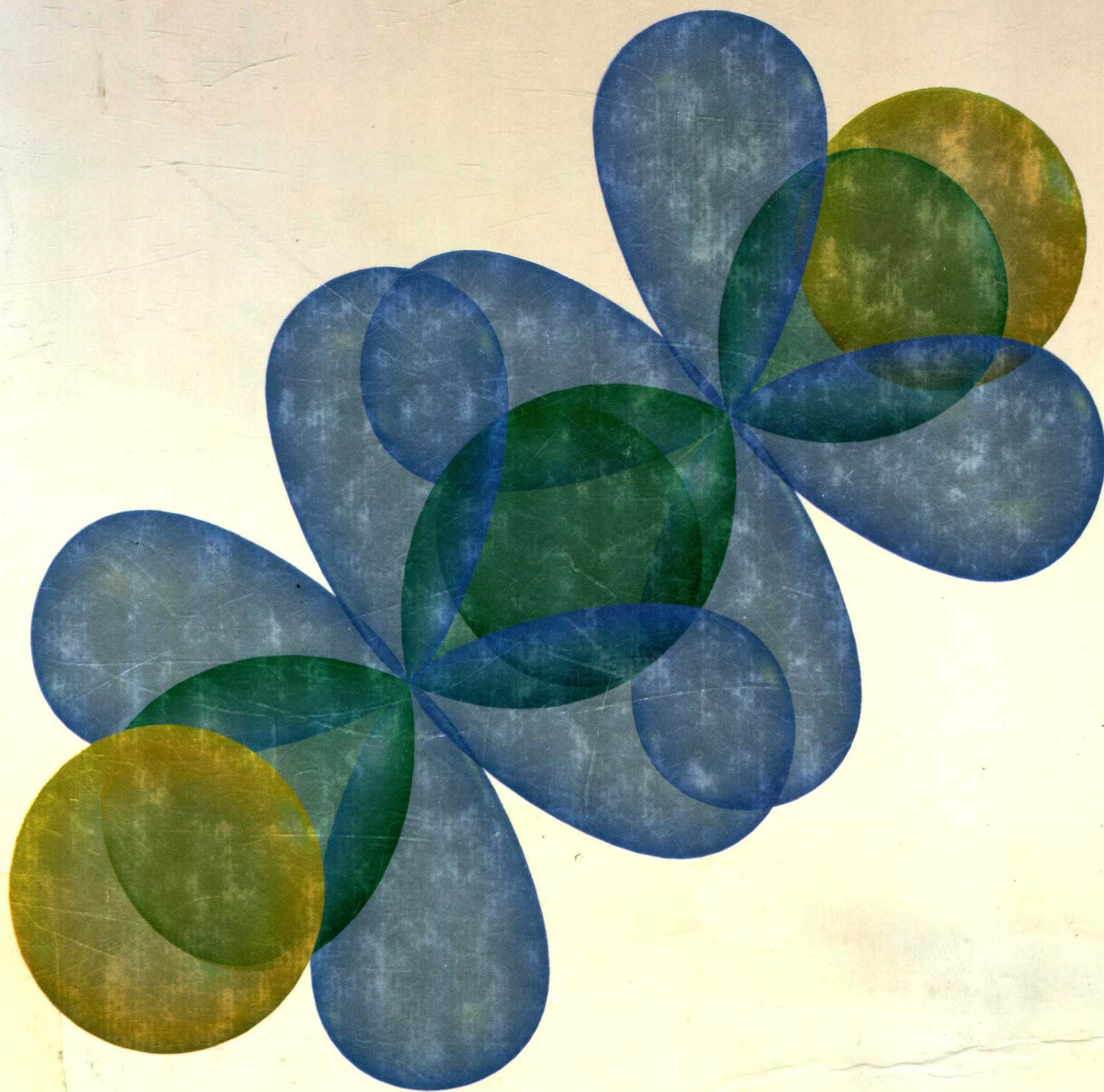


# Chemistry

Julia Burdge



# Chemistry

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JULIA BURDGE

With significant contributions  
from Raymond Chang



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## CHEMISTRY

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# Periodic Table of the Elements

Main group

Period number 1  
Group number 1A

1	1	H Hydrogen 1.008
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Atomic number	6	C	Symbol
Name	Carbon	12.01	Average atomic mass
An element			

Transitional metals

3B	4B	5B	6B	7B	8	9	10	11	12
3	4	5	6	7	8	9	10	11	12
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
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
71 Lu Lutetium 175.0	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
103 Lr Lawrencium (262)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (272)	112 — (285)

Main group

3A	4A	5A	6A	7A	8A
13	14	15	16	17	18
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
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
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
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
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)
113 — (284)	114 — (289)	115 — (288)	116 — (292)	117 — (294)	118 — (294)

Lanthanides 6	57 La Lanthanum 138.9	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
Actinides 7	89 Ac Actinium (227)	90 Th Thorium 232.0	91 Pa Protactinium 231.0	92 U Uranium 238.0	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)

