versus heterolytic bond dissociations. In Chapter 10, we expanded coverage of p–n junctions in diodes and show how these are applied in light emitting diodes (LEDs) and photovoltaic cells. We also address the issue of hybridization of terminal atoms in bonding descriptions. From a shape and structure point of view, when a molecule has a terminal atom with lone pairs of electrons, it is not necessary to assign hybrid orbitals to those lone pairs. However, hybridization of terminal atoms is commonly taught, especially in organic chemistry courses, where reactions result in a bond to the terminal atom. Our continued priority is to show how chemists use different bonding models for different purposes. As well, we added stick-like drawings to show the shapes of molecules—drawings that students can mimic—along with artistic three-dimensional renderings that students will not be able to reproduce easily.

Worked examples are one of the most important and well-used features in this textbook. To continue this strength, we have added some new worked examples, for example on reaction mechanisms in Chapter 13.

Finally, we reorganized Chapter 17 slightly by moving the discussion of the third law of thermodynamics earlier in the chapter with the rest of the quantitative discussion of entropy. We also introduced a new section, including worked examples, on making nonspontaneous processes spontaneous by coupling with exergonic reactions.

Our second goal was to update and "evergreen" the book. To do this, we replaced or updated "Chemistry in Your Day" boxes to make them more interesting and relevant to students and thereby enhance learning. New boxes include "Stack Sampling" (Chapter 5), "Weak Acids in Wine" (Chapter 15), "Fluoride and Teeth" (Chapter 16), and "Rechargeable Battery Recycling" (Chapter 18). We also added many new end-of chapter problems throughout the book, which gives instructors and students more opportunities to engage with chemistry content and practise problem solving.

ACKNOWLEDGEMENTS

During the development of this book, we obtained many helpful suggestions and comments from colleagues from across the country.

Editorial Advisory Board

We would like to thank the following professors for contributing their valuable time to meet with the author and the publishing team over the course of this project to provide a meaningful perspective on the most important challenges they face in teaching general chemistry and for providing insight and feedback on the third Canadian edition and MasteringChemistry course:

Louise Dawe, *Wilfrid Laurier University*
Phil Dutton, *University of Windsor*
Andrew Vreugdenhil, *Trent University*
James Xidos, *University of Manitoba*

We also thank the following reviewers who offered feedback on the previous edition of this textbook:

Francois Caron, *Laurentian University*
Linda Davis, *McMaster University*
Violeta Iosub, *University of Calgary*
Lori Jones, *University of Guelph*
Stephen Kariuki, *Nipissing University*
Jan Matejovic, *University of Ontario Institute of Technology*
Andrew Mosi, *Langara College*
Brad Pavelich, *Medicine Hat College*
Jason Pearson, *University of Prince Edward Island*

We acknowledge Prof. Dietmar Kennepohl (Athabasca University) and Dr. Nicole Sandblom (University of Calgary), Dr. Neil Anderson (Onyx Pharmaceuticals), Dr. Rebecca Goyan (Simon Fraser University), Drs. Barry Power, Chris Flinn, Karen Hattenhauer, Mike Katz, Ray Poirier, Peter Warburton, and Chris Kozak (Memorial University), Mr. Nicholas Ryan (Memorial University), and Drs. Lucio Gelmini and Robert Hilts (MacEwan University) for helpful discussions and their insightful comments.

Dr. Ian Hunt of the University of Calgary worked with us in the early development of the organic chemistry chapters. He provided sage advice on the organization of these chapters and made numerous suggestions on how to present organic chemistry in a way that is both rigorous and accessible to the first-year student.

Professor François Caron of Laurentian University provided expert advice on revisions to Chapter 19, improving the presentation of nuclear reaction energetics so that it is consistent with the field of nuclear chemistry.

We would like to thank our wives, Lisa and Tanya, for their encouragement and their continuing patience during all the evenings and weekends we spent working on this book when we could have been with our families.

