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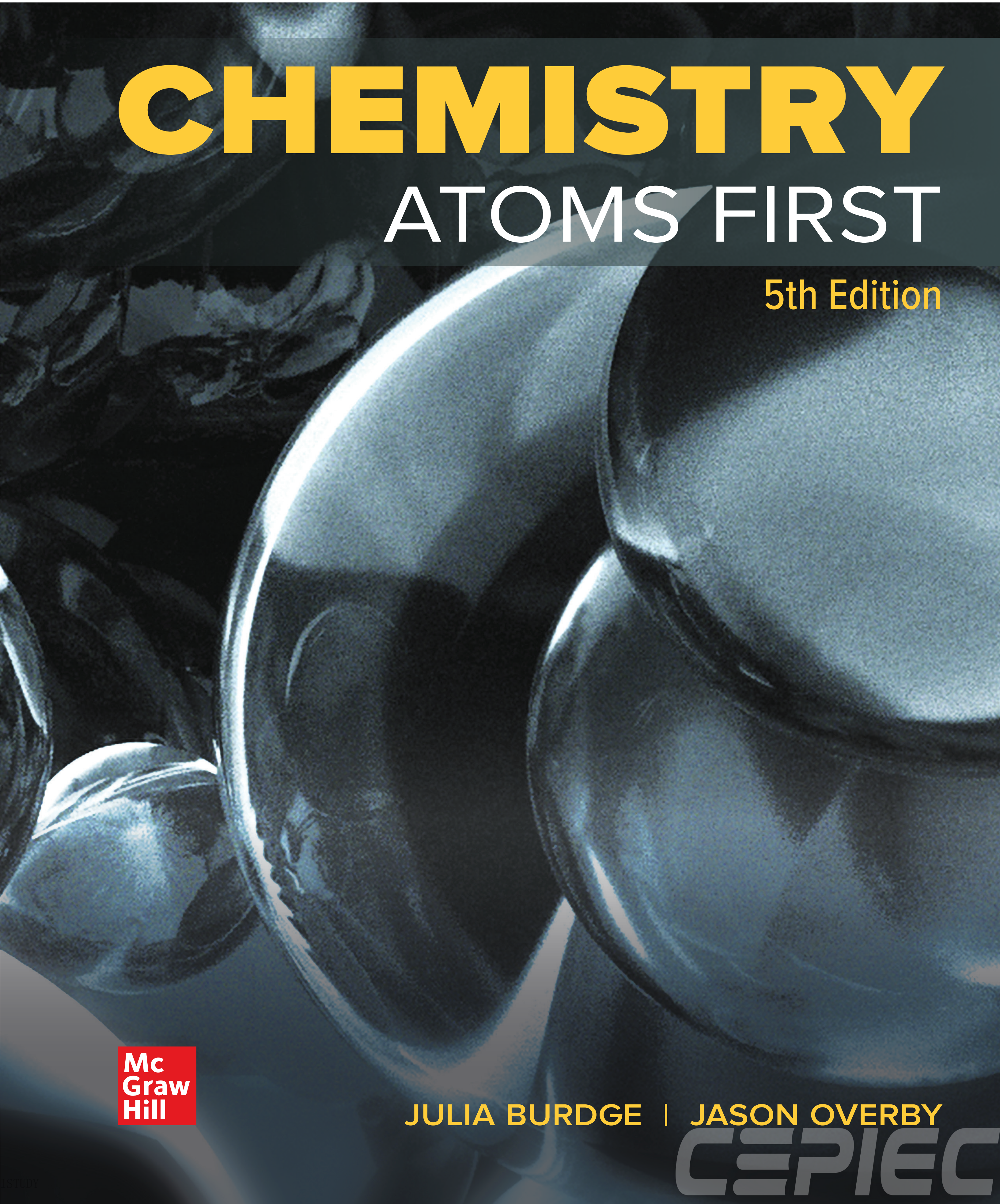

CHEMISTRY

ATOMS FIRST

5th Edition

JULIA BURDGE | JASON OVERBY

Mc Graw Hill

Fundamental Constants

Avogadro's number (N_A)	6.0221413×10^{23}
Electron charge (e)	1.6022×10^{-19} C
Electron mass	9.109387×10^{-28} g
Faraday constant (F)	96,485.3 C/mol e^-
Gas constant (R)	0.08206 L · atm/K · mol
	8.314 J/K · mol
	62.36 L · torr/K · mol
	1.987 cal/K · mol
Planck's constant (h)	6.6256×10^{-34} J · s
Proton mass	1.672623×10^{-24} g
Neutron mass	1.674928×10^{-24} g
Speed of light in a vacuum (c)	2.99792458×10^{8} m/s

Some Prefixes Used with SI Units

tera (T)	10^{12}	centi (c)	10^{-2}
giga (G)	10^{9}	milli (m)	10^{-3}
mega (M)	10^{6}	micro (μ)	10^{-6}
kilo (k)	10^{3}	nano (n)	10^{-9}
deci (d)	10^{-1}	pico (p)	10^{-12}

Useful Conversion Factors and Relationships

1 lb = 453.6 g

1 in = 2.54 cm (exactly)

1 mi = 1.609 km

1 km = 0.6215 mi

1 pm = 1×10^{-12} m = 1×10^{-10} cm

1 atm = 760 mmHg = 760 torr = 101,325 N/m^2 = 101,325 Pa

1 cal = 4.184 J (exactly)

1 L · atm = 101.325 J

1 J = 1 C × 1 V

$$?^\circ C = (^\circ F - 32^\circ F) \times \frac{5^\circ C}{9^\circ F}$$

$$?^\circ F = \frac{9^\circ F}{5^\circ C} \times (^\circ C) + 32^\circ F$$

$$?K = (^\circ C + 273.15^\circ C)\left(\frac{1K}{1^\circ C}\right)$$

Periodic Table of the Elements

Key

Atomic number	6
Symbol	C
Name	Carbon
Average atomic mass	12.01

An element

Main group (groups 1–2); Transition metals (groups 3–11); Main group (groups 13–18)

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Period
1	1 H Hydrogen 1.008																	2 He Helium 4.003	1
2	3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18	2
3	11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95	3
4	19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.41	31 Ga Gallium 69.72	32 Ge Germanium 72.64	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80	4
5	37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3	5
6	55 Cs Cesium 132.9	56 Ba Barium 137.3	57 La Lanthanum 138.9	72 Hf Hafnium 178.5	73 Ta Tantalum 180.9	74 W Tungsten 183.8	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)	6
7	87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (272)	108 Hs Hassium (277)	109 Mt Meitnerium (276)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (280)	112 Cn Copernicium (285)	113 Nh Nihonium (285)	114 Fl Flerovium (287)	115 Mc Moscovium (289)	116 Lv Livermorium (291)	117 Ts Tennessine (293)	118 Og Oganesson (294)	7

Lanthanoids	6	58 Ce Cerium 140.1	59 Pr Praseodymium 140.9	60 Nd Neodymium 144.2	61 Pm Promethium (145)	62 Sm Samarium 150.4	63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 175.0	6
Actinoids	7	90 Th Thorium 232.0	91 Pa Protactinium 231.0	92 U Uranium 238.0	93 Np Neptunium (237)	94 Pu Plutonium (239)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (249)	98 Cf Californium (252)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)	7

Metals

Nonmetals

Metalloids

List of the Elements with Their Symbols and Atomic Masses*

Element	Symbol	Atomic Number	Atomic Mass†	Element	Symbol	Atomic Number	Atomic Mass†
Actinium	Ac	89	(227)	Mendelevium	Md	101	(258)
Aluminum	Al	13	26.9815384	Mercury	Hg	80	200.592
Americium	Am	95	(243)	Molybdenum	Mo	42	95.95
Antimony	Sb	51	121.76	Moscovium	Mc	115	(289)
Argon	Ar	18	39.948	Neodymium	Nd	60	144.242
Arsenic	As	33	74.921595	Neon	Ne	10	20.1797
Astatine	At	85	(210)	Neptunium	Np	93	(237)
Barium	Ba	56	137.327	Nickel	Ni	28	58.6934
Berkelium	Bk	97	(249)	Niobium	Nb	41	92.90637
Beryllium	Be	4	9.0121831	Nihonium	Nh	113	(285)
Bismuth	Bi	83	208.9804	Nitrogen	N	7	14.00643
Bohrium	Bh	107	(272)	Nobelium	No	102	(259)
Boron	B	5	10.806	Oganesson	Og	118	(294)
Bromine	Br	35	79.904	Osmium	Os	76	190.23
Cadmium	Cd	48	112.414	Oxygen	O	8	15.9994
Calcium	Ca	20	40.078	Palladium	Pd	46	106.42
Californium	Cf	98	(252)	Phosphorus	P	15	30.973762
Carbon	C	6	12.0096	Platinum	Pt	78	195.084
Cerium	Ce	58	140.116	Plutonium	Pu	94	(239)
Cesium	Cs	55	132.905452	Polonium	Po	84	(209)
Chlorine	Cl	17	35.446	Potassium	K	19	39.0983
Chromium	Cr	24	51.9961	Praseodymium	Pr	59	140.90766
Cobalt	Co	27	58.933194	Promethium	Pm	61	(145)
Copernicium	Cn	112	(285)	Protactinium	Pa	91	231.03588
Copper	Cu	29	63.546	Radium	Ra	88	(226)
Curium	Cm	96	(247)	Radon	Rn	86	(222)
Darmstadtium	Ds	110	(281)	Rhenium	Re	75	186.207
Dubnium	Db	105	(262)	Rhodium	Rh	45	102.90549
Dysprosium	Dy	66	162.5	Roentgenium	Rg	111	(280)
Einsteinium	Es	99	(252)	Rubidium	Rb	37	85.4678
Erbium	Er	68	167.259	Ruthenium	Ru	44	101.07
Europium	Eu	63	151.964	Rutherfordium	Rf	104	(261)
Fermium	Fm	100	(257)	Samarium	Sm	62	150.36
Flerovium	Fl	114	(287)	Scandium	Sc	21	44.955908
Fluorine	F	9	18.99840316	Seaborgium	Sg	106	(266)
Francium	Fr	87	(223)	Selenium	Se	34	78.96
Gadolinium	Gd	64	157.25	Silicon	Si	14	28.0855
Gallium	Ga	31	69.723	Silver	Ag	47	107.8682
Germanium	Ge	32	72.64	Sodium	Na	11	22.9876928
Gold	Au	79	196.96657	Strontium	Sr	38	87.62
Hafnium	Hf	72	178.486	Sulfur	S	16	32.065
Hassium	Hs	108	(277)	Tantalum	Ta	73	180.94788
Helium	He	2	4.002602	Technetium	Tc	43	(98)
Holmium	Ho	67	164.930328	Tellurium	Te	52	127.6
Hydrogen	H	1	1.00784	Tennessine	Ts	117	(293)
Indium	In	49	114.818	Terbium	Tb	65	158.925354
Iodine	I	53	126.90447	Thallium	Tl	81	204.382
Iridium	Ir	77	192.217	Thorium	Th	90	232.0377
Iron	Fe	26	55.845	Thulium	Tm	69	168.934218
Krypton	Kr	36	83.798	Tin	Sn	50	118.71
Lanthanum	La	57	138.90547	Titanium	Ti	22	47.867
Lawrencium	Lr	103	(262)	Tungsten	W	74	183.84
Lead	Pb	82	207.2	Uranium	U	92	238.02891
Lithium	Li	3	6.941	Vanadium	V	23	50.9415
Livermorium	Lv	116	(291)	Xenon	Xe	54	131.293
Lutetium	Lu	71	174.9668	Ytterbium	Yb	70	173.045
Magnesium	Mg	12	24.3050	Yttrium	Y	39	88.90584
Manganese	Mn	25	54.938043	Zinc	Zn	30	65.409
Meitnerium	Mt	109	(276)	Zirconium	Zr	40	91.224