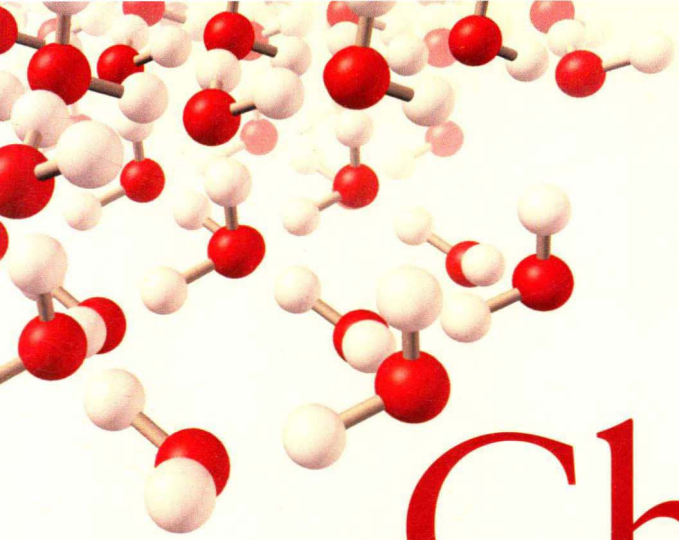


# List of the Elements with Their Symbols and Atomic Masses\*

Element	Symbol	Atomic Number	Atomic Mass <sup>†</sup>	Element	Symbol	Atomic Number	Atomic Mass <sup>†</sup>
Actinium	Ac	89	(227)	Mendelevium	Md	101	(258)
Aluminum	Al	13	26.9815386	Mercury	Hg	80	200.59
Americium	Am	95	(243)	Molybdenum	Mo	42	95.94
Antimony	Sb	51	121.760	Neodymium	Nd	60	144.242
Argon	Ar	18	39.948	Neon	Ne	10	20.1797
Arsenic	As	33	74.92160	Neptunium	Np	93	(237)
Astatine	At	85	(210)	Nickel	Ni	28	58.6934
Barium	Ba	56	137.327	Niobium	Nb	41	92.90638
Berkelium	Bk	97	(247)	Nitrogen	N	7	14.0067
Beryllium	Be	4	9.012182	Nobelium	No	102	(259)
Bismuth	Bi	83	208.98040	Osmium	Os	76	190.23
Bohrium	Bh	107	(264)	Oxygen	O	8	15.9994
Boron	B	5	10.811	Palladium	Pd	46	106.42
Bromine	Br	35	79.904	Phosphorus	P	15	30.973762
Cadmium	Cd	48	112.411	Platinum	Pt	78	195.084
Calcium	Ca	20	40.078	Plutonium	Pu	94	(244)
Californium	Cf	98	(251)	Polonium	Po	84	(209)
Carbon	C	6	12.0107	Potassium	K	19	39.0983
Cerium	Ce	58	140.116	Praseodymium	Pr	59	140.90765
Cesium	Cs	55	132.9054519	Promethium	Pm	61	(145)
Chlorine	Cl	17	35.453	Protactinium	Pa	91	231.03588
Chromium	Cr	24	51.9961	Radium	Ra	88	(226)
Cobalt	Co	27	58.933195	Radon	Rn	86	(222)
Copper	Cu	29	63.546	Rhenium	Re	75	186.207
Curium	Cm	96	(247)	Rhodium	Rh	45	102.90550
Darmstadtium	Ds	110	(281)	Roentgenium	Rg	111	(272)
Dubnium	Db	105	(262)	Rubidium	Rb	37	85.4678
Dysprosium	Dy	66	162.500	Ruthenium	Ru	44	101.07
Einsteinium	Es	99	(252)	Rutherfordium	Rf	104	(261)
Erbium	Er	68	167.259	Samarium	Sm	62	150.36
Europium	Eu	63	151.964	Scandium	Sc	21	44.955912
Fermium	Fm	100	(257)	Seaborgium	Sg	106	(266)
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	22.8976928
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	(269)	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
Lutetium	Lu	71	174.967	Yttrium	Y	39	88.90585
Magnesium	Mg	12	24.3050	Zinc	Zn	30	65.409
Manganese	Mn	25	54.938045	Zirconium	Zr	40	91.224
Meitnerium	Mt	109	(268)				

\*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



## ABOUT THE Author

**Julia Burdge** did most of her undergraduate work at Iowa State University and completed her degree in Chemistry at the University of South Florida in Tampa. Julia 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 who wanted to gain some experience teaching at the undergraduate level. In 2001, Julia relocated to the Honors College of Florida Atlantic University.

Julia lives in Florida with her family. Her personal interests include horseback riding with her children and involvement in the Pasco County Sheriff's Mounted Posse.



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



# Preface

Welcome to the exciting and dynamic world of chemistry! My desire to create a new general chemistry textbook grew out of my concern for the interests of students and faculty alike. Having taught general chemistry for many years and having helped new teachers and future faculty develop the skills necessary to teach general chemistry, I believe I have developed a distinct perspective on the common problems and misunderstandings that students encounter while learning the fundamental concepts of chemistry—and that professors encounter while teaching them. I believe that it is possible for a textbook to address many of these issues while conveying the wonder and possibilities that chemistry offers today. With this in mind, I have tried to write a text that balances the necessary fundamental concepts with engaging real-life examples and applications while utilizing a step-by-step problem-solving approach and an innovative art and media program.

## Modern Content—Solid Science

The world we live in is constantly changing, and the science of chemistry continues to expand and evolve to meet the challenges of our modern world. I have developed this new textbook to provide a solid grounding in the basic principles of chemistry while setting them within a context of up-to-date information that serves to capture and hold students' attention and prepare them for studies in a variety of fields. I have tried to connect the study of chemistry to the study of other sciences—including physical, biological, environmental, medical, and engineering. My goal is to help students build a solid conceptual understanding and to encourage mastery of chemical conventions including models, laws and equations, and such universally important principles as nomenclature, stoichiometry, measurement, and scale. While doing so I integrate coverage of organic chemistry, biochemistry, green chemistry, and other examples to enhance the relevance of fundamental principles.