Finally, we would also like to acknowledge the assistance of the many members of the team at Pearson Canada who were involved throughout the writing and production process: Cathleen Sullivan, Executive Acquisitions Editor; Kim Teska, Senior Marketing Manager; Kamilah Reid-Burrell, Content Manager; Martina van de Velde, Content Developer; Jessica Misfud, Project Manager; Leanne Rancourt, Production Editor and Proofreader; Susan Broadhurst, Copyeditor; and Anthony Leung, Senior Designer.

Travis D. Fridgen
Lawton E. Shaw

Relevant examples and clear language

Chemistry is relevant to every process occurring around you, at every second. The authors help you understand this connection by weaving specific, vivid examples throughout the text that tell the story of chemistry. Every chapter begins with a brief story that illustrates how chemistry is relevant to all people, at every moment.

8 Periodic Properties of the Elements

4 Chemical Reactions and Stoichiometry

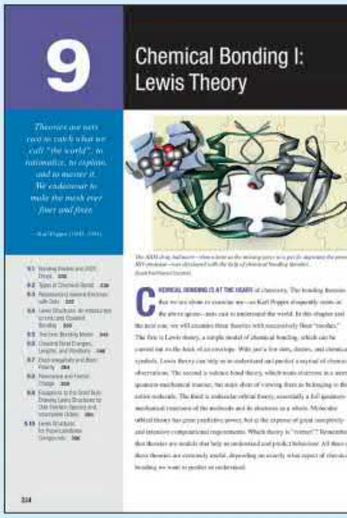
12 Solutions

Are you interested in knowing how nerve cells transmit signals?

See Chapter 8 to learn why periodic properties are essential to understanding this process.

What about the chemistry of everyday life?

Chapter 4 illustrates the role chemistry plays in cuisine, from baking a cake to why lemons go well with fish.



9 Chemical Bonding I: Lewis Theory

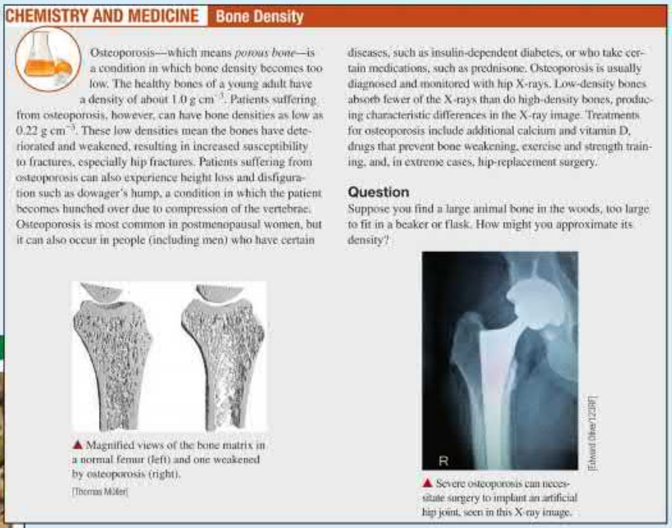
Chemical Bonding II: Molecular Shapes, Valence Bond Theory, and Molecular Orbital Theory 10

These examples make the material more accessible by contextualizing the chemistry and grounding it in the world you live in.

Connect Chemistry to **YOUR WORLD**

Student Interest

Throughout the narrative and in special boxed features, interesting descriptions of chemistry in the modern world demonstrate its importance.



CHEMISTRY AND MEDICINE **Bone Density**

Osteoporosis—which means *porous bone*—is a condition in which bone density becomes too low. The healthy bones of a young adult have a density of about 1.0 g cm^{-3}. Patients suffering from osteoporosis, however, can have bone densities as low as 0.22 g cm^{-3}. These low densities mean the bones have deteriorated and weakened, resulting in increased susceptibility to fractures, especially hip fractures. Patients suffering from osteoporosis can also experience height loss and disfiguration such as dowager's hump, a condition in which the patient becomes hunched over due to compression of the vertebrae. Osteoporosis is most common in postmenopausal women, but it can also occur in people (including men) who have certain diseases, such as insulin-dependent diabetes, or who take certain medications, such as prednisone. Osteoporosis is usually diagnosed and monitored with hip X-rays. Low-density bones absorb fewer of the X-rays than do high-density bones, producing characteristic differences in the X-ray image. Treatments for osteoporosis include additional calcium and vitamin D, drugs that prevent bone weakening, exercise and strength training, and, in extreme cases, hip-replacement surgery.