*These atomic masses show as many significant figures as are known for each element. The atomic masses in the periodic table are shown to four significant figures, which is sufficient for solving the problems in this book.

†Approximate values of atomic masses for radioactive elements are given in parentheses.

Chemistry

ATOMS FIRST

FIFTH EDITION

Julia Burdge
COLLEGE OF WESTERN IDAHO

Jason Overby
COLLEGE OF CHARLESTON

Mc Graw Hill

CHEMISTRY: ATOMS FIRST

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About the Authors

McGraw Hill

Julia Burdge received her Ph.D. (1994) from the University of Idaho in Moscow, Idaho. Her research and dissertation focused on instrument development for analysis of trace sulfur compounds in air and the statistical evaluation of data near the detection limit.

In 1994 she accepted a position at The University of Akron in Akron, Ohio, as an assistant professor and director of the Introductory Chemistry program. In the year 2000, she was tenured and promoted to associate professor at The University of Akron on the merits of her teaching, service, and research in chemistry education. In addition to directing the general chemistry program and supervising the teaching activities of graduate students, she helped establish a future-faculty development program and served as a mentor for graduate students and post-doctoral associates. In 2008, Julia relocated back to the northwest to be near family. She lives in Boise, Idaho; and she holds an affiliate faculty position as associate professor in the Chemistry Department at the University of Idaho and teaches general chemistry at the College of Western Idaho.

In her free time, Julia enjoys horseback riding, precious time with her three children, and quiet time at home with Erik Nelson, her husband and best friend.

McGraw Hill

Jason Overby received his B.S. degree in chemistry and political science from the University of Tennessee at Martin. He then received his Ph.D. in inorganic chemistry from Vanderbilt University (1997) studying main group and transition metal metallocenes and related compounds. Afterwards, Jason conducted postdoctoral research in transition metal organometallic chemistry at Dartmouth College.

Jason began his academic career at the College of Charleston in 1999 as an assistant professor. Currently, he is an associate professor with teaching interests in general and inorganic chemistry. He is also interested in the integration of technology into the classroom, with a particular focus on adaptive learning. Additionally, he conducts research with undergraduates in inorganic and organic synthetic chemistry as well as computational organometallic chemistry.

In his free time, Jason enjoys boating, bowling, and cooking. On many weekends throughout the year, he can often be found on the deck of a pool working as a nationally certified USA Swimming official. He lives in South Carolina with his wife Robin and two daughters, Emma and Sarah.

Brief Contents

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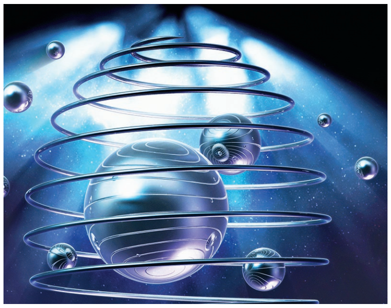

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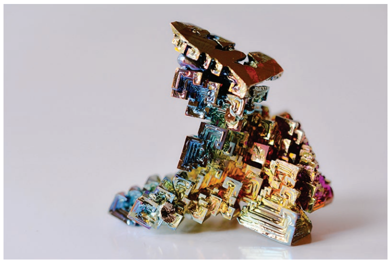

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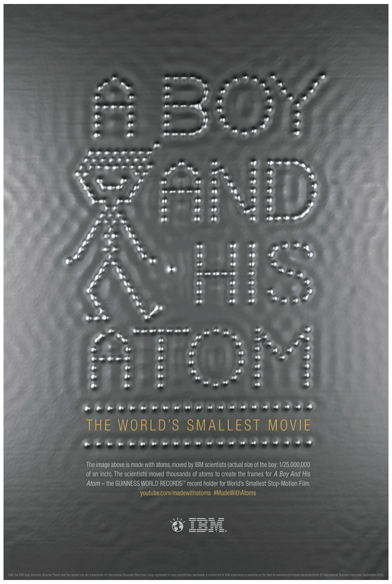

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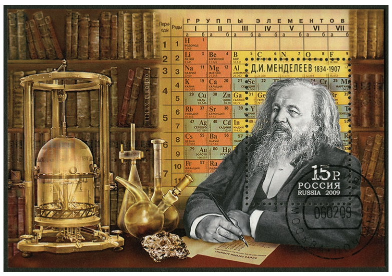

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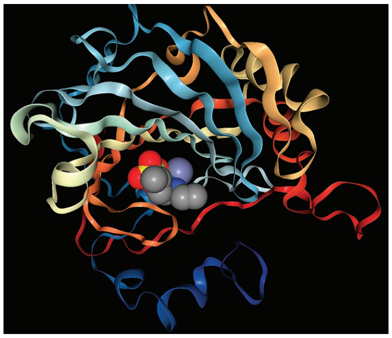
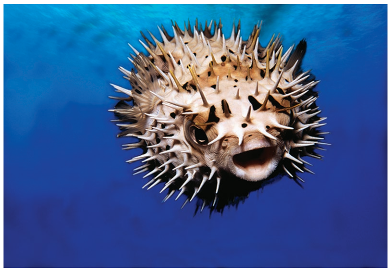


Jason Overby



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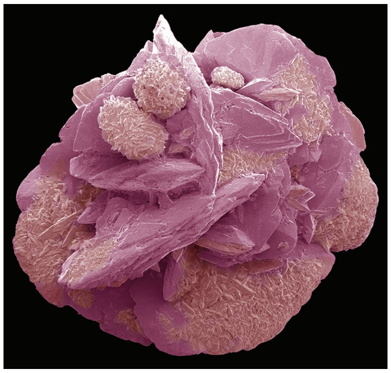
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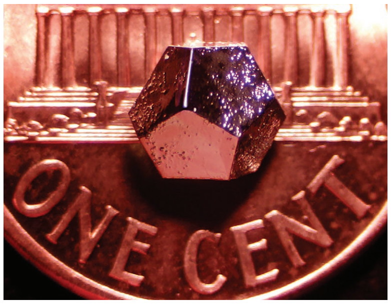

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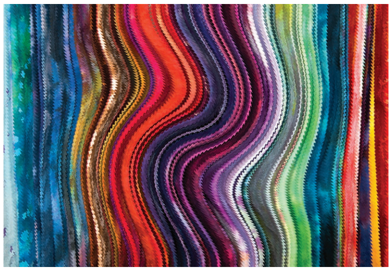
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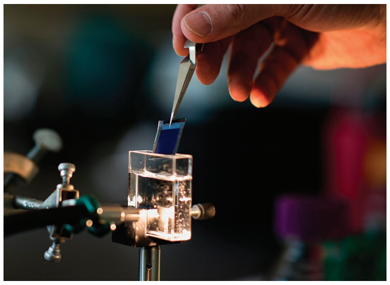
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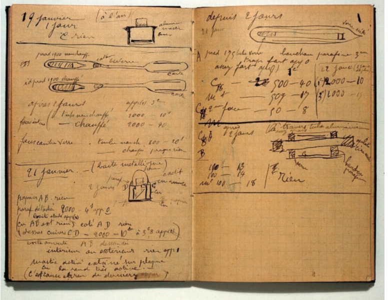

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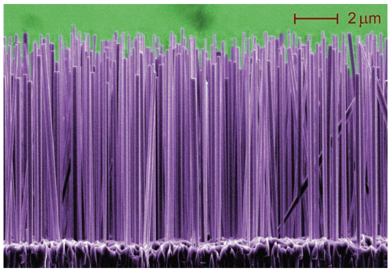

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List of Applications

Thinking Outside the Box

Environmental Aspects

Key Skills

Profiles in Chemistry

Preface

The fifth edition of *Chemistry: Atoms First* by Burdge and Overby builds further on the success of the first four editions. Changes to this edition focus on new additions to the pedagogy, refinement of the current approach, and other innovations driven by feedback from instructors and students alike.

