CHEMISTRY atoms first

Second Edition

Julia Burdge

Jason Overby

Chemistry

ATOMS FIRST

SECOND EDITION

Julia Burdge
UNIVERSITY OF IDAHO

Jason Overby
COLLEGE OF CHARLESTON

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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)	Manganese	Mn	25	54.938045
Aluminum	Al	13	26.9815386	Meitnerium	Mt	109	(276)
Americium	Am	95	(243)	Mendelevium	Md	101	(258)
Antimony	Sb	51	121.760	Mercury	Hg	80	200.59
Argon	Ar	18	39.948	Molybdenum	Mo	42	95.94
Arsenic	As	33	74.92160	Neodymium	Nd	60	144.242
Astatine	At	85	(210)	Neon	Ne	10	20.1797
Barium	Ba	56	137.327	Neptunium	Np	93	(237)
Berkelium	Bk	97	(247)	Nickel	Ni	28	58.6934
Beryllium	Be	4	9.012182	Niobium	Nb	41	92.90638
Bismuth	Bi	83	208.98040	Nitrogen	N	7	14.0067
Bohrium	Bh	107	(272)	Nobelium	No	102	(259)
Boron	B	5	10.811	Osmium	Os	76	190.23
Bromine	Br	35	79.904	Oxygen	O	8	15.9994
Cadmium	Cd	48	112.411	Palladium	Pd	46	106.42
Calcium	Ca	20	40.078	Phosphorus	P	15	30.973762
Californium	Cf	98	(251)	Platinum	Pt	78	195.084
Carbon	C	6	12.0107	Plutonium	Pu	94	(244)
Cerium	Ce	58	140.116	Polonium	Po	84	(209)
Cesium	Cs	55	132.9054519	Potassium	K	19	39.0983
Chlorine	Cl	17	35.453	Praseodymium	Pr	59	140.90765
Chromium	Cr	24	51.9961	Promethium	Pm	61	(145)
Cobalt	Co	27	58.933195	Protactinium	Pa	91	231.03588
Copernicium	Cn	112	(285)	Radium	Ra	88	(226)
Copper	Cu	29	63.546	Radon	Rn	86	(222)
Curium	Cm	96	(247)	Rhenium	Re	75	186.207
Darmstadtium	Ds	110	(281)	Rhodium	Rh	45	102.90550
Dubnium	Db	105	(268)	Roentgenium	Rg	111	(280)
Dysprosium	Dy	66	162.500	Rubidium	Rb	37	85.4678
Einsteinium	Es	99	(252)	Ruthenium	Ru	44	101.07
Erbium	Er	68	167.259	Rutherfordium	Rf	104	(267)
Europium	Eu	63	151.964	Samarium	Sm	62	150.36
Fermium	Fm	100	(257)	Scandium	Sc	21	44.955912
Flerovium	Fl	114	(289)	Seaborgium	Sg	106	(271)
Fluorine	F	9	18.9984032	Selenium	Se	34	78.96
Francium	Fr	87	(223)	Silicon	Si	14	28.0855
Gadolinium	Gd	64	157.25	Silver	Ag	47	107.8682
Gallium	Ga	31	69.723	Sodium	Na	11	22.98976928
Germanium	Ge	32	72.64	Strontium	Sr	38	87.62
Gold	Au	79	196.966569	Sulfur	S	16	32.065
Hafnium	Hf	72	178.49	Tantalum	Ta	73	180.94788
Hassium	Hs	108	(270)	Technetium	Tc	43	(98)
Helium	He	2	4.002602	Tellurium	Te	52	127.60
Holmium	Ho	67	164.93032	Terbium	Tb	65	158.92535
Hydrogen	H	1	1.00794	Thallium	Tl	81	204.3833
Indium	In	49	114.818	Thorium	Th	90	232.03806
Iodine	I	53	126.90447	Thulium	Tm	69	168.93421
Iridium	Ir	77	192.217	Tin	Sn	50	118.710
Iron	Fe	26	55.845	Titanium	Ti	22	47.867
Krypton	Kr	36	83.798	Tungsten	W	74	183.84
Lanthanum	La	57	138.90547	Uranium	U	92	238.02891
Lawrencium	Lr	103	(262)	Vanadium	V	23	50.9415
Lead	Pb	82	207.2	Xenon	Xe	54	131.293
Lithium	Li	3	6.941	Ytterbium	Yb	70	173.04
Livermorium	Lv	116	(293)	Yttrium	Y	39	88.90585
Lutetium	Lu	71	174.967	Zinc	Zn	30	65.409
Magnesium	Mg	12	24.3050	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.