Question

Suppose you find a large animal bone in the woods, too large to fit in a beaker or flask. How might you approximate its density?

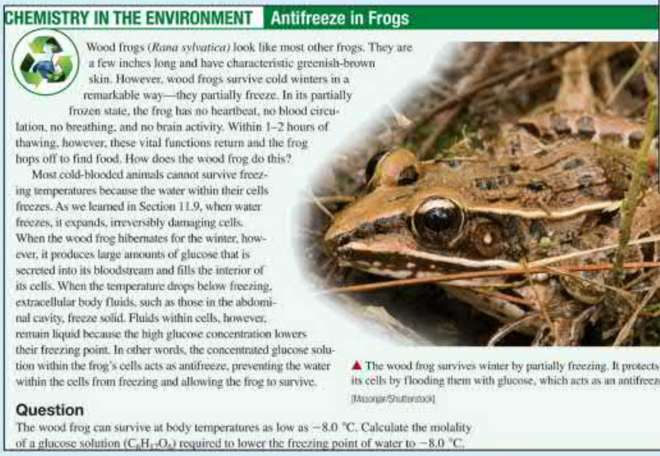
▲ Magnified views of the bone matrix in a normal femur (left) and one weakened by osteoporosis (right).

[Thomas Müller]

R

▲ Severe osteoporosis can necessitate surgery to implant an artificial hip joint, seen in this X-ray image.

[Edward Olive/123RF]



CHEMISTRY IN THE ENVIRONMENT **Antifreeze in Frogs**

Wood frogs (*Rana sylvatica*) look like most other frogs. They are a few inches long and have characteristic greenish-brown skin. However, wood frogs survive cold winters in a remarkable way—they partially freeze. In its partially frozen state, the frog has no heartbeat, no blood circulation, no breathing, and no brain activity. Within 1–2 hours of thawing, however, these vital functions return and the frog hops off to find food. How does the wood frog do this?

Most cold-blooded animals cannot survive freezing temperatures because the water within their cells freezes. As we learned in Section 11.9, when water freezes, it expands, irreversibly damaging cells. When the wood frog hibernates for the winter, however, it produces large amounts of glucose that is secreted into its bloodstream and fills the interior of its cells. When the temperature drops below freezing, extracellular body fluids, such as those in the abdominal cavity, freeze solid. Fluids within cells, however, remain liquid because the high glucose concentration lowers their freezing point. In other words, the concentrated glucose solution within the frog's cells acts as antifreeze, preventing the water within the cells from freezing and allowing the frog to survive.

▲ The wood frog survives winter by partially freezing. It protects its cells by flooding them with glucose, which acts as an antifreeze.

[Masonjar/Shutterstock]

Question

The wood frog can survive at body temperatures as low as −8.0 °C. Calculate the molality of a glucose solution ($C_6H_{12}O_6$) required to lower the freezing point of water to −8.0 °C.

▲ Chemistry and Medicine boxes show applications relevant to biomedical and health-related topics.

◀ Chemistry in the Environment boxes relate chapter topics to current environmental and societal issues.

▼ Chemistry in Your Day boxes demonstrate the importance of chemistry in everyday situations.

CHEMISTRY IN YOUR DAY **How Soap Works**

Imagine eating a greasy cheeseburger with both hands and without napkins. By the end of the meal, your hands are coated with grease and oil. If you try to wash them with only water, they remain greasy. However, if you add a little soap, the grease washes away. Why? As we just learned, water molecules are polar and the molecules that compose grease and oil are nonpolar. As a result, water and grease do not mix.

The molecules that compose soap, however, have a special structure that allows them to interact strongly with both water and grease. One end of a soap molecule is polar, while the other end is nonpolar.