NEW! Environmental Aspects

Given the current climate of environmental awareness in both the classroom and the public in general, we have added a new series of vignettes in the form of boxed features titled Environmental Aspects. Each of the first twenty chapters of the text contains one of these boxes, which provides instructors an opportunity to include timely, environmentally focused material within the context of each chapter. To encourage student engagement with the Environmental Aspects material, many of the boxes have accompanying end-of-chapter problems associated with them. These problems are designated with the Environmental Aspects icon.

Environmental Aspects

Global Climate Change

Those who describe themselves as "skeptical" about climate change sometimes posit that global temperature change is normal, and that any observed increase in temperature is simply the result of natural processes—outside the control of humans. However, there is an enormous body of climate research that clearly demonstrates otherwise. One line of inquiry that has helped to established the connection between human activity and so-called "global warming" involves what is known as *vertical structure of temperature*.

Earth's atmosphere is divided into a series of altitudinal layers: the troposphere (ground-level to 8–14.5 km), the stratosphere (top of the troposphere–50 km), the mesosphere (50–80 km), the thermosphere (80–700 km), and the exosphere (700–10,000 km). The troposphere is where we live, where weather events occur, and where nearly all human activity takes place. When we burn fossil fuels, we increase the amount of CO_2 in the *troposphere*.

In 1988, atmospheric scientist V. Ramanathan, now of the Scripps Institution of Oceanography at the University of California, San Diego, proposed that global temperature change caused by the anthropogenic increase in atmospheric CO_2 could be readily distinguished from that caused by *natural* events, such as increased solar activity. Global temperature increase caused by the Sun, he reasoned, would occur in both the troposphere *and* the stratosphere. Conversely, changes caused by the enhanced greenhouse effect (the result of increased atmospheric CO_2 concentration) would cause warming of the troposphere; but *cooling* of the stratosphere—because more of the heat radiating from Earth's surface would be trapped by greenhouse gases in the troposphere, thus never reaching the stratosphere. Indeed, temperature monitoring over several decades has demonstrated an *increase* in tropospheric temperature, and a *decrease* in stratospheric temperature. This is one of the observations that climate scientists refer to as a *human fingerprint* on global climate change.

Reflecting the Diverse World Around

McGraw Hill believes in unlocking the potential of every learner at every stage of life. To accomplish that, we are dedicated to creating products that reflect, and are accessible to, all the diverse, global customers we serve. Within McGraw Hill, we foster a culture of belonging, and we work with partners who share our commitment to equity, inclusion, and diversity in all forms. In McGraw Hill Higher Education, this includes, but is not limited to, the following:

- Refreshing and implementing inclusive content guidelines around topics including generalizations and stereotypes, gender, abilities/disabilities, race/ethnicity, sexual orientation, diversity of names, and age.
- Enhancing best practices in assessment creation to eliminate cultural, cognitive, and affective bias.
- Maintaining and continually updating a robust photo library of diverse images that reflect our student populations.
- Including more diverse voices in the development and review of our content.
- Strengthening art guidelines to improve accessibility by ensuring meaningful text and images are distinguishable and perceivable by users with limited color vision and moderately low vision.

NEW! Profiles in Chemistry

Many important discoveries and contributions have been made by people whose names may not be well known in the history of chemistry. Our Profiles in Chemistry boxes feature the names and accomplishments of some of those people.

Profiles in Chemistry

St. Elmo Brady

Image courtesy of the University of Illinois Archives

St. Elmo Brady (1916–1966) was the first African American to earn a Ph.D. in chemistry in the United States. He attended Fisk University in Nashville, Tennessee, and then did his graduate work at the University of Illinois Urbana-Champaign. There he did exhaustive studies on the impact that various substituents have on the strength of carboxylic acids. He went on to teach at the Tuskegee Normal and Industrial Institute, now Tuskegee University. He later became chair of the chemistry department at Howard University in Washington, DC. Howard University, founded in 1867, is the oldest HBCU (historically Black colleges and universities) in the United States. Later, Brady would return to lead the chemistry department at Fisk University, his undergraduate alma mater. There he designed the nation's first HBCU graduate program in chemistry. Eventually, he would go on to develop such programs at several other HBCUs. In 2019, Brady was honored posthumously with a National Historic Chemical Landmark by the American Chemical Society.

Updated Pedagogy

To refresh student self-assessments, we have updated all Section Review questions to reimagined or completely new questions. Students report benefiting from these self-evaluation questions as they assess their level of mastery of the material in one section before proceeding to the next. They also report using them to review for quizzes and exams. In addition, there is a significant number of new or revised end-of-chapter problems.

All numerical values in tables and appendices have been updated to match the values that students will encounter in ALEKS. Figures and tables have been refined for accessibility and ADA compliance.

New and Updated Chapter Content

Chapter 1—A new Student Annotation has been added to note the recent redefinition of the meter and of the kilogram.

Chapter 2—A new chapter-opening photo and caption detail the first observation of the radioactive decay of bismuth-209. We have also updated the value of Avogadro's number.

Chapter 5—A new chapter-opening photo and caption describe non-stoichiometric compounds.

Chapter 6—Electronegativity values have been updated to reflect the most recent determinations.

Chapter 7—New Profiles in Chemistry box features the work of Linus Pauling.

Chapter 8—A new Profiles in Chemistry box features the work of Marie-Anne Paulze Lavoisier.

Chapter 11—A new Profiles in Chemistry box features the work of Fritz Haber.

Chapter 13—A new Profiles in Chemistry box features the work of Alice Ball.

Chapter 14—We have refined the introduction of catalysis and have updated the reaction pathway figure to more accurately reflect the function of a catalyst.

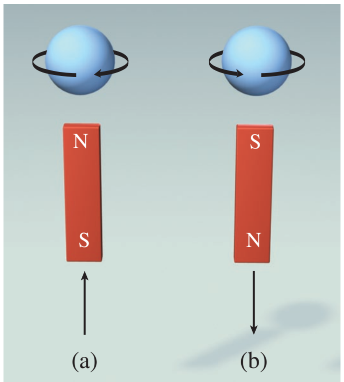


Figure 3.16 (a) Clockwise and (b) counterclockwise spins of an electron. The magnetic fields generated by these two spinning motions are analogous to those from the two magnets. The upward and downward arrows are used to denote the direction of spin.

Figure 14.7 From left to right: The decrease in bromine concentration as time elapses is indicated by the loss of color.
Ken Karp/McGraw Hill

Chapter 15—A new chapter-opening photo and caption allude to the statistical treatment of entropy and a new conceptual end-of-chapter problem queries students' understanding of the description of entropy as "time's arrow."

Chapter 17—The description of Brønsted acid-base reactions has been enhanced by the addition of curved arrows to illustrate the movement of electrons. A new Profiles in Chemistry box features the work of St. Elmo Brady.

Chapter 19—A new Thinking Outside the Box features the use of molten carbonate fuel cells for carbon capture.

ARTWORK

A popular feature of our book is the use of thought-provoking chapter-opening photos that may not be immediately obvious in their connection to the content of chapter. The accompanying captions elucidate the important connections. We continue this with new photos and updated captions in many of the chapters.

The Construction of a Learning System

Writing a textbook and its supporting learning tools is a multifaceted process. McGraw Hill's 360° Development Process is an ongoing, market-oriented approach to building accurate and innovative learning systems. It is dedicated to continual large scale and incremental improvement, driven by multiple customer feedback loops and checkpoints.

This is initiated during the early planning stages of new products and intensifies during the development and production stages. The 360° Development Process then begins again upon publication, in anticipation of the next version of each print and digital product. This process is designed to provide a broad, comprehensive spectrum of feedback for refinement and innovation of learning tools for both student and instructor. The 360° Development Process includes market research, content reviews, faculty and student focus groups, course- and product-specific symposia, accuracy checks, and art reviews, all guided by carefully selected Content Advisors.

The Learning System Used in *Chemistry: Atoms First*

Building Problem-Solving Skills. The entirety of the text emphasizes the importance of problem solving as a crucial element in the study of chemistry. Beginning with Chapter 1, a basic guide fosters a consistent approach to solving problems throughout the text. Each **Worked Example** is divided into four consistently applied steps: *Strategy* lays the basic framework for the problem; *Setup* gathers the necessary information for solving the problem; *Solution* takes us through the steps and calculations; *Think About It* makes us consider the feasibility of the answer or information illustrating the relevance of the problem.

WORKED EXAMPLE 3.3

One type of laser used in the treatment of vascular skin lesions is a neodymium-doped yttrium aluminum garnet, or Nd:YAG, laser. The wavelength commonly used in these treatments is 532 nm. What is the frequency of this radiation?

Strategy We must convert the wavelength to meters and solve for frequency using Equation 3.3 ($c = \lambda\nu$).

Setup Rearranging Equation 3.3 to solve for frequency gives $\nu = \frac{c}{\lambda}$. The speed of light, c, is 3.00×10^8 m/s. λ (in meters) = $532 \text{ nm} \times \frac{1 \times 10^{-9}\text{ m}}{1 \text{ nm}} = 5.32 \times 10^{-7}$ m.

Solution

$$\nu = \frac{3.00 \times 10^8 \text{ m/s}}{5.32 \times 10^{-7} \text{ m}} = 5.64 \times 10^{14} \text{ s}^{-1}$$

Think About It

Make sure your units cancel properly. A common error in this type of problem is neglecting to convert wavelength to meters.

Practice Problem ATTEMPT What is the wavelength (in meters) of an electromagnetic wave whose frequency is 1.61×10^{12} s^{-1}?

Practice Problem BUILD What is the frequency (in reciprocal seconds) of electromagnetic radiation with a wavelength of 1.03 cm?