To the people who will always matter the most: Katie, Beau, and Sam.
Julia Burdge

To my wonderful wife, Robin, and daughters, Emma and Sarah.
Jason Overby

About the Authors

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. Julia has recently 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.

In her free time, Julia enjoys horseback riding with her daughter, fun Facebook conversations with her youngest son, and quiet time at home with Erik Nelson, her partner and best friend.

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, he enjoys boating, exercising, and cooking. He is also involved with USA Swimming as a certified stroke-and-turn official. He lives in South Carolina with his wife Robin and two daughters, Emma and Sarah.

Preface

The second edition of *Atoms First* by Burdge and Overby builds on the innovative approach established in the first edition—focusing on helping students construct the "story of chemistry," beginning with the atom. Changes are intended to make the story flow even better, while maintaining and expanding the student-centered pedagogical features that have made this book so popular with professors and students alike.

Worked Examples

Each Worked Example is now followed by three Practice Problems: Attempt, Build, and Conceptualize.

Practice Problem A (now called "Attempt") asks the student to apply the same Strategy to solve a problem very similar to the Worked Example. In general, the same Setup and series of steps in the Solution to the Worked Example can be used to solve Practice Problem A.

Practice Problem B (now called "Build") assesses mastery of the same skills as those required for the Worked Example and Practice Problem A, but everywhere possible, Practice Problem B employs a slightly different perspective and cannot be solved using the same Strategy used for the Worked Example and for Practice Problem A. This provides the student an opportunity to develop a strategy independently, and combats the tendency that some students have to want to apply a "template" approach to solving chemistry problems.

Practice Problem C (called "Conceptualize") provides an exercise that probes the student's conceptual understanding of the material. Practice Problems C are new to this edition and most employ concept and molecular art. Some Practice Problems Attempt and Build have been incorporated into the problems available in McGraw-Hill Connect and can be used in online homework and/or quizzing.

Worked Example 1.8

An average adult has 5.2 L of blood. What is the volume of blood in cubic meters?

Strategy There are several ways to solve a problem such as this. One way is to convert liters to cubic centimeters and then cubic centimeters to cubic meters.

Setup 1 L = 1000 cm^3 and 1 cm = 1×10^{-2} m. When a unit is raised to a power, the corresponding conversion factor must also be raised to that power in order for the units to cancel appropriately.

Solution

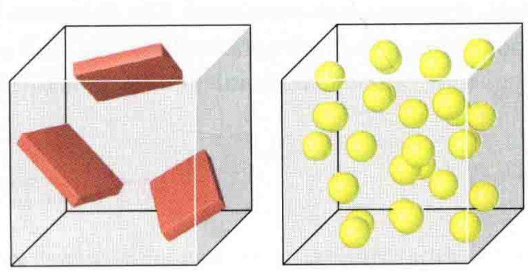
$$5.2 \text{ L} \times \frac{1000 \text{ cm}^3}{1 \text{ L}} \times \left(\frac{1 \times 10^{-2} \text{ m}}{1 \text{ cm}}\right)^3 = 5.2 \times 10^{-3} \text{ m}^3$$

Think About It
Based on the preceding conversion factors, 1 L = 1×10^{-3} m^3. Therefore, 5 L of blood would be equal to 5×10^{-3} m^3, which is close to the calculated answer.

Practice Problem ATTEMPT The density of silver is 10.5 g/cm^3. What is its density in kg/m^3?

Practice Problem BUILD The density of mercury is 13.6 g/cm^3. What is its density in pounds per cubic foot (lb/ft^3)? (1 lb = 453.6 g, 1 in = 2.54 cm)

Practice Problem CONCEPTUALIZE
Each diagram [(i) or (ii)] shows the objects contained within a cubical space. In each case, determine to the appropriate number of significant figures the number of objects that would be contained within a cubical space in which the length of the cube's edge is exactly five times that of the cube shown in the diagram.



(i) (ii)

New Pedagogy

A description of each Key Equation helps students identify and understand the purpose of each equation, including how to apply it, and when it is appropriate to do so.

Key Equations

1.1 $K = °C + 273.15$	Temperature in kelvins is determined by adding 273.15 to the temperature in Celsius. Often we simply add 273, depending on the precision with which the Celsius temperature is known.
1.2 $\text{temperature in °F} = \frac{9°F}{5°C} \times (\text{temperature in °C}) + 32°F$	Temperature in Celsius is used to determine temperature in Fahrenheit.
1.3 $d = \frac{m}{V}$	Density is the ratio of mass to volume. For liquids and solids, densities are typically expressed in g/cm^3.

All of the end-of-chapter problems outside of the Additional Problems are clearly categorized and grouped under the heading of Conceptual Problems or Computational Problems.