The nonpolar end is a long hydrocarbon chain. Hydrocarbons are always nonpolar because the electronegativity difference between carbon and hydrogen is small, and because the tetrahedral arrangement about each carbon atom tends to cancel any small dipole moments of individual bonds. The polar head of a soap molecule—usually (though not always) ionic—strongly attracts water molecules, while the nonpolar tail interacts more strongly with grease and oil molecules (we examine the nature of these interactions in Chapter 11). Thus, soap acts as a sort of molecular liaison—one end interacting with water and the other end interacting with grease. Soap allows water and grease to mix, removing the grease from your hands and washing it down the drain.

[Soare Cecilia/Fotolia]

Polar head attracts water.

Nonpolar tail interacts with grease.

$CH_3(CH_2)_{11}OCH_2CH_2OH$

Question

Consider the detergent molecule at right. Which end do you think is polar? Which end is nonpolar?

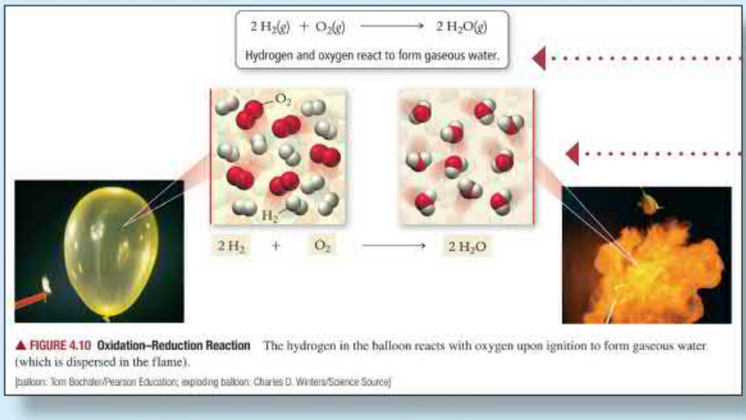
Pioneering artwork makes
CONCEPTS CLEAR

Annotated Molecular Art

Many illustrations have three parts:

- a macroscopic image (what you can see with your eyes)
- a molecular image (what the molecules are doing)
- a symbolic representation (how chemists represent the process with symbols and equations)

The goal is for you to connect what you see and experience (the macroscopic world) with the molecules responsible for that world, and with the way chemists represent those molecules. After all, this is what chemistry is all about.



$2\,H_2(g) + O_2(g) \longrightarrow 2\,H_2O(g)$

Hydrogen and oxygen react to form gaseous water.

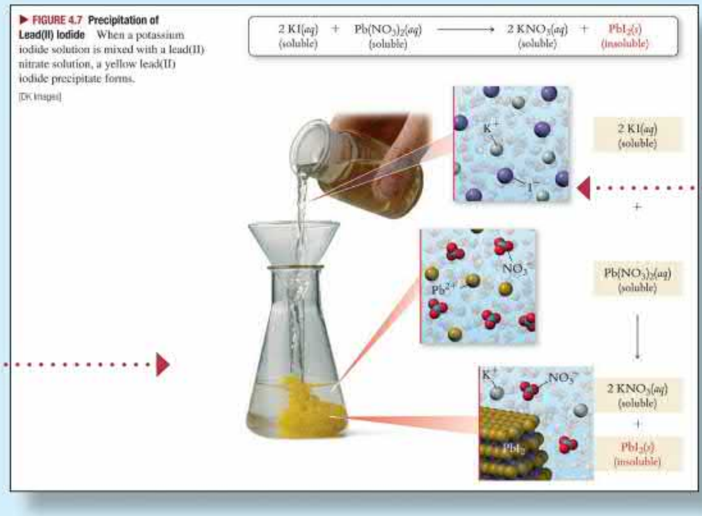
▲ **FIGURE 4.10 Oxidation–Reduction Reaction** The hydrogen in the balloon reacts with oxygen upon ignition to form gaseous water (which is dispersed in the flame).