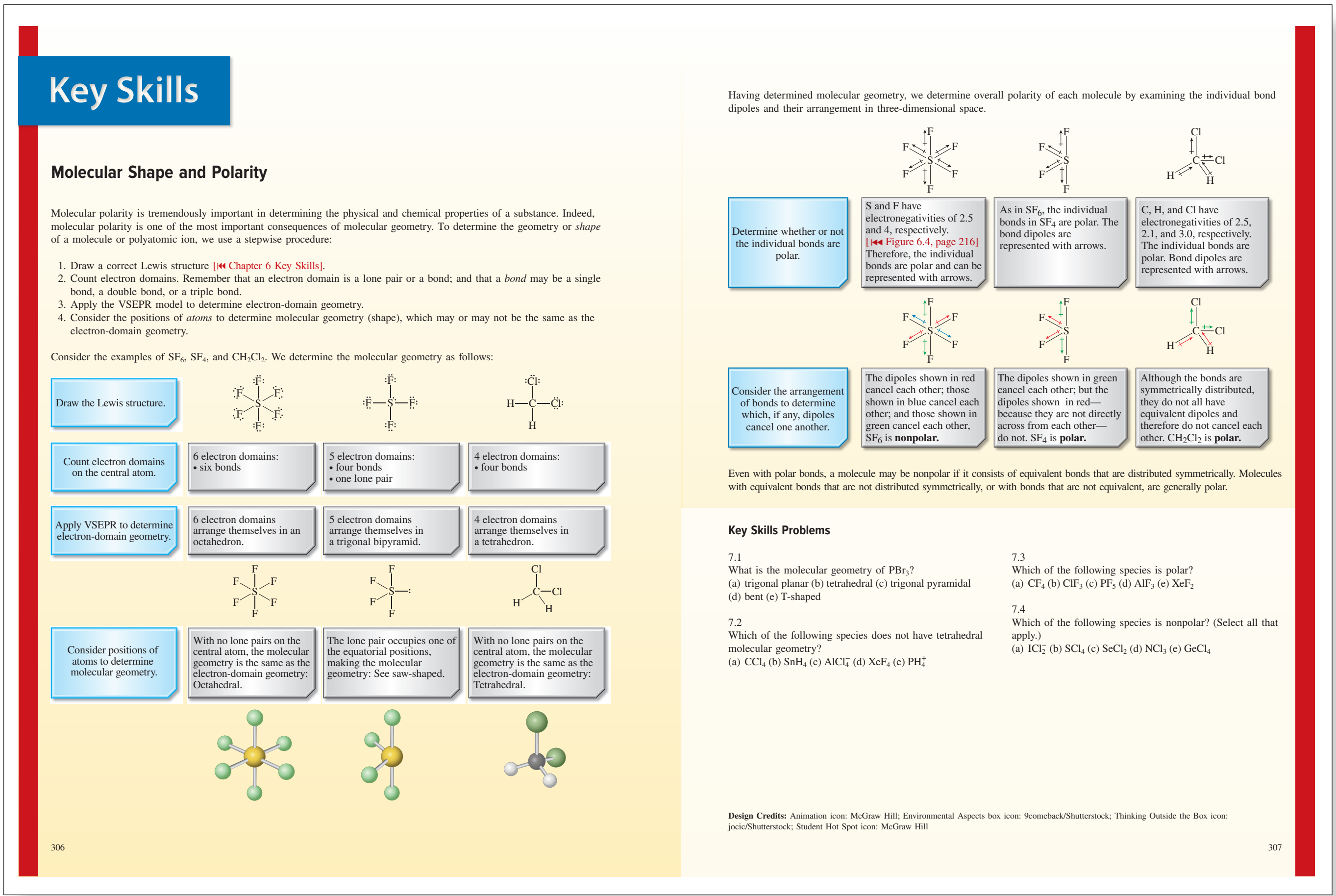
Practice Problem CONCEPTUALIZE Which of the following sets of waves best represents the relative wavelengths/frequencies of visible light of the colors shown?

After working through this problem-solving approach in the Worked Examples, there are three Practice Problems for students to solve. *Practice Problem A* (Attempt) is always very similar to the Worked Example and can be solved using the same strategy and approach.

Although *Practice Problem B* (Build) probes comprehension of the same concept as Practice Problem A, it generally is sufficiently different in that it cannot be solved using the exact approach used in the Worked Example. Practice Problem B takes problem solving to another level by requiring students to develop a strategy independently. *Practice Problem C* (Conceptualize) provides an exercise that further probes the student's conceptual understanding of the material and many employ concept and molecular art. The regular use of the Worked Example and Practice Problems in this text will help students develop a robust and versatile set of problem-solving skills.

Section Review. Every section of the book that contains Worked Examples and Practice Problems ends with a Section Review. The Section Review enables the student to evaluate whether they understand the concepts presented in the section.

Key Skills. Newly located immediately before end-of-chapter problems, Key Skills are easy to find review modules where students can return to refresh and hone specific skills that the authors know are vital to success in later chapters. The answers to the Key Skills can be found in the Answer Appendix in the back of the book.



Key Skills

Molecular Shape and Polarity

Molecular polarity is tremendously important in determining the physical and chemical properties of a substance. Indeed, molecular polarity is one of the most important consequences of molecular geometry. To determine the geometry or *shape* of a molecule or polyatomic ion, we use a stepwise procedure:

1. Draw a correct Lewis structure [⏮ Chapter 6 Key Skills].
2. Count electron domains. Remember that an electron domain is a lone pair or a bond; and that a *bond* may be a single bond, a double bond, or a triple bond.
3. Apply the VSEPR model to determine electron-domain geometry.
4. Consider the positions of *atoms* to determine molecular geometry (shape), which may or may not be the same as the electron-domain geometry.

Consider the examples of SF_6, SF_4, and CH_2Cl_2. We determine the molecular geometry as follows:

	SF_6	SF_4	CH_2Cl_2
Draw the Lewis structure.			
Count electron domains on the central atom.	6 electron domains: • six bonds	5 electron domains: • four bonds • one lone pair	4 electron domains: • four bonds
Apply VSEPR to determine electron-domain geometry.	6 electron domains arrange themselves in an octahedron.	5 electron domains arrange themselves in a trigonal bipyramid.	4 electron domains arrange themselves in a tetrahedron.
Consider positions of atoms to determine molecular geometry.	With no lone pairs on the central atom, the molecular geometry is the same as the electron-domain geometry: Octahedral.	The lone pair occupies one of the equatorial positions, making the molecular geometry: See saw-shaped.	With no lone pairs on the central atom, the molecular geometry is the same as the electron-domain geometry: Tetrahedral.

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Having determined molecular geometry, we determine overall polarity of each molecule by examining the individual bond dipoles and their arrangement in three-dimensional space.

	SF_6	SF_4	CH_2Cl_2
Determine whether or not the individual bonds are polar.	S and F have electronegativities of 2.5 and 4, respectively. [⏮ Figure 6.4, page 216] Therefore, the individual bonds are polar and can be represented with arrows.	As in SF_6, the individual bonds in SF_4 are polar. The bond dipoles are represented with arrows.	C, H, and Cl have electronegativities of 2.5, 2.1, and 3.0, respectively. The individual bonds are polar. Bond dipoles are represented with arrows.
Consider the arrangement of bonds to determine which, if any, dipoles cancel one another.	The dipoles shown in red cancel each other; those shown in blue cancel each other; and those shown in green cancel each other, SF_6 is **nonpolar.**	The dipoles shown in green cancel each other; but the dipoles shown in red—because they are not directly across from each other—do not. SF_4 is **polar.**	Although the bonds are symmetrically distributed, they do not all have equivalent dipoles and therefore do not cancel each other. CH_2Cl_2 is **polar.**

Even with polar bonds, a molecule may be nonpolar if it consists of equivalent bonds that are distributed symmetrically. Molecules with equivalent bonds that are not distributed symmetrically, or with bonds that are not equivalent, are generally polar.

Key Skills Problems

7.1
What is the molecular geometry of PBr_3?
(a) trigonal planar (b) tetrahedral (c) trigonal pyramidal (d) bent (e) T-shaped

7.2
Which of the following species does not have tetrahedral molecular geometry?
(a) CCl_4 (b) SnH_4 (c) $AlCl_4^-$ (d) XeF_4 (e) PH_4^+

7.3
Which of the following species is polar?
(a) CF_4 (b) ClF_3 (c) PF_5 (d) AlF_3 (e) XeF_2

7.4
Which of the following species is nonpolar? (Select all that apply.)
(a) ICl_2^- (b) SCl_4 (c) $SeCl_2$ (d) NCl_3 (e) $GeCl_4$

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Student Hot Spots. In the text, we have identified areas of particularly difficult content as "Student Hot Spots"—and use them to direct students to a variety of learning resources specific to that content. Students will be able to access over 1,000 digital learning resources throughout this text's eBook. These learning resources present summaries of concepts and worked examples, including over 200 videos of chemistry faculty solving problems or modeling concepts which students can view over and over again.

Student Hot Spot

Student data indicate you may struggle with VSEPR. Access your eBook to view additional Learning Resources on this topic.

Applications. Each chapter offers a variety of tools designed to help facilitate learning. *Student Annotations* provide helpful hints and simple suggestions to the student.

The nomenclature of molecular compounds follows in a similar manner to that of ionic compounds. Most molecular compounds are composed of two nonmetals (see [⏮ Section 2.6, Figure 2.10]). To name such a compound, we first name the element that appears first in the formula. For HCl that would be hydrogen. We then name the second element, changing the ending of its name to *–ide*. For HCl, the second element is chlorine, so we would change chlorine to chloride. Thus, the systematic name of HCl is *hydrogen chloride*. Similarly, HI is hydrogen iodide (iod*ine* ⟶ iod*ide*) and SiC is silicon carbide (carb*on* ⟶ carb*ide*).