Questions and Problems

SECTION 1.1: THE STUDY OF CHEMISTRY

Review Questions

1.1 Define the terms *chemistry* and *matter.*
1.2 Explain what is meant by the scientific method.
1.3 What is the difference between a hypothesis and a theory?

Computational Problems

1.4 Classify each of the following statements as a hypothesis, law, or theory. (a) Beethoven's contribution to music would have been much greater if he had married. (b) An autumn leaf gravitates toward the ground because there is an attractive force between the leaf and Earth. (c) All matter is composed of very small particles.

1.5 Classify each of the following statements as a hypothesis, law, or theory. (a) The force acting on an object is equal to its mass times its acceleration. (b) The universe as we know it started with a big bang. (c) There are many civilizations more advanced than ours on other planets.

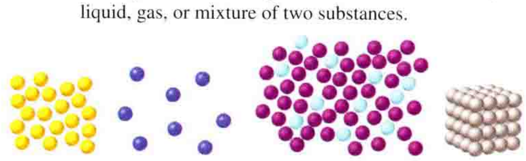
SECTION 1.2: CLASSIFICATION OF MATTER

Review Questions

1.6 Give an example for each of the following terms: (a) matter, (b) substance, (c) mixture.
1.7 Give an example of a homogeneous mixture and an example of a heterogeneous mixture.

Conceptual Problem

1.8 Identify each of the diagrams shown here as a solid, liquid, gas, or mixture of two substances.



(a) (b) (c) (d)

1.13 Determine which of the following properties are intensive and which are extensive: (a) length, (b) volume, (c) temperature, (d) mass.

Computational Problems

1.14 Determine whether the following statements describe chemical or physical properties: (a) Oxygen gas supports combustion. (b) Ingredients in antacids reduce acid reflux. (c) Water boils above 100°C in a pressure cooker. (d) Carbon dioxide is denser than air. (e) Uranium combines with fluorine to form a gas.

1.15 Classify the following as qualitative or quantitative statements, giving your reasons. (a) The sun is approximately 93 million miles from Earth. (b) Leonardo da Vinci was a better painter than Michelangelo. (c) Ice is less dense than water. (d) Butter tastes better than margarine. (e) A stitch in time saves nine.

1.16 Determine whether each of the following describes a physical change or a chemical change: (a) A soda loses its fizz and goes flat. (b) A bruise develops on a football player's arm and gradually changes color. (c) A pile of leaves is burned. (d) Frost forms on a windshield after a cold night. (e) Wet clothes are hung out to dry in the sun.

1.17 Determine whether each of the following describes a physical change or a chemical change: (a) The helium gas inside a balloon tends to leak out after a few hours. (b) A flashlight beam slowly gets dimmer and finally goes out. (c) Frozen orange juice is reconstituted by adding water to it. (d) The growth of plants depends on the sun's energy in a process called photosynthesis. (e) A spoonful of sugar dissolves in a cup of coffee.

SECTION 1.4: SCIENTIFIC MEASUREMENT

Review Questions

1.18 Name the SI base units that are important in chemistry, and give the SI units for expressing the following: (a) length, (b) volume, (c) mass, (d) time, (e) temperature.
1.19 Write the numbers represented by the following prefixes:

New and Updated Chapter Content

Chapter 2—A new section (2.4) has been added to introduce the concept of nuclear stability and provide students insight into why some nuclei are stable, and others are not.

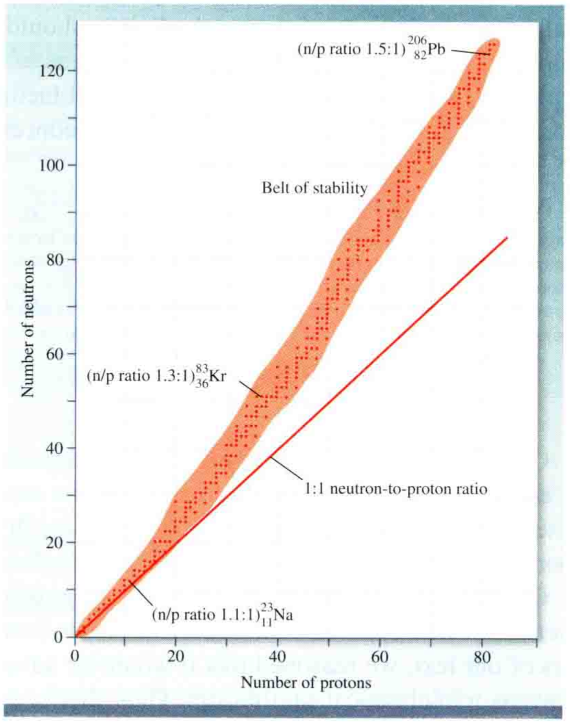
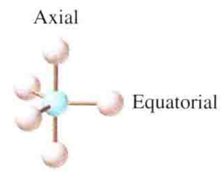


Figure 2.9 Plot of neutrons versus protons for various stable isotopes, represented by dots. The straight line represents the points at which the neutron-to-proton ratio is 1. The shaded area represents the belt of stability.