[balloon: Tom Bochsler/Pearson Education; exploding balloon: Charles D. Winters/Science Source]

Symbolic representation

Molecular image

Macroscopic image



▶ **FIGURE 4.7 Precipitation of Lead(II) Iodide** When a potassium iodide solution is mixed with a lead(II) nitrate solution, a yellow lead(II) iodide precipitate forms.

[DK Images]

$\underset{\text{(soluble)}}{2\,KI(aq)} + \underset{\text{(soluble)}}{Pb(NO_3)_2(aq)} \longrightarrow \underset{\text{(soluble)}}{2\,KNO_3(aq)} + \underset{\text{(insoluble)}}{PbI_2(s)}$

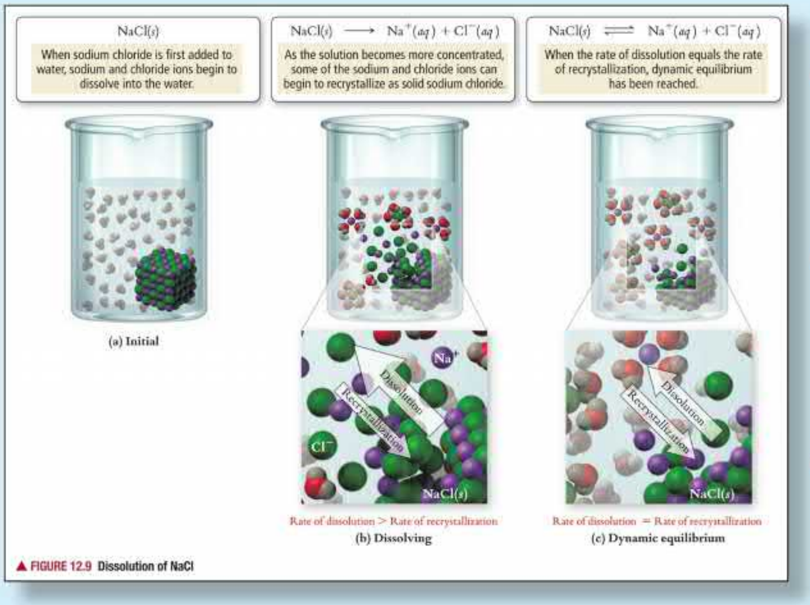
Annotations tell the story of the image concisely.

Molecular image

Macroscopic image

Multipart Images

Multipart images make connections among graphical representations, molecular processes, and the macroscopic world.



$NaCl(s)$

When sodium chloride is first added to water, sodium and chloride ions begin to dissolve into the water.

$NaCl(s) \longrightarrow Na^+(aq) + Cl^-(aq)$

As the solution becomes more concentrated, some of the sodium and chloride ions can begin to recrystallize as solid sodium chloride.

$NaCl(s) \rightleftharpoons Na^+(aq) + Cl^-(aq)$

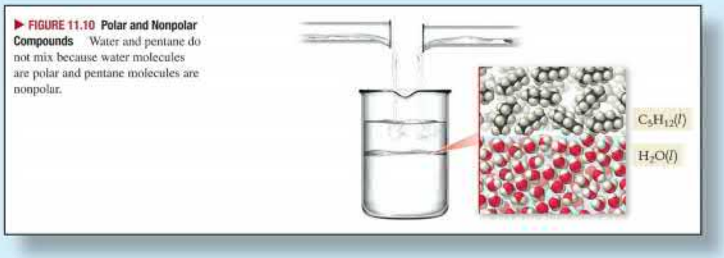
When the rate of dissolution equals the rate of recrystallization, dynamic equilibrium has been reached.