Student Annotation: Recall that compounds composed of two elements are called *binary* compounds.

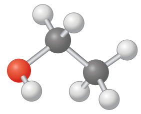
Thinking Outside the Box is an application providing a more in-depth look into a specific topic. *Learning Outcomes* provide a brief overview of the concepts the student should understand after reading the chapter. It's an opportunity to review areas that the student does not feel confident about upon reflection.

Thinking Outside the Box

Functional Groups

Many organic compounds are derivatives of alkanes in which one of the H atoms has been replaced by a group of atoms known as a ***functional group.*** The functional group determines many of the chemical properties of a compound because it typically is where a chemical reaction *occurs.* Table 5.9 lists the names and provides ball-and-stick models of several important functional groups.

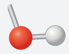
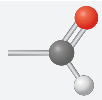
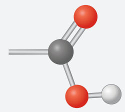
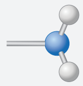
Ethanol, for example, the alcohol in alcoholic beverages, is ethane (C_2H_6) with one of the hydrogen atoms replaced by an alcohol (—OH) group. Its name is derived from that of *ethane,* indicating that it contains *two* carbon atoms.



Ethanol

The molecular formula of ethanol can also be written C_2H_6O, but C_2H_5OH conveys more information about the structure of the molecule. Organic compounds and several functional groups are discussed in greater detail in Chapter 23.

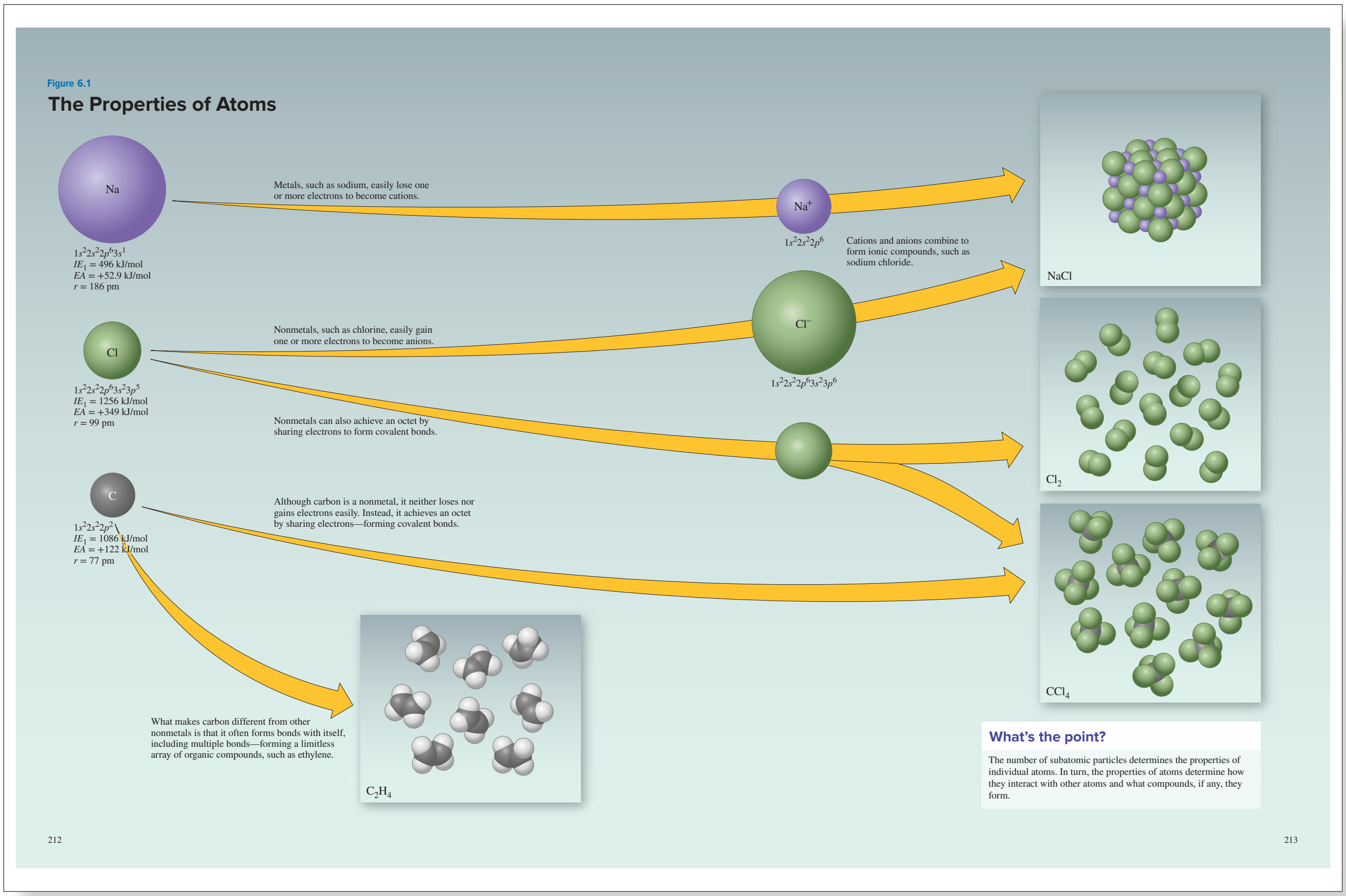
TABLE 5.9 Organic Functional Groups

Name	Functional Group	Model
Alcohol	—OH	
Aldehyde	—CHO	
Carboxylic acid	—COOH	
Amine	$—NH_2$	

Visualization. This text seeks to enhance student understanding through a variety of both unique and conventional visual techniques. A truly unique element in this text is the inclusion of a distinctive feature entitled **Visualizing Chemistry.** These two-page spreads appear as needed to emphasize fundamental, vitally important principles of chemistry. Setting them apart visually makes them easier to find and revisit as needed throughout the course term. Each Visualizing Chemistry feature concludes with a "What's the Point?" box that emphasizes the correct take-away message.

There is a series of conceptual end-of-chapter problems for each Visualizing Chemistry piece. The answers to the Visualizing Chemistry problems, Key Skills problems, and all odd-numbered end of chapter Problems can be found in the Answer Appendix at the end of the text.

Flow Charts and a variety of inter-textual materials such as *Rewind* and *Fast Forward Buttons* and *Section Review* are meant to enhance student understanding and comprehension by reinforcing current concepts and connecting new concepts to those covered in other parts of the text.



Media. Many Visualizing Chemistry pieces have been made into captivating and pedagogically-effective *animations* for additional reinforcement of subject matter first encountered in the textbook. Each Visualizing Chemistry animation is noted by an icon.

Video 7.8
Chemical bonding—formation of molecular orbitals.

Integration of Electronic Homework. You will find the *electronic homework* integrated into the text in numerous places. A large number of the end-of-chapter problems are in the electronic homework system ready to assign to students.

For us, this text will always remain a work in progress. We encourage you to contact us with any comments or questions.

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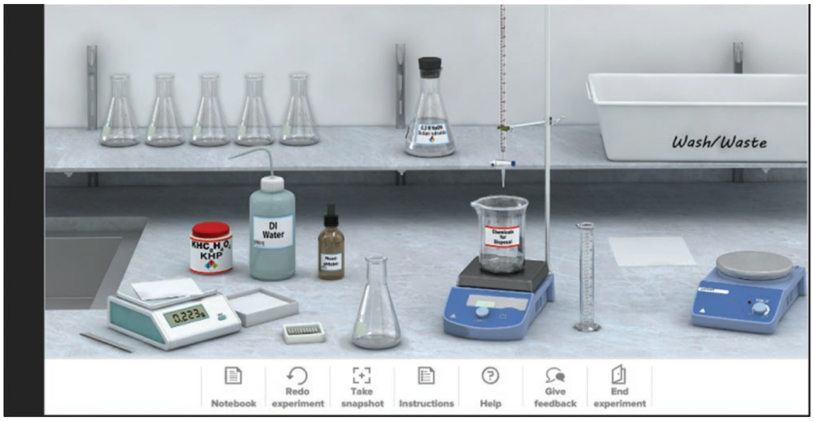
McGraw Hill Virtual Labs is a must-see, outcomes-based lab simulation. It assesses a student's knowledge and adaptively corrects deficiencies, allowing the student to learn faster and retain more knowledge with greater success. First, a student's knowledge is adaptively leveled on core learning outcomes: Questioning reveals knowledge deficiencies that are corrected by the delivery of content that is conditional on a student's response. Then, a simulated lab experience requires the student to think and act like a scientist: recording, interpreting, and analyzing data using simulated equipment found in labs and clinics. The student is allowed to make mistakes—a powerful part of the learning experience! A virtual coach provides subtle hints when needed, asks questions about the student's choices, and allows the student to reflect on and correct those mistakes. Whether your need is to overcome the logistical challenges of a traditional lab, provide better lab prep, improve student performance, or make your online experience one that rivals the real world, McGraw Hill Virtual Labs accomplishes it all.



Instructors have access to the following instructor resources:

- **Art** Full-color digital files of all illustrations, photos, and tables in the book can be readily incorporated into lecture presentations, exams, or custom-made classroom materials. In addition, all files have been inserted into PowerPoint slides for ease of lecture preparation.
- **Animations** Numerous full-color animations illustrating important processes are also provided. Harness the visual impact of concepts in motion by importing these files into classroom presentations or online course materials.

- **Accessible PowerPoint Lecture Outlines** Ready-made presentations that combine art and lecture notes are provided for each chapter of the text.
- **Instructor's Solutions Manual** This supplement contains complete, worked-out solutions for the Practice Problem C questions, Key Skills questions, and *all* the end-of-chapter problems in the text.
- **Computerized Test Bank** Also among the instructor resources is a computerized test bank. The testing software TestGen® can be used to create customized exams quickly. Hundreds of text-specific, open-ended, and multiple-choice questions are included in the question bank.