Toward this end I have also placed my chapter on organic chemistry (Chapter 10) earlier than most texts. It is not an exhaustive chapter, but presents a handful of organic reactions, germane to applications presented in the book, in the context of bonding and molecular structure. One example is the reaction of the hydroxide ion with carbon dioxide to form the hydrogen carbonate ion. Examples such as this are intended to serve both as a functional introduction to organic chemistry and as reinforcement of bonding theories and the importance of hybridization, molecular polarity, and electron density. I believe that this approach will be beneficial to those who go on to take organic chemistry.

Each individual chapter outline serves as an advance organizer for key concepts and is followed by a set of chapter learning objectives—these are two of the many pedagogical devices designed to foster crucial organization and good study habits. Additionally, I have used my own teaching experiences to identify and address common student misconceptions. One way that I have done this is through the use of margin notes written specifically for the student. These notes include “bite-sized” additional information such as common pitfall alerts, analogies to clarify concepts, pertinent reminders, and alternative perspectives.

## 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 Worked Examples and Sample Problems throughout the text. Each **Sample Problem** is divided into four consistently applied steps:

1. **Strategy.** This step lays the basic framework for the problem. We begin by reading the problem thoroughly to determine exactly what is being asked. Next, we determine what skills are necessary, and lay out a plan for solving the problem. Where appropriate, we make a ballpark estimate of the magnitude of the correct result.
2. **Setup.** In this step we gather the necessary information for solving the problem, including information given within the problem itself, equations, constants, and tabulated data.
3. **Solution.** Using the information gathered in the second step, we now calculate the answer to the problem. A particular emphasis on attention to units is made during this step. The final step here is to ensure that the answer has the correct number of significant figures.
4. **Think About It.** At this stage we consider whether or not the result makes sense. In some cases, the Think About It section shows an alternate route to the same answer. In other cases, it may include information that illustrates the relevance of the problem.

After working through this problem-solving approach in the Sample Problems, there is always at least one **Practice Problem** to complete. This is very similar to the sample problem and can be solved using a similar strategy. Most Sample Problems also have a second Practice Problem that tests the same skills but requires an approach slightly different from the one used to solve the preceding Sample and Practice Problems. The regular use of the Sample Problems and Practice Problems in this text will help students develop an effective set of problem-solving skills and assess their readiness to move on to the next concept.

## Greater Relevance Through Modern Examples and Applications

I believe that the study of chemistry can be less daunting for students if they know how it applies to interesting, real-life examples. For this reason, I introduce each chapter with a brief and interesting story that relates the concepts in the chapter to something familiar. Examples include *Chemical Reactions and Chemotherapy* (Chapter 3) and *Lasers in Medicine* (Chapter 6). The **Applying What You've Learned** feature at the end of each chapter recalls the subject of the opening story and includes a multipart exercise requiring students to use several of the skills they have just learned. **Bringing Chemistry to Life** segments also work toward this goal, utilizing engaging narrative to further explore applications in the real world, such as *The Stoichiometry of Metabolism* (Chapter 3) or *Heat Capacity and Hypothermia* (Chapter 5). **Inquiry Boxes** always address a question of interest. These may tackle a topical subject such as *How Important Are Units?* (Chapter 1) but many also address important fundamental skills such as *How Do I Assign Oxidation Numbers?* (Chapter 4) or *How Am I Supposed to Remember All These Reactions?* (Chapter 3). The end-of-chapter Problem Sets also include a wide range of real-world problems and specific science, medical, and engineering applications. By using so many authentic, modern, real-world examples, I have placed the science of chemistry within a human context that will provide for a more engaging learning environment and lead to a fuller understanding of the subject matter and a greater capacity to retain the material.

## Greater Understanding Through Chemical Visualization

This text seeks to enhance student understanding through a variety of both unique and conventional visual techniques. A truly unique new element in this text is the inclusion of a distinctive new 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. As an example, Chapter 4 includes a Visualizing Chemistry section on *Preparing a Solution from a Solid*. Each Visualizing Chemistry feature concludes with a **What's the Point** box that emphasizes the take-away message.

The use of both **Macro-Micro Art** and **Three-Dimensional Art** build on the principle of breaking down the complex into simpler, more user-friendly concepts. Breaking down chemical processes into molecular-level figures makes it easier for students to grasp what is happening on an atomic level. The same theory of breaking down the complex is evident in the treatment of hybrid orbitals. Through experience, I have learned that this is often a difficult—yet fundamentally crucial—element to grasp. So, for example, I have broken down the process of hybridization