▲ FIGURE 12.9 Dissolution of NaCl

Symbolic representation

Macroscopic image

Molecular image



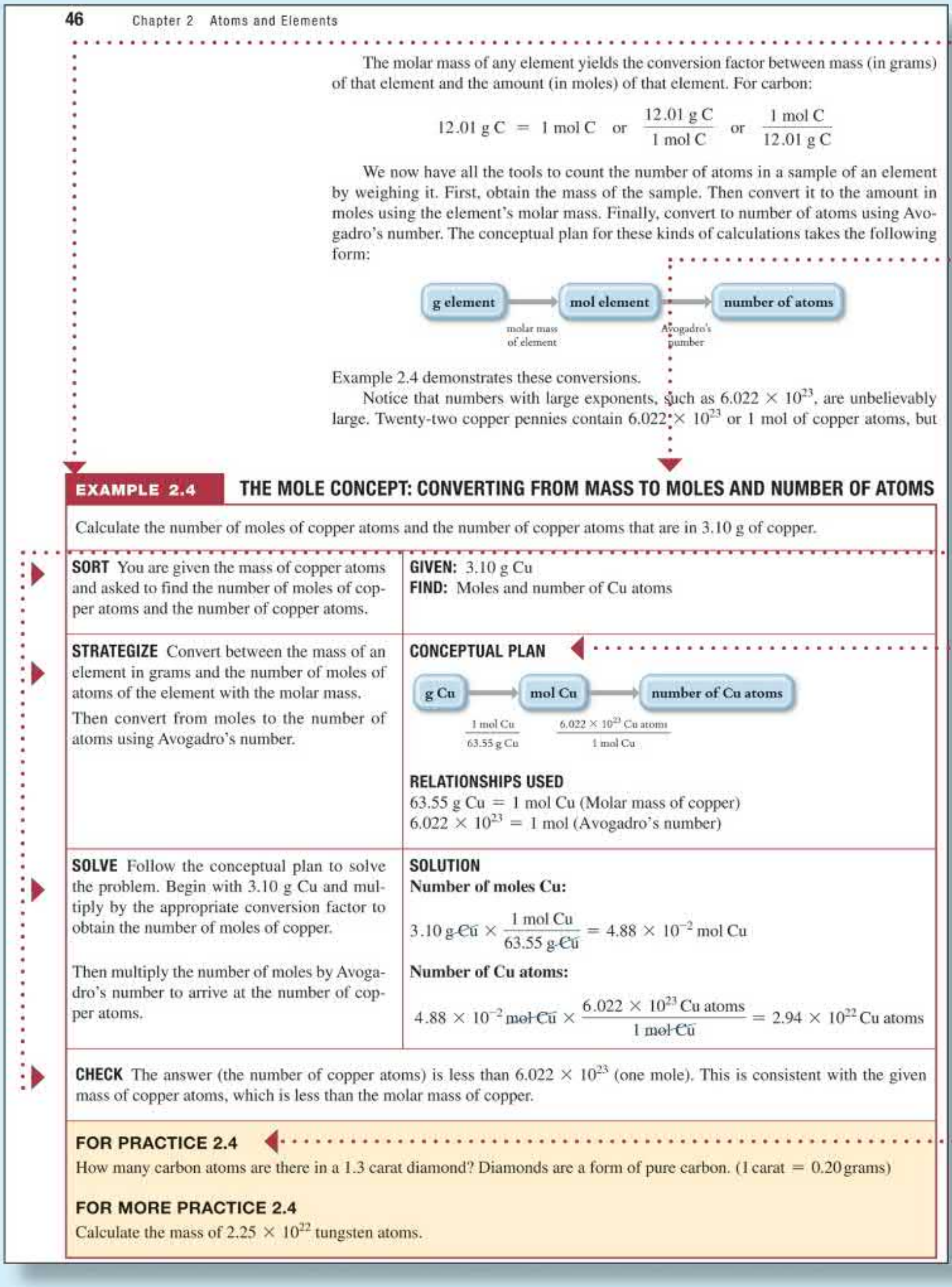
▶ **FIGURE 11.10 Polar and Nonpolar Compounds** Water and pentane do not mix because water molecules are polar and pentane molecules are nonpolar.

Graphical representation

Consistent strategies help you
SOLVE PROBLEMS

Two-Column Example

A consistent approach to problem solving is used throughout the book.