Chapter 6—A small section on Lewis acids and bases has been added in conjunction with Lewis structures. The importance of the Lewis concept of acids and bases—and the importance of molecular structure in determining acid-base properties are critical to a student's understanding of chemical reactivity; and we believe it is beneficial to introduce it early in this context. (More comprehensive coverage of Lewis acids and bases also remains in Chapter 16.)

Chapter 7—We have added a graphic to illustrate more clearly the axial and equatorial positions in trigonal bipyramidal structures.

> AB_5 molecules contain two different bond angles between adjacent bonds. The reason for this is that, unlike those in the other AB_x molecules, the positions occupied by bonds in a trigonal bipyramid are not all equivalent. The three bonds that are arranged in a trigonal plane are referred to as ***equatorial.*** The bond angle between any two of the three equatorial bonds is 120°. The two bonds that form an axis perpendicular to the trigonal plane are referred to as ***axial.***



> The bond angle between either of the axial bonds and any one of the equatorial bonds is 90°. (As in the case of the AB_6 molecule, the angle between any two A—B bonds that point in opposite

And, because we believe it is important to illustrate at every opportunity the importance of structure in determining function, intermolecular forces are now presented in Section 7.3, immediately following the material on molecular polarity. We view the early inclusion of this material in the context of structure as a logical extension of a true atoms-first approach. Further, introducing intermolecular forces earlier in the first half of the textbook allows more thorough development of this crucially important topic throughout the remaining chapters.

> ## 7.3 INTERMOLECULAR FORCES
>
> An important consequence of molecular polarity is the existence of attractive forces between neighboring molecules, which we refer to as ***intermolecular forces.*** We have already encountered an example of "intermolecular" forces in the form of ionic bonding [⏮ Section 5.3], where the mag-

Chapter 9—In Section 9.5, we now introduce the concept of pH in the context of acid-base chemistry and have students learn to perform relatively simple pH calculations for strong acids and bases. The benefits of introducing pH early are twofold: It requires students to become reacquainted with the logarithmic functions on their calculators in a relatively simple context, with straightforward conversions between hydronium ion concentration and pH. Later, in the context of equilibrium, proper use of these calculations should be a ready tool—rather than another layer of complication amid a chapter with a large volume of new material. A second benefit of introducing the pH scale and pH calculations early is that it facilitates the inclusion of more experiments in the laboratory portion of the course—a perennial concern for the atoms-first curriculum.

The pH Scale

The acidity of an aqueous solution depends on the concentration of hydronium ions $[H_3O^+]$. This concentration can range over many orders of magnitude, which can make reporting the numbers cumbersome. To describe the acidity of a solution, rather than report the molar concentration of hydronium ions, we typically use the more convenient pH scale. The ***pH*** of a solution is defined as the negative base-10 logarithm of the hydronium ion concentration (in mol/L).

$$pH = -\log [H_3O^+] \text{ or } pH = -\log [H^+] \qquad \textbf{Equation 9.5}$$

Student Annotation: Equation 9.5 converts numbers that can span an enormous range ($\sim 10^{-1}$ to 10^{-14}) to numbers generally ranging from ~1 to 14.

Chapter 12—With the movement of intermolecular forces to an earlier position in the textbook, this chapter is now more tightly focused on the nature of liquids and solids. We have rearranged the sections for what we believe is a more logical flow, and we have included a new section on the vapor pressure of solids. As before, the chapter culminates with phase changes and phase diagrams.

Chapter 14—In the first edition of Chemistry: Atoms First, Chapter 14 was Chemical Kinetics. However, in our vision of a true atoms-first approach, and as the result of discussion with users of our text, we reasoned that it would be advantageous to introduce thermodynamics as the predecessor of chemical equilibrium. Thus, thermodynamics is now presented earlier in the second half of the text. We believe that the earlier coverage of entropy and Gibbs free energy will enable students to develop a more robust understanding of the origins of chemical equilibrium.