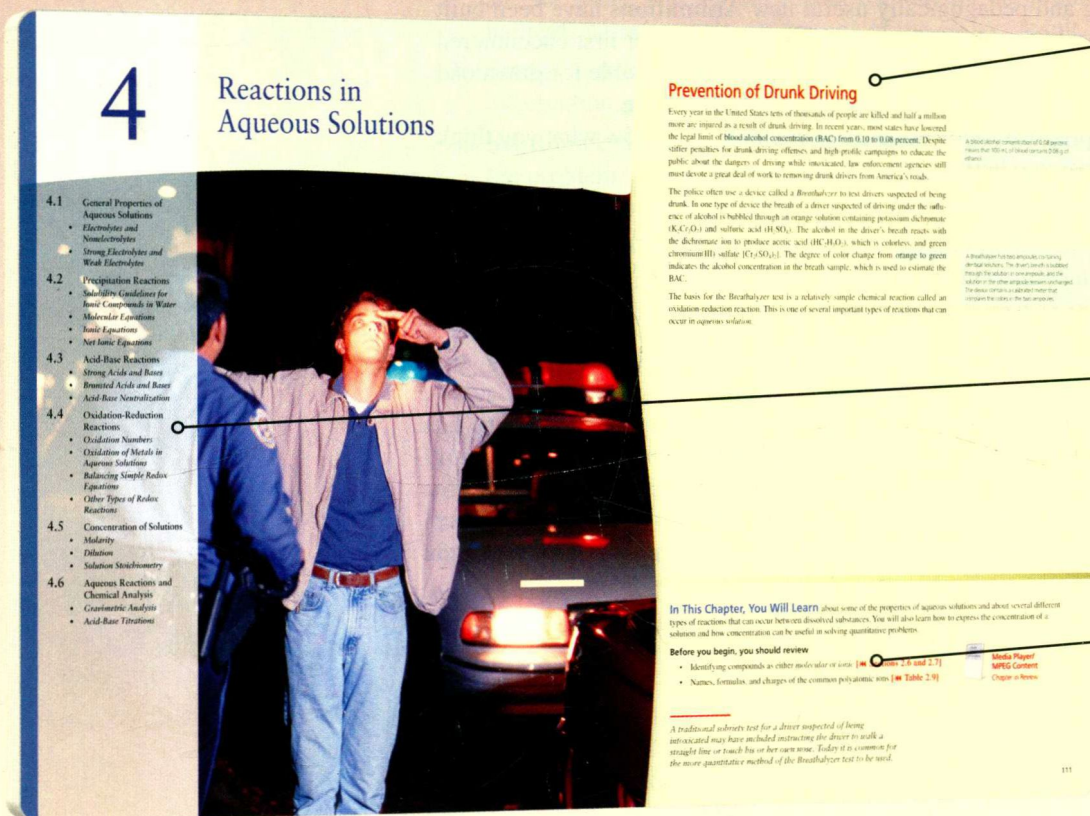
through a simple step-by-step visual treatment. **Flow Charts** and a variety of intertextual materials such as **Rewind** and **Fast Forward Buttons** and **Chapter Checkpoint** sections are meant to enhance student understanding and comprehension by reinforcing current concepts and connecting new concepts to those covered in other parts of the text.

In addition to the text itself, students will have access to innovative applications of new educational technologies. Captivating and pedagogically useful new **Animations** have been built based upon the textual art, providing additional reinforcement of subject matter first encountered in the textbook. **MPEG Files** of the Visualizing Chemistry pieces will be available for download as **Podcasts**, allowing for convenient viewing to foster increased comprehension.

For me, this remains a work in progress, and I encourage you to let me know what you think of my efforts and what I can do to serve you better.

Julia Burdge  
juliaburde@hotmail.com

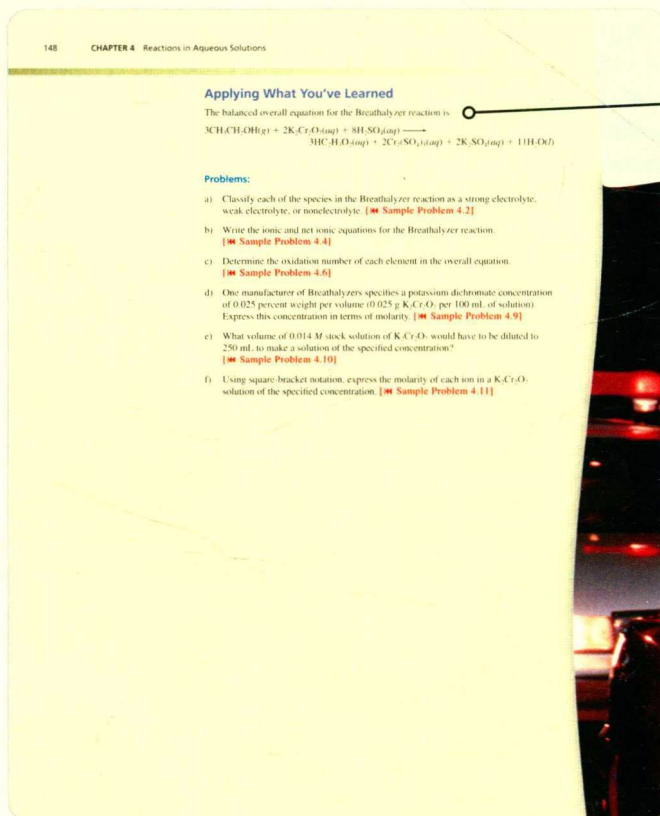
## Setting the Stage . . .



Set the stage for understanding concepts in this chapter with an engaging real-world situation.

Begin with the chapter outline to understand the big picture and focus on the main ideas.

Before reading this chapter, review important material from previous chapters.



Reinforce the chapter concepts by working the realistic situational problems found in the Applying What You've Learned sections at the end of each chapter.






## Problem Solving . . .

- Master these problem-solving skill steps to build a consistent strategy for success.

SECTION 4.3 Acid-Base Reactions 125

### Sample Problem 4.5

Milk of magnesia, an over-the-counter laxative, is a mixture of magnesium hydroxide ( $\text{Mg}(\text{OH})_2$ ) and water. Because  $\text{Mg}(\text{OH})_2$  is insoluble in water (see Table 4.3), milk of magnesia is a suspension rather than a solution. The undissolved solid is responsible for the milky appearance of the product. When acid such as  $\text{HCl}$  is added to milk of magnesia, the suspended  $\text{Mg}(\text{OH})_2$  dissolves, and the result is a clear, colorless solution. Write and balance the molecular equation, and then give the ionic and net ionic equations for this reaction.