Create

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Student Solutions Manual

Students will find answers to the Visualizing Chemistry and Key Skills questions and detailed solutions and explanations for the odd-numbered problems from the text in the solutions manual.

Laboratory Manual

Laboratory Manual to Accompany Chemistry: Atoms First by Gregg Dieckmann and John Sibert from the University of Texas at Dallas. This laboratory manual presents a lab curriculum that is organized around an atoms-first approach to general chemistry. The philosophy behind this manual is to (1) provide engaging experiments that tap into student curiosity, (2) emphasize topics that students find challenging in the general chemistry lecture course, and (3) create a laboratory environment that encourages students to "solve puzzles" or "play" with course content and not just "follow recipes." The laboratory manual represents a terrific opportunity to get students turned on to science while creating an environment that connects the relevance of the experiments to a greater understanding of their world. This manual has been written to provide instructors with tools that engage students, while providing important connections to the material covered in an atoms-first lecture course.

Important features of this laboratory manual:

- Early experiments focus on topics introduced early in an atoms-first course—properties of light and the use of light to study nanomaterials, line spectra and the structure of atoms, periodic trends, etc.
- Prelab or *foundation* exercises encourage students to understand the important concepts/calculations/procedures in the experiment through working together.
- Postlab or *reflection* exercises put the lab content in the context of a larger chemistry/science picture.
- Instructor's resources (found in the Instructor Resources on Connect®) provided with each experiment outline variations that can be incorporated to enrich the student experience or tailor the lab to the resources/equipment available at the institution.

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Chemistry

ATOMS FIRST

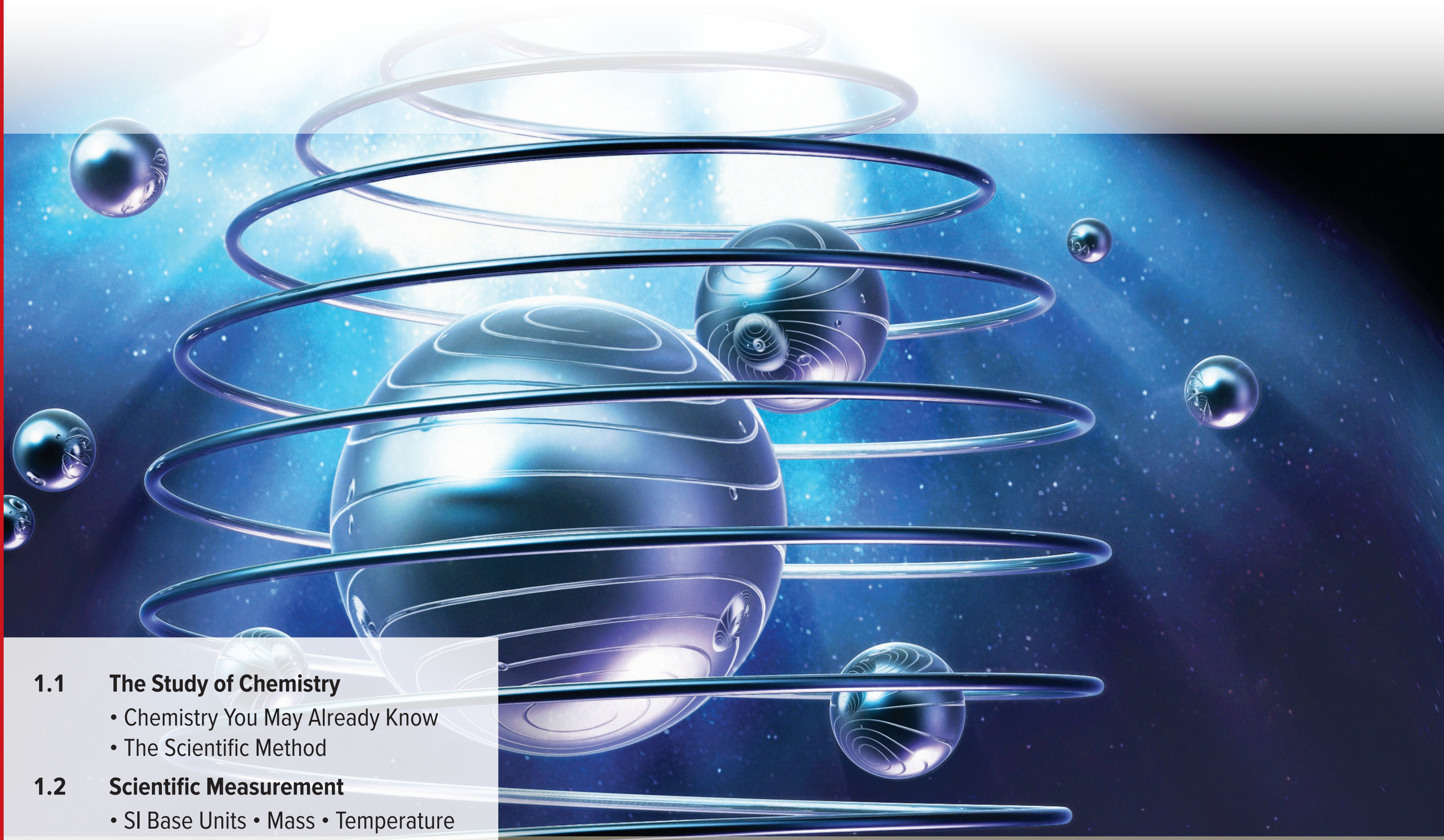
FIFTH EDITION

Julia Burdge
COLLEGE OF WESTERN IDAHO

Jason Overby
COLLEGE OF CHARLESTON

Chapter **1**

Chemistry: The Science of Change



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1.1 The Study of Chemistry
- Chemistry You May Already Know
- The Scientific Method

1.2 Scientific Measurement
- SI Base Units • Mass • Temperature
- Derived Units: Volume and Density

1.3 Uncertainty in Measurement
- Significant Figures
- Calculations with Measured Numbers
- Accuracy and Precision

1.4 Using Units and Solving Problems
- Conversion Factors
- Dimensional Analysis—Tracking Units

1.5 Classification of Matter
- States of Matter • Mixtures

1.6 The Properties of Matter
- Physical Properties • Chemical Properties • Extensive and Intensive Properties

AT ONLY a billionth of a degree above absolute zero, ultra-cold atomic gases are used to study the behaviors exhibited by simple quantum particles when they interact with one another. These quantum mechanical interactions ultimately give rise to observable phenomena such as high-temperature superconductivity and quantum magnetism. Research on atomic behavior under these conditions may facilitate new discoveries in fields ranging from materials science to quantum computing.

Before You Begin, Review These Skills

- Basic algebra
- Scientific notation [Appendix 1]

1.1 THE STUDY OF CHEMISTRY

Chemistry often is called the *central science* because knowledge of the principles of chemistry can facilitate understanding of other sciences, including physics, biology, geology, astronomy, oceanography, engineering, and medicine. ***Chemistry*** is the study of *matter* and the *changes* that matter undergoes. Matter is what makes up our bodies, our belongings, our physical environment, and in fact our entire universe. ***Matter*** is anything that has mass and occupies space.

Chemistry You May Already Know

You may already be familiar with some of the terms used in chemistry. Even if this is your first chemistry course, you may have heard of *molecules* and know them to be tiny pieces of a substance—much too tiny to see. Further, you may know that molecules are made up of *atoms,* even smaller pieces of matter. And even if you don't know what a *chemical formula* is, you probably know that H_2O is water. You may have used, or at least heard, the term *chemical reaction;* and you are undoubtedly familiar with a variety of common processes that are chemical reactions, such as those shown in Figure 1.1. Don't worry if you are not familiar with these terms; they are defined in the early chapters of this book.

The processes illustrated in Figure 1.1 are all things that you can observe at the *macroscopic level.* In other words, these processes and their results are visible to the human eye. In studying chemistry, you will learn to visualize and understand these same processes at the *submicroscopic* or *molecular level.*

Student Annotation: Macroscopic means *large enough to be seen with the unaided eye.*

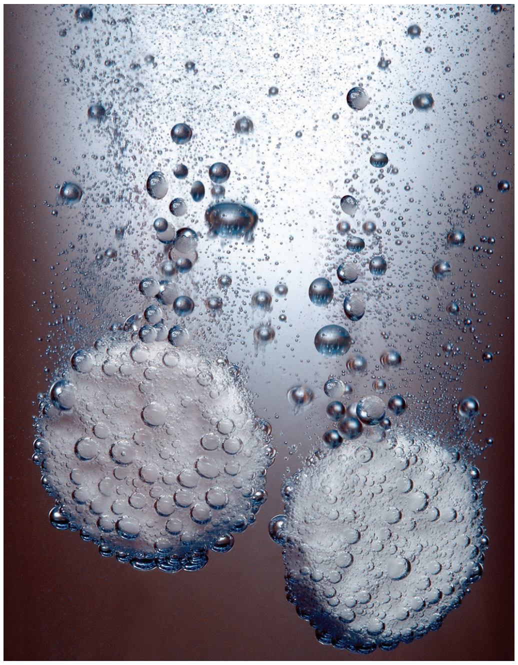
Student Annotation: Submicroscopic means *too small to be seen, even with a microscope.* Atoms and molecules are *submicroscopic*.