TABLE 14.4 Predicting the Sign of ΔG Using Equation 14.10 and the Signs of ΔH and ΔS

When ΔH is	And ΔS is	ΔG will be	And the process is	Example
Negative	Positive	Negative	Always spontaneous	$2H_2O_2(aq) \longrightarrow 2H_2O(l) + O_2(g)$
Positive	Negative	Positive	Always nonspontaneous	$3O_2(g) \longrightarrow 2O_3(g)$
Negative	Negative	Negative when $T\Delta S < \Delta H$ Positive when $T\Delta S > \Delta H$	Spontaneous at low T Nonspontaneous at high T	$H_2O(l) \longrightarrow H_2O(s)$ (freezing of water)
Positive	Positive	Negative when $T\Delta S > \Delta H$ Positive when $T\Delta S < \Delta H$	Spontaneous at high T Nonspontaneous at low T	$2HgO(s) \longrightarrow 2Hg(l) + O_2(g)$

Chapter 15—This chapter remains focused solely on equilibrium as with the previous edition, but now we are able to present equilibrium from the standpoint of its thermodynamic underpinnings. In this way, we are able to provide an introduction to equilibrium and the development of the equilibrium constant along with the reaction quotient. Then we explore the intimate relationship between Gibbs free energy and the reaction quotient, and how Gibbs free energy ultimately is related to the equilibrium constant under standard-state conditions.

Chapter 18—With the movement of thermodynamics to an earlier chapter, the coverage of electrochemistry (Formerly Chapter 19) is now moved up. Because electrochemistry is also related to Gibbs free energy and ultimately the equilibrium constant, this provides logical continuity of the atoms-first approach with respect to equilibrium.

Chapter 19—Because we now have a sequential group of chapters relating thermodynamics and equilibrium, we have moved the kinetics chapter later in the book. One benefit of this reorganization is that students will be better prepared to understand the kinetics of reactions in which there is a fast initial step. Another benefit is that with kinetics in Chapter 19, this material is followed immediately by the nuclear chapter (Chapter 20), affording students the opportunity to put into timely practice their knowledge of first-order kinetics—in the context of nuclear decay processes.