(a) Milk of magnesia (b) Addition of  $\text{HCl}$  (c) Resulting clear, colorless solution

**Strategy** Determine the products of the reaction; then write and balance the equation. Remember that one of the reactants,  $\text{Mg}(\text{OH})_2$ , is a solid. Identify any strong electrolytes and rewrite the equation showing strong electrolytes as ions. Identify and cancel the spectator ions.

**Setup** Because this is an acid-base neutralization reaction, one of the products is water. The other product is a salt comprising the cation from the base,  $\text{Mg}^{2+}$ , and the anion from the acid,  $\text{Cl}^-$ . In order for the formula to be neutral, these ions combine in a 1:2 ratio, giving  $\text{MgCl}_2$  as the formula of the salt.

**Solution**

$$\text{Mg}(\text{OH})_2(s) + 2\text{HCl}(aq) \longrightarrow 2\text{H}_2\text{O}(l) + \text{MgCl}_2(aq)$$

Of the species in the molecular equation, only  $\text{HCl}$  and  $\text{MgCl}_2$  are strong electrolytes. Therefore, the ionic equation is

$$\text{Mg}(\text{OH})_2(s) + 2\text{H}^+(aq) + 2\text{Cl}^-(aq) \longrightarrow 2\text{H}_2\text{O}(l) + \text{Mg}^{2+}(aq) + 2\text{Cl}^-(aq)$$

$\text{Cl}^-$  is the only spectator ion. The net ionic equation is

$$\text{Mg}(\text{OH})_2(s) + 2\text{H}^+(aq) \longrightarrow 2\text{H}_2\text{O}(l) + \text{Mg}^{2+}(aq)$$

**Think About It** Make sure your equation is balanced and that you only show strong electrolytes as ions.  $\text{Mg}(\text{OH})_2$  is not shown as aqueous ions because it is insoluble.

**Practice Problem A** Write and balance the molecular equation and then give the ionic and net ionic equations for the neutralization reaction between  $\text{Ba}(\text{OH})_2(aq)$  and  $\text{HBr}(aq)$ .

**Practice Problem B** Write and balance the molecular equation and then give the ionic and net ionic equations for the neutralization reaction between  $\text{NH}_3(aq)$  and  $\text{H}_2\text{SO}_4(aq)$ .

### Checkpoint 4.3 Acid-Base Reactions

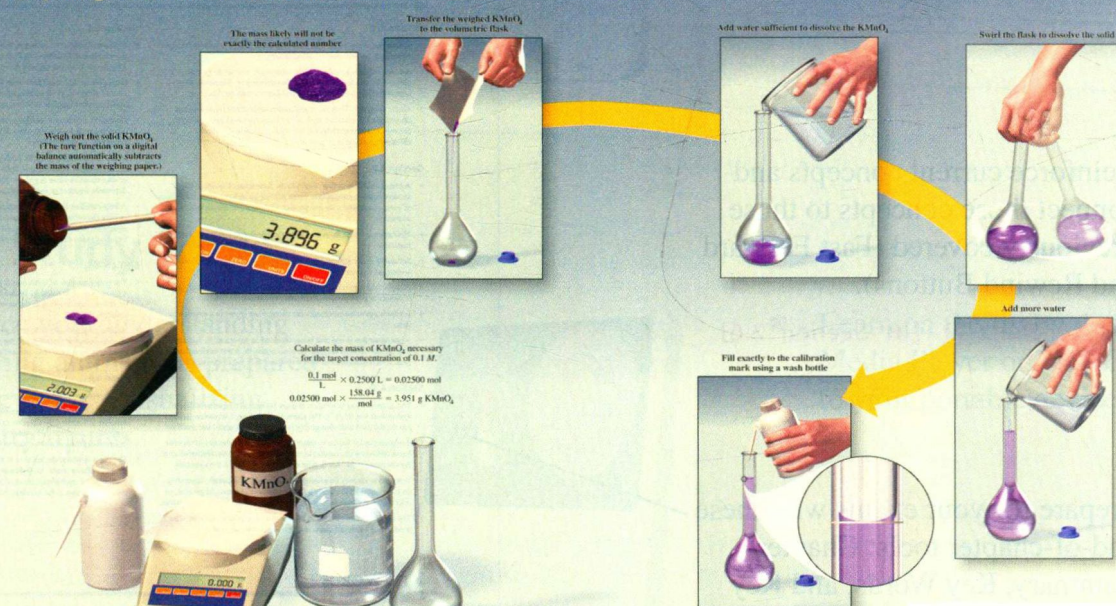
**4.3.1** Identify the Brønsted acid in the following equation:  
 $\text{H}_2\text{SO}_4(aq) + 2\text{NH}_3(aq) \longrightarrow (\text{NH}_4)_2\text{SO}_4(aq)$   
 a)  $\text{H}_2\text{SO}_4(aq)$   
 b)  $\text{NH}_3(aq)$   
 c)  $\text{H}_2\text{O}$   
 d)  $(\text{NH}_4)_2\text{SO}_4$   
 e) This equation does not contain a Brønsted acid.

**4.3.2** Identify the Brønsted base in the following equation:  
 $\text{HCl}(aq) + \text{NO}_2^-(aq) \longrightarrow \text{HNO}_2(aq) + \text{Cl}^-(aq)$   
 a)  $\text{HCl}(aq)$   
 b)  $\text{NO}_2^-(aq)$   
 c)  $\text{HNO}_2(aq)$   
 d)  $\text{Cl}^-(aq)$   
 e)  $\text{H}_2\text{O}$

## Visualizing . . .

- Understand chemical principles by comprehending the visual breakdown of important chemical concepts.