46 Chapter 2 Atoms and Elements

The molar mass of any element yields the conversion factor between mass (in grams) of that element and the amount (in moles) of that element. For carbon:

$$12.01\ \text{g C} = 1\ \text{mol C} \quad \text{or} \quad \frac{12.01\ \text{g C}}{1\ \text{mol C}} \quad \text{or} \quad \frac{1\ \text{mol C}}{12.01\ \text{g C}}$$

We now have all the tools to count the number of atoms in a sample of an element by weighing it. First, obtain the mass of the sample. Then convert it to the amount in moles using the element's molar mass. Finally, convert to number of atoms using Avogadro's number. The conceptual plan for these kinds of calculations takes the following form:

$$\boxed{\text{g element}} \xrightarrow[\text{of element}]{\text{molar mass}} \boxed{\text{mol element}} \xrightarrow[\text{number}]{\text{Avogadro's}} \boxed{\text{number of atoms}}$$

Example 2.4 demonstrates these conversions.

Notice that numbers with large exponents, such as 6.022×10^{23}, are unbelievably large. Twenty-two copper pennies contain 6.022×10^{23} or 1 mol of copper atoms, but

EXAMPLE 2.4 **THE MOLE CONCEPT: CONVERTING FROM MASS TO MOLES AND NUMBER OF ATOMS**

Calculate the number of moles of copper atoms and the number of copper atoms that are in 3.10 g of copper.

SORT You are given the mass of copper atoms and asked to find the number of moles of copper atoms and the number of copper atoms.	**GIVEN:** 3.10 g Cu **FIND:** Moles and number of Cu atoms
STRATEGIZE Convert between the mass of an element in grams and the number of moles of atoms of the element with the molar mass. Then convert from moles to the number of atoms using Avogadro's number.	**CONCEPTUAL PLAN** $\boxed{\text{g Cu}} \xrightarrow{\frac{1\ \text{mol Cu}}{63.55\ \text{g Cu}}} \boxed{\text{mol Cu}} \xrightarrow{\frac{6.022 \times 10^{23}\ \text{Cu atoms}}{1\ \text{mol Cu}}} \boxed{\text{number of Cu atoms}}$ **RELATIONSHIPS USED** $63.55\ \text{g Cu} = 1\ \text{mol Cu}$ (Molar mass of copper) $6.022 \times 10^{23} = 1\ \text{mol}$ (Avogadro's number)
SOLVE Follow the conceptual plan to solve the problem. Begin with 3.10 g Cu and multiply by the appropriate conversion factor to obtain the number of moles of copper. Then multiply the number of moles by Avogadro's number to arrive at the number of copper atoms.	**SOLUTION** **Number of moles Cu:** $3.10\ \text{g}\ \cancel{\text{Cu}} \times \frac{1\ \text{mol Cu}}{63.55\ \text{g}\ \cancel{\text{Cu}}} = 4.88 \times 10^{-2}\ \text{mol Cu}$ **Number of Cu atoms:** $4.88 \times 10^{-2}\ \cancel{\text{mol Cu}} \times \frac{6.022 \times 10^{23}\ \text{Cu atoms}}{1\ \cancel{\text{mol Cu}}} = 2.94 \times 10^{22}\ \text{Cu atoms}$

CHECK The answer (the number of copper atoms) is less than 6.022×10^{23} (one mole). This is consistent with the given mass of copper atoms, which is less than the molar mass of copper.

FOR PRACTICE 2.4
How many carbon atoms are there in a 1.3 carat diamond? Diamonds are a form of pure carbon. (1 carat = 0.20 grams)

FOR MORE PRACTICE 2.4
Calculate the mass of 2.25×10^{22} tungsten atoms.

The **left column** explains how the problem is solved.

The **right column** shows the implementation of the steps explained in the left column.

A **four-part structure ("Sort, Strategize, Solve, Check")** provides you with a framework for analyzing and solving problems.

Many problems are solved with a **conceptual plan** that provides a visual outline of the steps leading from the given information to the solution.

Every worked Example is followed by one or more "For Practice" problems that you can try to solve on your own. Answers to "For Practice" problems are in Appendix IV.