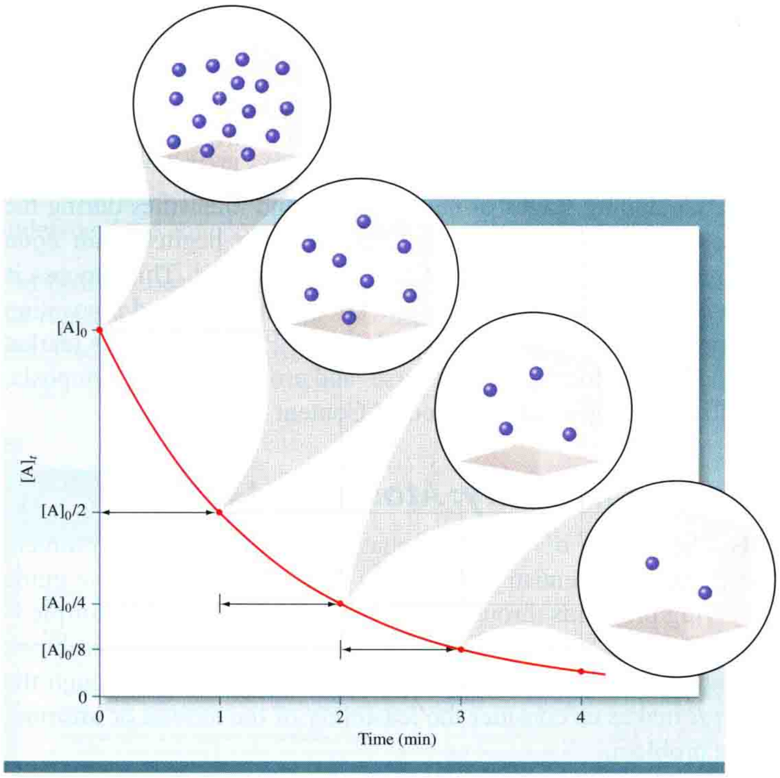
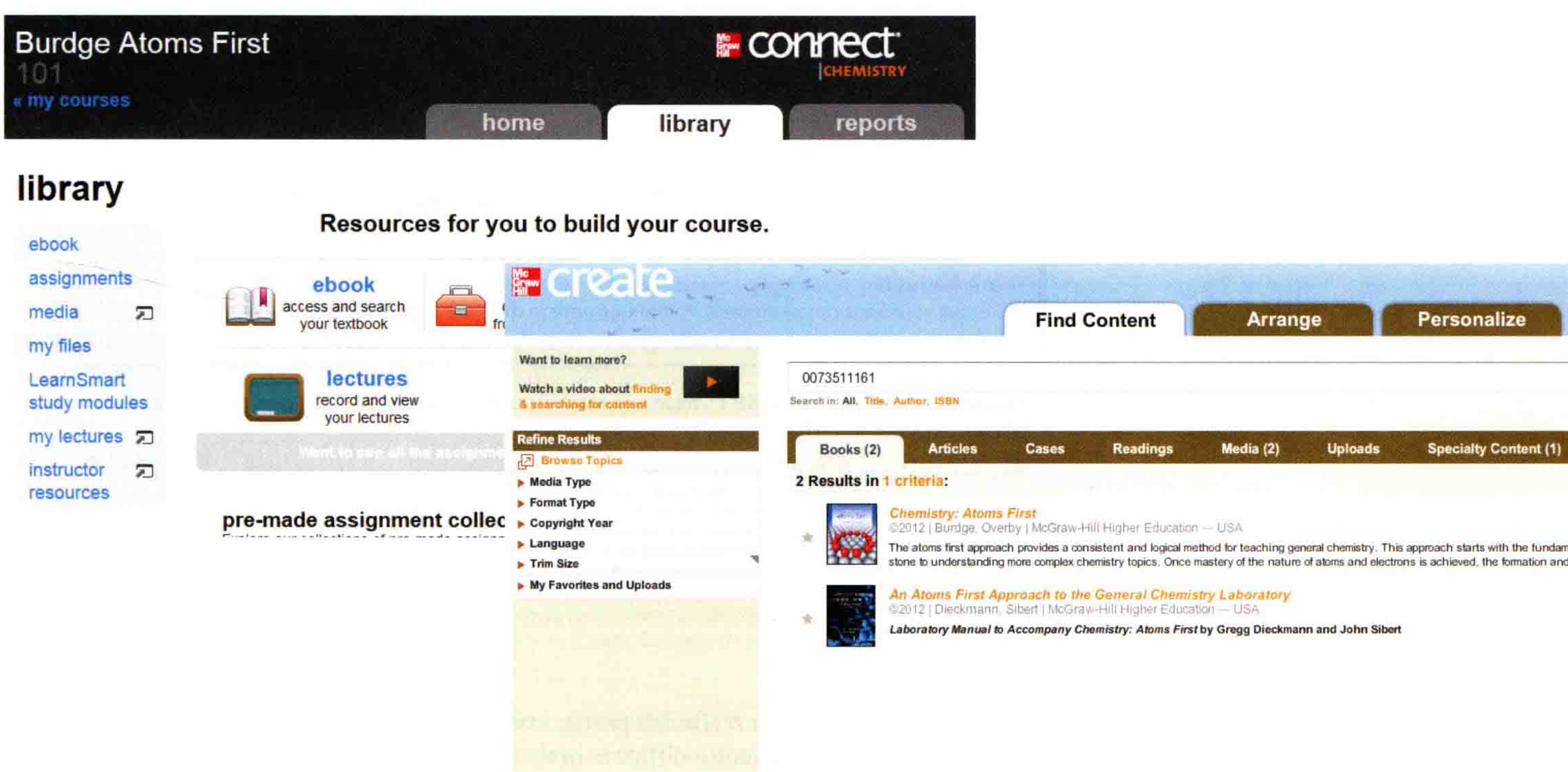


Figure 19.13 A plot of [A] versus time for the first-order reaction A ⟶ products. The half-life of the reaction is 1 min. The concentration of A is halved every half-life.

Chapters 23–25—In response to feedback from professors, we have reduced the size of the printed book by removing the chapter on chemistry of the nonmetals (formerly Chapter 23). Thus, Chapters 23 and 24 are now Organic Chemistry and Modern Materials, respectively. We realize, of course, that coverage of nonmetals is important material—and that some professors will still wish to present it and/or provide it to their students. Therefore, what was formerly Chapter 23 has been renumbered Chapter 25, Nonmetallic Elements and Their Compounds, and is available as a free digital download via the text's online learning center and/or the Instructor Resources in Connect. Chapter 25 is also available for text customization in McGraw-Hill Create.



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.

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.

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 $1.61 \times 10^{12}\text{ s}^{-1}$?