**Figure 4.9**  
Preparing a Solution from a Solid



**Step 1: Weigh out the solid  $\text{KMnO}_4$ .** (The tare function on a digital balance automatically subtracts the mass of the weighing paper.)

**Step 2: Transfer the weighed  $\text{KMnO}_4$  to the volumetric flask.**

**Step 3: Add water sufficient to dissolve the  $\text{KMnO}_4$ .**

**Step 4: Swirl the flask to dissolve the solid.**

**Step 5: Add more water.**

**Step 6: Fill exactly to the calibration mark using a wash bottle.**

**Calculate the mass of  $\text{KMnO}_4$  necessary for the target concentration of 0.1 M.**

$$0.1 \frac{\text{mol}}{\text{L}} \times 0.2500 \text{ L} = 0.02500 \text{ mol}$$

$$0.02500 \text{ mol} \times \frac{158.04 \text{ g}}{\text{mol}} = 3.951 \text{ g } \text{KMnO}_4$$

**Calculate the actual concentration of the solution.**

$$3.896 \text{ g } \text{KMnO}_4 \times \frac{1 \text{ mol}}{158.04 \text{ g}} = 0.024652 \text{ mol}$$

$$\frac{0.024652 \text{ mol}}{0.2500 \text{ L}} = 0.09861 \text{ M}$$

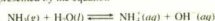
**What's the point?**

The goal is to prepare a solution of precisely known concentration, with that concentration being very close to the target concentration of 0.1 M. Note that because 0.1 is a specified number, it does not limit the number of significant figures in our calculations.



# Further Study Tools . . .

double arrow,  $\rightleftharpoons$ , in this equation and in two earlier equations, including denotes a reaction that occurs in both directions and does not result in all the acids being converted permanently to products (e.g., hydrogen ions and forward and reverse reactions both occur, and a state of *dynamic chemical* acid molecules ionize, the resulting ions have a strong tendency to recombine molecules again. Eventually, the ions produced by the ionization will be at the same rate at which they are produced, and there will be no further change in the number of molecules, hydrogen ions, or acetate ions. Because there is a stronger tendency for the molecules to recombine than for the molecules to ionize, at any given point in time, most acid exists as molecules that are not ionized (reactant). Only a very small form of hydrogen ions and acetate ions (products). If a weak base, while similar in many ways to the ionization of a weak acid, full explanation. Ammonia ( $\text{NH}_3$ ) is a common weak base. The ionization of represented by the equation



In a state of dynamic chemical equilibrium, or simply equilibrium, both forward and reverse reactions continue to occur. However, because they are occurring at the same rate, no net change is observed over time in the amounts of reactants or products. Chemical equilibrium is the subject of Chapters 15 to 17.

## Inquiry Application

### How Can I Tell if a Compound Is an Electrolyte?

While the experimental method described in Figure 4.1 can be useful, often you will have to characterize a compound as a non-electrolyte, a weak electrolyte, or a strong electrolyte just by looking at its formula. A good first step is to determine whether the compound is *ionic* or *molecular*.

An ionic compound contains a cation (which is either a metal ion or the ammonium ion) and an anion (which may be atomic or polyatomic). A binary compound that contains a metal and a nonmetal is almost always ionic. This is a good time to review the polyatomic anions in Table 2.8 (in Section 2.7). You will need to be able to recognize them in the formulas of compounds. Any ionic compound that dissolves in water is a strong electrolyte.

If a compound does not contain a metal cation or the ammonium cation, it is molecular. In this case, you will need to determine whether or not the compound is an acid. Acids generally can be recognized by the way their formulas are written, with the ionizable hydrogen written first.  $\text{HCl}$ ,  $\text{H}_2\text{SO}_4$ ,  $\text{HClO}_4$ , and  $\text{H}_3\text{PO}_4$  are acetic acid, carbonic acid, and phosphoric acid, respectively. Formulas of carboxylic acids, such as acetic acid, often are written with their ionizable hydrogen atoms *last* in order to keep the functional group together in the formula. Thus, either  $\text{HC}_2\text{H}_3\text{O}_2$  or  $\text{CH}_3\text{COOH}$  is correct for acetic acid. To make it easier to identify compounds as acids, in this chapter we will write all acid formulas with the ionizable H atom(s) first. If a compound is an acid, it is an electrolyte. If it is one of the acids listed in Table 4.1, it is a strong acid and therefore a strong electrolyte. Any acid not listed in Table 4.1 is a weak acid and therefore a weak electrolyte.

If a molecular compound is not an acid, you must then consider whether or not it is a weak base. Many weak bases are related to ammonia in that they consist of a nitrogen atom bonded to hydrogen and/or carbon atoms. Examples include methylamine ( $\text{CH}_3\text{NH}_2$ ), pyridine ( $\text{C}_5\text{H}_5\text{N}$ ), and hydrosulfuric acid ( $\text{HS}^-\text{NH}_2$ ). Weak bases are weak electrolytes.

If a molecular compound is neither an acid nor a weak base, it is a nonelectrolyte.

#### Sample Problem 4.2

Classify each of the following compounds as a nonelectrolyte, a weak electrolyte, or a strong electrolyte: (a) methanol ( $\text{CH}_3\text{OH}$ ), (b) sodium hydroxide ( $\text{NaOH}$ ), (c) ethylamine ( $\text{C}_2\text{H}_5\text{NH}_2$ ), and (d) hydrofluoric acid ( $\text{HF}$ ).