The Scientific Method

Advances in our understanding of chemistry (and other sciences) are the result of scientific experiments. Although scientists do not all take the same approach to experimentation, they must follow a set of guidelines known as the ***scientific method*** to have their results added to the larger body of knowledge within a given field. The flowchart in Figure 1.2 illustrates this basic process. The method begins with the gathering of data via observations and experiments. Scientists study these data and try to identify *patterns* or *trends.* When they find a pattern or trend, they may summarize their findings with a ***law,*** a concise verbal or mathematical statement of a reliable relationship between phenomena. Scientists may then formulate a ***hypothesis,*** a tentative explanation for their observations. Further experiments are designed to test the hypothesis. If experiments indicate that the hypothesis is incorrect, the scientists go back to the drawing board, try to come up with a different interpretation of their data, and formulate a new hypothesis. The new hypothesis will then be tested by experiment. When a hypothesis stands the test of extensive experimentation, it may evolve into a theory. A ***theory*** is a unifying principle that explains a body of experimental observations and the laws that are based on them. Theories can also be used to predict related phenomena, so theories are constantly being tested. If a theory is disproved by experiment, then it must be discarded or modified so that it becomes consistent with experimental observations.

(a)

(c)



(b)

(d)

Figure 1.1 Many familiar processes are chemical reactions: (a) The flame of a gas stove is the combustion of natural gas, which is primarily methane. (b) The bubbles produced when Alka-Seltzer dissolves in water are carbon dioxide, produced by a chemical reaction between two ingredients in the tablets. (c) The formation of rust is a chemical reaction that occurs when iron, water, and oxygen are all present. (d) Many baked goods "rise" as the result of a chemical reaction that produces carbon dioxide.

(a): Caspar Benson/fStop/Getty Images; (b): Colin Anderson Productions pty ltd/Stockbyte/Brand X Pictures/Getty Images; (c): Anthony Grote/Getty Images; (d): Sharon Dominick/iStock Exclusive/Getty Images

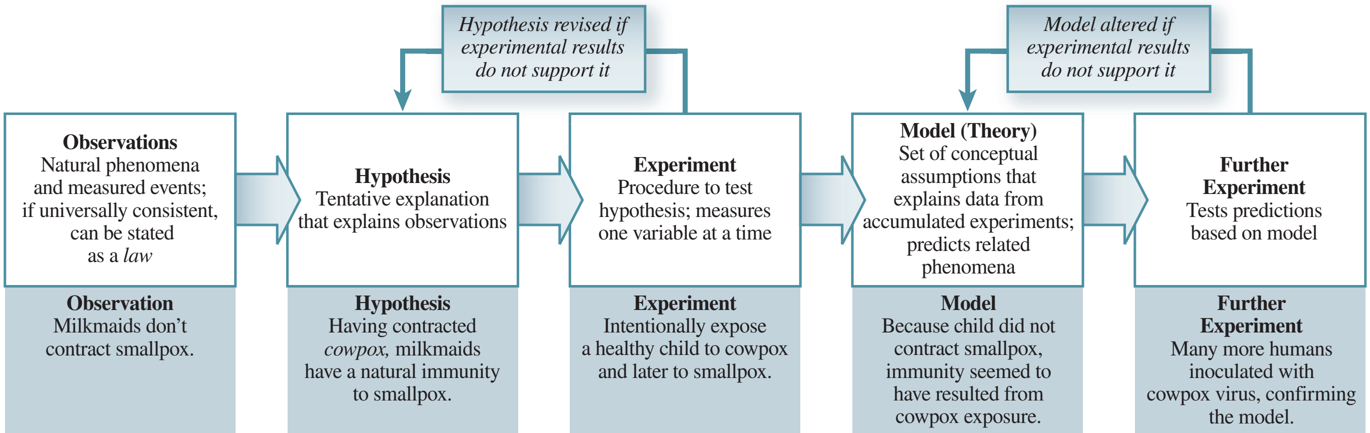


Figure 1.2 Flowchart of the scientific method.

A fascinating example of the use of the scientific method is the story of how smallpox was eradicated. Late in the eighteenth century, an English doctor named Edward Jenner observed that even during outbreaks of smallpox in Europe, milkmaids seldom contracted the disease. He reasoned that when people who had frequent contact with cows contracted *cowpox,* a similar but far less harmful disease, they developed a natural immunity to smallpox. He predicted that intentional exposure to the cowpox virus would produce the same immunity. In 1796, Jenner exposed an 8-year-old boy to the cowpox virus using pus from the cowpox lesions of an infected milkmaid. Six weeks later, he exposed the boy to the *smallpox* virus and, as Jenner had predicted, the boy did *not* contract the disease. Subsequent experiments using the same technique (later dubbed *vaccination* from the Latin *vacca* meaning *cow*) confirmed that immunity to smallpox could be induced.

A superbly coordinated international effort on the part of healthcare workers was successful in eliminating smallpox worldwide. In 1980, the World Health Organization declared smallpox officially eradicated. This historic triumph over a dreadful disease, one of the greatest medical advances of the twentieth century, began with Jenner's astute observations, inductive reasoning, and careful experimentation—the essential elements of the *scientific method.*

Until recently, almost everyone had a smallpox vaccine scar—usually on the upper arm.

Chris Livingston/Getty Images

Student Annotation: The last naturally occurring case was in 1977 in Somalia.

Thinking Outside the Box

Tips for Success in Chemistry Class

Success in a chemistry class depends largely on problem-solving ability. The Worked Examples throughout the text are designed to help you develop problem-solving skills. Each is divided into four steps: Strategy, Setup, Solution, and Think About It.

Strategy: Read the problem carefully and determine what is being asked and what information is provided. The Strategy step is where you should think about what skills are required and lay out a plan for solving the problem. Give some thought to what you expect the result to be. If you are asked to determine the number of atoms in a sample of matter, for example, you should expect the answer to be a whole number. Determine what, if any, units should be associated with the result. When possible, make a ballpark estimate of the magnitude of the correct result, and make a note of your estimate.

Setup: Next, gather the information necessary to solve the problem. Some of the information will have been given in the problem itself. Other information, such as equations, constants, and tabulated data (including atomic masses) should also be brought together in this step. Write down and label clearly all of the information you will use to solve the problem. Be sure to write appropriate units with each piece of information.

Solution: Using the necessary equations, constants, and other information, calculate the answer to the problem. Pay particular attention to the units associated with each number, tracking and canceling units carefully throughout the calculation. In the event that multiple calculations are required, label any intermediate results. If rounding is necessary, do it only after the last step in the calculation.

Think About It: Consider your calculated result and ask yourself whether or not it makes sense. Compare the units and the magnitude of your result with your ballpark estimate from the Strategy step. If your result does not have the appropriate units, or if its magnitude or sign is not reasonable, check your solution for possible errors. A very important part of problem solving is being able to judge whether the answer is reasonable. It is relatively easy to spot a wrong sign or incorrect units, but you should also develop a sense of *magnitude* and be able to tell when an answer is either way too big or way too small. For example, if a problem asks you to determine the length of a sheet of paper in millimeters and you calculate a number that is less than 1, you should know that it cannot be correct.

Each Worked Example is followed by three Practice Problems: A, B, and C. Practice Problem A, "Attempt," typically is a problem very similar to the Worked Example that can be solved using the same strategy. Practice Problems B and C, "Build" and "Conceptualize" generally test the same skills, but require approaches slightly different from the one used to solve the preceding Worked Example and Practice Problems.

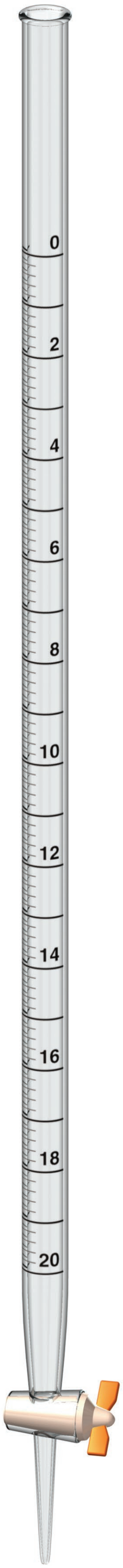
Finally, each section that contains one or more Worked Examples concludes with a Section Review. These consist of multiple-choice problems that enable you to assess your comprehension of the material in the section before moving on to the next section. Answers to Practice Problems A and B and to Section Review Questions can be found at the end of each chapter.

Regular use of the Worked Examples, Practice Problems, and Section Reviews in this text can help you develop an effective set of problem-solving skills. They can also help you assess whether you are ready to move on to the next new concepts. If you struggle with the Practice Problems or Section Reviews, then you probably need to review the corresponding Worked Example and the concepts that led up to it.

1.2 SCIENTIFIC MEASUREMENT

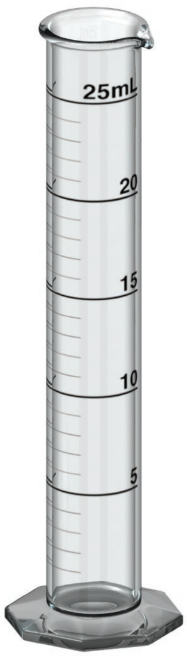
Scientists use a variety of devices to measure the properties of matter. A meterstick is used to measure length; a burette, pipette, graduated cylinder, and volumetric flask are used to measure volume (Figure 1.3); a balance is used to measure mass; and a thermometer is used to measure temperature. Properties that can be measured are called *quantitative* properties because they are expressed using numbers. When we express a measured quantity with a number, though, we must always include the appropriate unit; otherwise, the measurement is meaningless. For example, to say that the depth of a swimming pool is 3 is insufficient to distinguish between one that is 3 *feet* (0.9 meter) and one that is 3 *meters* (9.8 feet) deep. Units are essential to reporting measurements correctly.