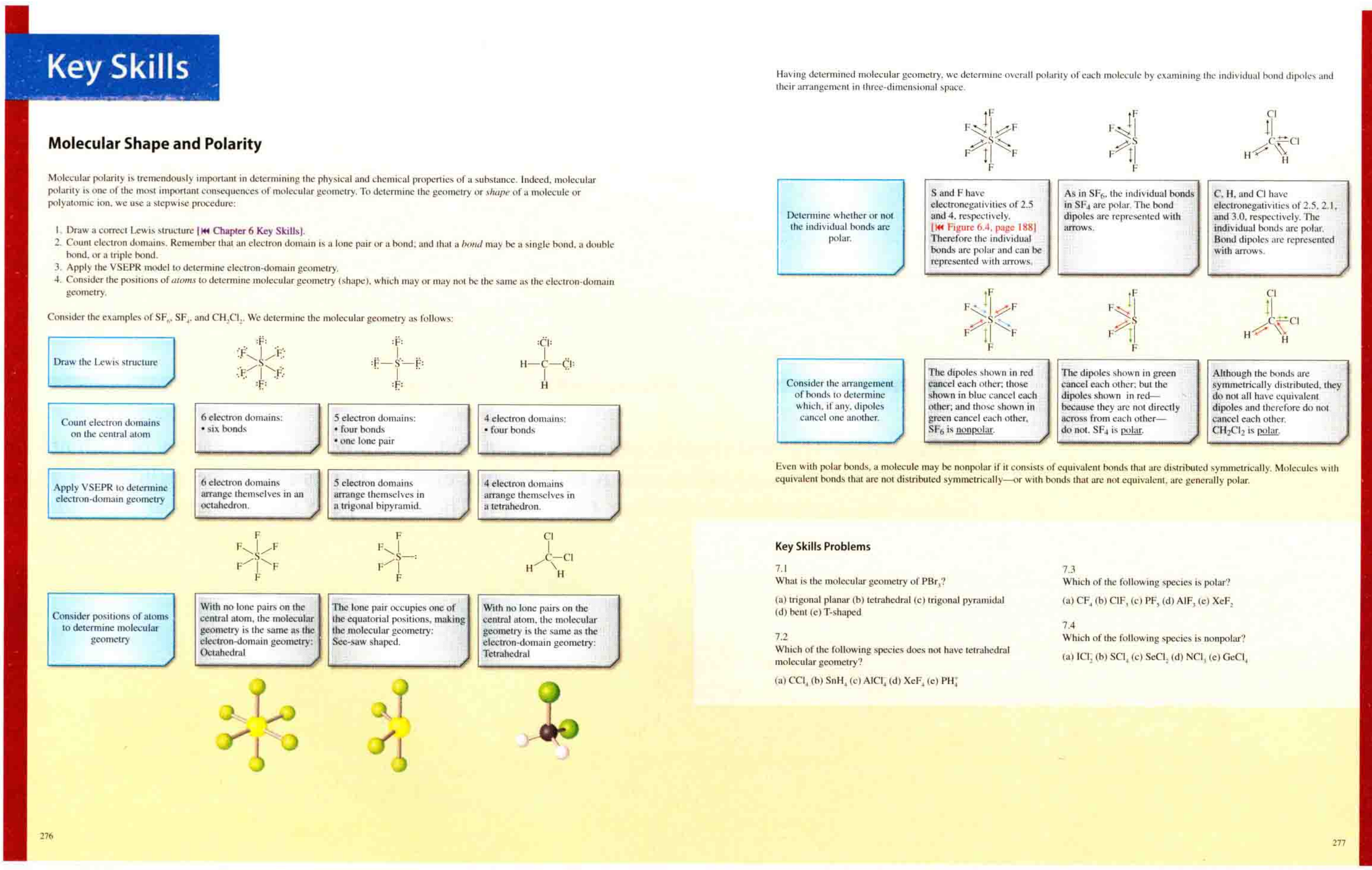
Practice Problem BUILD What is the frequency (in reciprocal seconds) of electromagnetic radiation with a wavelength of 1.03 cm?

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

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. Practice Problems C are new to this edition 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. Located between chapters, 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 188] 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?
(a) ICl_2^- (b) SCl_4 (c) $SeCl_2$ (d) NCl_3 (e) $GeCl_4$

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

Empirical Formulas

In addition to the methods we have learned so far, molecular substances can also be represented using ***empirical formulas.*** The word *empirical* means "from experience" or, in the context of chemical formulas, "from experiment." The empirical formula tells what elements are present in a molecule and in what whole-number ratio they are combined. For example, the molecular formula of hydrogen peroxide is H_2O_2, but its empirical formula is simply HO. Hydrazine, which has been used as a rocket fuel, has the molecular formula N_2H_4, so its empirical formula is NH_2. Although the ratio of nitrogen to hydrogen is 1:2 in both the molecular formula (N_2H_4) and the empirical for-

Student Annotation: The formulas of ionic compounds are usually *empirical* formulas.

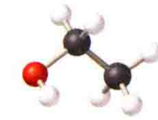
Thinking Outside the Box is an application providing a more in-depth look into a specific topic. *Learning Outcomes* provide a brief overview of the concepts the student should understand after reading the chapter. It's an opportunity to review areas that the student does not feel confident about upon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

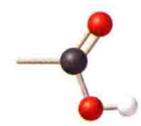
Ethanol, for example, the alcohol in alcoholic beverages, is ethane (C_2H_6) with one of the hydrogen atoms replaced by an alcohol (—OH) group. Its name is derived from that of *ethane*, indicating that it contains *two* carbon atoms.