**Strategy** Classify each compound as ionic or molecular. Soluble ionic compounds are strong electrolytes. Classify each molecular compound as an acid, base, or neither. Molecular compounds that are neither acids nor bases are nonelectrolytes. Molecular compounds that are acids are weak electrolytes. Finally, classify acids as either strong or weak. Strong acids are strong electrolytes, and weak acids are weak electrolytes.

**Setup** (a) Methanol contains neither a metal cation nor the ammonium ion. It is therefore molecular. Its formula does not begin with H, so it is probably not an acid, and it does not contain a nitrogen atom, so it is not a weak base. Molecular compounds that are neither acids nor bases are nonelectrolytes. (b) Sodium hydroxide contains a metal cation ( $\text{Na}^+$ ) and is therefore ionic. It is also one of the strong bases.

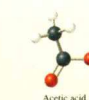
(c) Ethylamine contains no cations and is therefore molecular. It is also a nitrogen-containing base, similar to ammonia. (d) Hydrofluoric acid is, as its name suggests, an acid. However, it is not on the list of strong acids in Table 4.1 and is, therefore, a weak acid.

#### Solution

- (a) Nonelectrolyte  
(b) Strong electrolyte  
(c) Weak electrolyte  
(d) Weak electrolyte

**Practice Problem A** Identify the following compounds as nonelectrolytes, weak electrolytes, or strong electrolytes: ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ), nitrous acid ( $\text{HNO}_2$ ), and sodium bicarbonate ( $\text{NaHCO}_3$ , also known as *baking soda*).

**Practice Problem B** Identify the following compounds as nonelectrolytes, weak electrolytes, or strong electrolytes: phosphoric acid ( $\text{H}_3\text{PO}_4$ ), hydrogen peroxide ( $\text{H}_2\text{O}_2$ ), and ammonium sulfate ( $[\text{NH}_4]_2\text{SO}_4$ ).



Acetic acid

**Think About It** Make sure that you have correctly identified compounds that are ionic and compounds that are molecular. Remember that strong acids are strong electrolytes, weak acids and weak bases are weak electrolytes, and strong bases are strong electrolytes (by virtue of their being soluble ionic compounds). Molecular compounds, with the exceptions of acids and weak bases, are nonelectrolytes.

■ Use the helpful hints and simple suggestions found in the margin to gain further comprehension.

■ Delve more deeply into a concept by reading these engaging applications.

## Bringing Chemistry to Life

174 CHAPTER 5 Thermodynamics

**Think About It** The units cancel properly to give appropriate units for heat capacity. Moreover,  $\Delta T$  is a negative number because the temperature of the pellet decreases.

From Equation 5.14, we have

$$-3242.6 \text{ J} = C_{\text{pellet}} \times (-57.1^\circ\text{C})$$

This,

$$C_{\text{pellet}} = 57 \text{ J/}^\circ\text{C}$$

**Practice Problem A** What would the final temperature be if the pellet from Sample Problem 5.5, usually at  $95^\circ\text{C}$ , were dropped into a 218-g sample of water, initially at  $23.8^\circ\text{C}$ ?

**Practice Problem B** What mass of water could be warmed from  $23.8^\circ\text{C}$  to  $46.3^\circ\text{C}$  by the pellet in Sample Problem 5.5 initially at  $116^\circ\text{C}$ ?

### Bringing Chemistry to Life

#### Heat Capacity and Hypothermia

Like a warm metal pellet, the human body loses heat when it is immersed in cold water. Because we are warm-blooded animals, our body temperature is maintained at around  $37^\circ\text{C}$ . The human body is about 70 percent water by mass and water has a very high specific heat, so fluctuations in body temperature normally are very small. An air temperature of  $25^\circ\text{C}$  (often described as "room temperature") feels warm to us because air has a small specific heat (about  $1 \text{ J/g} \cdot ^\circ\text{C}$ ) and a low density. Consequently, very little heat is lost from the body to the surrounding air. The situation is drastically different if the body is immersed in water at  $25^\circ\text{C}$ . The heat lost by the human body when immersed in water can be thousands of times greater than that lost to air of the same temperature.

Hypothermia occurs when the body's mechanisms for producing and conserving heat are exceeded by loss of heat to the surroundings. Although hypothermia is dangerous and potentially deadly, there are certain circumstances under which it may actually be beneficial. A colder body temperature slows down all the normal biochemical processes, reducing the brain's need for oxygen, and prolonging the time period during which resuscitation efforts can be effective. Occasionally a near drowning victim who was submerged for a long period of time. These victims are usually small children who were submerged in icy water. The small size and, therefore, small heat capacity of a child allows for rapid cooling and may afford some protection from hypoxia—the lack of oxygen that causes death in drowning victims.



Hypothermia routinely is induced in patients undergoing open heart surgery, drastically reducing the body's need for oxygen. Under these conditions, the heart can be stopped for the duration of the surgery.

KEY WORDS 149

## CHAPTER SUMMARY

### Section 4.1

- A solution is a homogeneous mixture consisting of a *solvent* and one or more dissolved species called *solutes*.
- An *electrolyte* is a compound that dissolves in water to give an electrically conducting solution. *Nonelectrolytes* dissolve to give nonconducting solutions. Acids and bases are electrolytes.
- Electrolytes may be ionic or molecular. Ionic electrolytes undergo *dissociation* in solution; molecular electrolytes undergo *ionization*. Strong electrolytes dissociate (or ionize) completely. Weak electrolytes ionize only partially.