The two systems of units with which you are probably most familiar are the *English system* (foot, gallon, pound, etc.) and the *metric system* (meter, liter, kilogram, etc.). Although there has been an increase in the use of metric units in the United States in recent years, English units still are used commonly. For many years, scientists



Burette
(a)

Volumetric pipette
(b)



Graduated cylinder
(c)

Volumetric flask
(d)

Figure 1.3 (a) A burette is used to measure the volume of a liquid that has been added to a container. A reading is taken before and after the liquid is delivered, and the volume delivered is determined by subtracting the first reading from the second. (b) A volumetric pipette is used to deliver a precise amount of liquid. (c) A graduated cylinder is used to measure a volume of liquid. It is less precise than the volumetric flask. (d) A volumetric flask is used to prepare a precise volume of a solution for use in the laboratory.

recorded measurements in metric units, but in 1960, the General Conference on Weights and Measures, the international authority on units, proposed a revised metric system for universal use by scientists. We use both metric and revised metric (SI) units in this book.

Student Annotation: According to the U.S. Metric Association (USMA), the United States is "the only significant holdout" with regard to adoption of the metric system. The other countries that continue to use traditional units are Myanmar (formerly Burma) and Liberia.

SI Base Units

The revised metric system is called the ***International System of Units*** (abbreviated SI, from the French *Système Internationale d'Unités*). Table 1.1 lists the seven SI base units. All other units of measurement can be derived from these base units. The ***SI unit*** for *volume,* for instance, is derived by cubing (raising to the power 3) the SI base unit for *length.* The prefixes listed in Table 1.2 are used to denote decimal fractions and decimal multiples of SI units. The use of these prefixes enables scientists to tailor the magnitude of a unit to a particular application. For example, the meter (m) is appropriate for describing the dimensions of a classroom, but the kilometer (km), 1000 m, is more appropriate for describing the distance between two cities. Units that you will encounter frequently in the study of chemistry include those for mass, temperature, volume, and density.

TABLE 1.1 Base SI Units

Base Quantity	Name of Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Student Annotation: Although historically defined using physical objects, the SI base units *meter* and *kilogram* have been redefined in terms of universal physical constants. The meter is now defined in terms of the speed of light in a vacuum [⏭ Section 3.2], and the kilogram is defined in terms of Planck's constant [⏭ Section 3.3].

TABLE 1.2 Prefixes Used with SI Units

Prefix	Symbol	Meaning	Example
Tera-	T	1×10^{12} (1,000,000,000,000)	1 teragram (Tg) = 1×10^{12} g
Giga-	G	1×10^{9} (1,000,000,000)	1 gigawatt (GW) = 1×10^{9} W
Mega-	M	1×10^{6} (1,000,000)	1 megahertz (MHz) = 1×10^{6} Hz
Kilo-	k	1×10^{3} (1,000)	1 kilometer (km) = 1×10^{3} m
Deci-	d	1×10^{-1} (0.1)	1 deciliter (dL) = 1×10^{-1} L
Centi-	c	1×10^{-2} (0.01)	1 centimeter (cm) = 1×10^{-2} m
Milli-	m	1×10^{-3} (0.001)	1 millimeter (mm) = 1×10^{-3} m
Micro-	μ	1×10^{-6} (0.000001)	1 microliter (μL) = 1×10^{-6} L
Nano-	n	1×10^{-9} (0.000000001)	1 nanosecond (ns) = 1×10^{-9} s
Pico-	p	1×10^{-12} (0.000000000001)	1 picogram (pg) = 1×10^{-12} g

Mass

Although the terms *mass* and *weight* often are used interchangeably, they do not mean the same thing. Strictly speaking, weight is the force exerted by an object or sample due to gravity. ***Mass*** is a measure of the amount of matter in an object or sample. Because gravity varies from location to location (gravity on the Moon is only about one-sixth that on Earth), the weight of an object varies depending on where it is measured. The mass of an object remains the same regardless of where it is measured. The SI base unit of mass is the kilogram (kg), but in chemistry the smaller gram (g) often is more convenient and is more commonly used:

$$1 \text{ kg} = 1000 \text{ g} = 1 \times 10^3 \text{ g}$$

Occasionally, the most convenient and/or commonly used unit for a particular application is not an SI unit. One such example is the atomic mass unit. The ***atomic mass unit (amu),*** as the name suggests, is used to express the masses of atoms—and other objects of similar size. In terms of SI units, the amu is equal to $1.6605378 \times 10^{-24}$ g or $1.6605378 \times 10^{-27}$ kg. Another example is the ***angstrom (Å),*** a measure of length that is equal to 1×10^{-10} m.

Temperature

Student Annotation: There is no such thing as a negative temperature on the Kelvin scale.

Student Annotation: The theoretical basis of the Kelvin scale has to do with the behavior of gases. [⏭ Chapter 11]

Student Annotation: Depending on the precision required, the conversion from degrees Celsius to kelvins often is done simply by adding 273, rather than 273.15.

There are two temperature scales used in chemistry: the *Celsius* scale and the *absolute* or *Kelvin* scale. Their units are the *degree Celsius* (°C) and the *kelvin* (K), respectively. The ***Celsius*** scale [named after Swedish physicist Ander Celsius (1701–1744)] was originally defined using the freezing point (0°C) and the boiling point (100°C) of pure water at sea level. As Table 1.1 shows, the SI base unit of temperature is the ***kelvin.*** Kelvin is also known as the *absolute* temperature scale because the lowest temperature theoretically possible is 0 K, a temperature referred to as *absolute zero.* No *degree* sign (°) is used to represent a temperature on the Kelvin scale.

Units of the Celsius and Kelvin scales are equal in magnitude, so *a degree Celsius* is equivalent to a *kelvin.* Thus, if the temperature of an object increases by 5°C, it also increases by 5 K. Absolute zero on the Kelvin scale is equivalent to −273.15°C on the Celsius scale. We use the following equation to convert a temperature from units of degrees Celsius to kelvins:

Equation 1.1 $$\text{K} = {}^\circ\text{C} + 273.15$$

Worked Example 1.1 illustrates conversions between these two temperature scales.

WORKED EXAMPLE 1.1

Normal human body temperature can range over the course of the day from about 36°C in the early morning to about 37°C in the afternoon. Express these two temperatures and the range that they span using the Kelvin scale.

Strategy Use Equation 1.1 to convert temperatures from the Celsius scale to the Kelvin scale. Then convert the range of temperatures from degrees Celsius to kelvins, keeping in mind that 1°C is equivalent to 1 K.

Setup Equation 1.1 is already set up to convert the two temperatures from degrees Celsius to kelvins. No further manipulation of the equation is needed. The range in kelvins will be the same as the range in degrees Celsius.

Solution 36°C + 273 = 309 K, 37°C + 273 = 310 K, and the range of 1°C is equal to a range of 1 K.

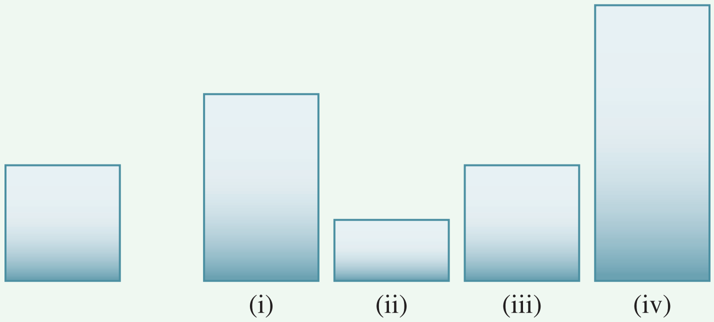
Think About It

Check your math and remember that converting a temperature from degrees Celsius to kelvins is different from converting a *difference* in temperature from degrees Celsius to kelvins.

Practice Problem ATTEMPT Express the freezing point of water (0°C), the boiling point of water (100°C), and the range spanned by the two temperatures using the Kelvin scale.

Practice Problem BUILD According to the website of the National Aeronautics and Space Administration (NASA), the average temperature of the universe is 2.7 K. Convert this temperature to degrees Celsius.

Practice Problem CONCEPTUALIZE If a single degree on the Celsius scale is represented by the rectangle on the left, which of the rectangles on the right best represents a single kelvin?



Outside of scientific circles, the Fahrenheit temperature scale is the one most used in the United States. Before the work of Daniel Gabriel Fahrenheit (German physicist, 1686–1736), there were numerous different, arbitrarily defined temperature scales, none of which gave consistent measurements. Accounts of exactly how Fahrenheit devised his temperature scale vary from source to source. In one account, in 1724, Fahrenheit labeled as 0° the lowest artificially attainable temperature at the time (the temperature of a mixture of ice, water, and a substance called *ammonium chloride*). Using a traditional scale consisting of 12 degrees, he labeled the temperature of a healthy human body as the twelfth degree. On this scale, the freezing point of water occurred at the fourth degree. For better resolution, each degree was further divided into eight smaller degrees. This convention makes the freezing point of water 32°F and normal body temperature 96°F. (Today we consider normal body temperature to be somewhat higher than 96°F.)

The boiling point of water on the Fahrenheit scale is 212°, meaning that there are 180 degrees (212°F minus 32°F) between the freezing and boiling points. This separation is considerably more degrees than the 100 between the freezing point and boiling point of water on the Celsius scale. Thus, the size of a degree on the Fahrenheit scale is only 100/180 or five-ninths of a degree on the Celsius scale. Equation 1.2 gives the relationship between temperatures on the Fahrenheit and Celsius scales.

$$\text{temperature in °F} = \frac{9\text{°F}}{5\text{°C}} \times (\text{temperature in °C}) + 32\text{°F} \qquad \textbf{Equation 1.2}$$

Worked Example 1.2 lets you practice converting from Celsius to Fahrenheit.

WORKED EXAMPLE 1.2

A body temperature above 39°C constitutes a high fever. Convert this temperature to the Fahrenheit scale.

Strategy We are given a temperature in degrees Celsius and are asked to convert it to degrees Fahrenheit.

Setup We use Equation 1.2:

$$\text{temperature in Fahrenheit} = \frac{9\text{°F}}{5\text{°C}} \times (\text{temperature in degrees Celsius}) + 32\text{°F}$$

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