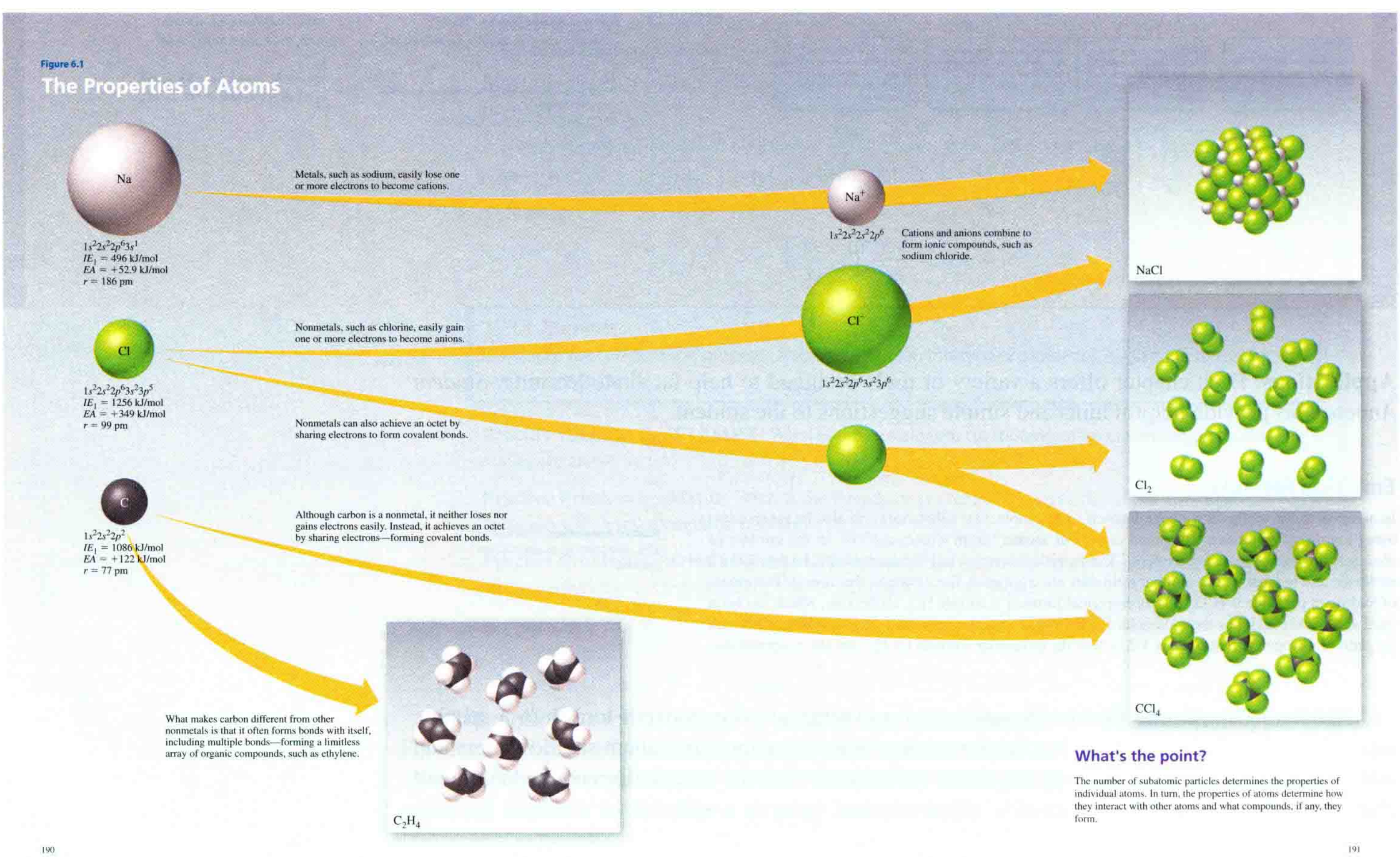
Ethanol

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 24.

TABLE 5.9 Organic Functional Groups

Name	Functional group	Molecular 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. These problems have been incorporated into the online homework and allow students to assess their understanding of the principles in each piece.

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 text-book. Each Visualizing Chemistry animation is noted by an icon.

Multi 7.8
Formation of pi bonds in ethylene and acetylene

Integration of Electronic Homework. You will find the *electronic homework* integrated into the text in numerous places. All Practice Problem B's are available in our electronic homework program for practice or assignments. A large number of the end-of-chapter problems and animations 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.

Julia Burdge
juliaburdge@hotmail.com

Jason Overby
overbyj@cofc.edu