### Section 4.2

- A *precipitation reaction* results in the formation of an insoluble product called a *precipitate*. From general guidelines about solubilities of ionic compounds, we can predict whether a precipitate will form in a reaction.
- Hydration* is the process in which water molecules surround solute particles.
- Solubility* is the amount of solute that will dissolve in a specified amount of a given solvent at a specified temperature.
- A *molecular equation* represents a reaction as though none of the reactants or products has dissociated or ionized.
- An *ionic equation* represents the strong electrolytes in a reaction as ions.
- A *spectator ion* is one that is not involved in the reaction. Spectator ions appear on both sides of the ionic equation. A *net ionic equation* is an ionic equation from which spectator ions have been eliminated.

### Section 4.3

- The hydrogen ion in solution is more realistically represented as the *hydronium ion* ( $\text{H}_3\text{O}^+$ ). The terms *hydrogen ion*, *hydronium ion*, and *proton* are used interchangeably in the context of acid-base reactions.
- Arrhenius acids* ionize in water to give  $\text{H}^+$  ions, whereas *Arrhenius bases* ionize (or dissociate) in water to give  $\text{OH}^-$  ions. *Bronsted acids* donate protons ( $\text{H}^+$  ions), whereas *Bronsted bases* accept protons.
- Bronsted acids may be *monoprotic*, *diprotic*, or *triprotic*, depending on the number of ionizable hydrogen atoms they have. In general, an acid with more than one ionizable hydrogen atom is called *polyprotic*.
- The reaction of an acid and a base is a *neutralization reaction*. The products of a neutralization reaction are water and a salt.

## KEY WORDS

Activity series, 130	Concentration, 136	Endpoint, 144	Hydronium ion, 123
Arrhenius acid, 123	Dilution, 137	Equivalence point, 144	Indicator, 144
Arrhenius base, 123	Diprotic acid, 123	Gravimetric analysis, 142	Ionic equation, 120
Base, 112	Displacement reaction, 130	Half-reaction, 127	Ionization, 112
Bronsted acid, 123	Disproportionation reaction, 134	Half-reaction method, 131	Molar concentration, 136
Bronsted base, 123	Dissociation, 112	Hydration, 117	Molarity, 136
Combustion, 134	Electrolyte, 112	Hydrogen displacement, 133	Molecular equation, 119

■ Reinforce current concepts and connect those concepts to those previously covered (Fast Forward and Rewind Buttons).

[▶▶ Appendix 1] [◀◀ Section 2.6]

■ Prepare for your exams with these end-of-chapter tools: Chapter Summary, Key Words, and Key Equations.



## Test Your Knowledge . . .

- Immediately check your understanding after you answer the questions found in the Section Checkpoints.
- Master the chapter content by solving the Questions and Problems found at the end of each chapter! The Questions and Problems are organized by section for easy reference.
- Solve these problems before taking standardized pre-professional examinations.

### Checkpoint 4.1 General Properties of Aqueous Solutions

- 4.1.1** Soluble ionic compounds are
- always nonelectrolytes
  - always weak electrolytes
  - always strong electrolytes
  - never strong electrolytes
  - sometimes nonelectrolytes
- 4.1.2** Soluble molecular compounds are
- always nonelectrolytes
  - always weak electrolytes
  - always strong electrolytes
  - never strong electrolytes
  - sometimes strong electrolytes
- 4.1.3** Which of the following compounds is a weak electrolyte?
- $\text{LiCl}$
  - $(\text{C}_2\text{H}_5)_3\text{NH}$
  - $\text{KNO}_3$
  - $\text{NaI}$
  - $\text{HNO}_3$
- 4.1.4** Which of the following compounds is a strong electrolyte?
- $\text{HF}$
  - $\text{H}_2\text{CO}_3$
  - $\text{NaF}$
  - $\text{NH}_3$
  - $\text{H}_2\text{O}$

### PRE-PROFESSIONAL PRACTICE EXAM PROBLEMS: VERBAL REASONING

English writer and essayist Lady Mary Wortley Montagu (1689–1762) traveled extensively and was fascinated by the customs in other countries. While in Turkey, she observed the practice of “engrafting” wherein people were inoculated against smallpox by intentional exposure to a mild form of the disease. She was so convinced of the efficacy and the safety of engrafting that she had both of her children inoculated. She herself had survived smallpox as a child. Lady Montagu campaigned for the practice when she returned to England, and despite opposition from doctors and religious leaders, inoculation came into common use. It remained the primary defense against the scourge of smallpox for decades—until Jenner developed the practice of vaccination.

- The main point of the passage is that:
  - Lady Montagu survived smallpox as a child.
  - Lady Montagu brought the practice of engrafting from Turkey to England.
  - Doctors in eighteenth-century England were opposed to the practice of engrafting.
  - Jenner developed the practice of vaccination.

- Based on the passage, Lady Montagu was most likely:
  - a doctor.
  - Turkish.
  - severely scarred by smallpox.
  - a member of a prominent British family.

- The author refers to Lady Montagu having survived smallpox in order to:
  - explain why Lady Montagu was fascinated by the practice of engrafting.
  - compare Lady Montagu to the doctors and religious leaders in England.
  - explain why Lady Montagu herself did not undergo the engrafting procedure.
  - emphasize Lady Montagu's fascination with other cultures.
- Based on the passage, the author most likely thinks that Lady Montagu was:
  - educated and influential.
  - inconsequential in the prevention of smallpox in England.
  - trained in science and medicine.
  - married to the British ambassador to Turkey.

### ANSWERS TO IN-CHAPTER MATERIALS

#### Practice Problems

**1.1A** 773 K and 373 K, range = 100 K; **1.1B** 270.5°C, 1.2 233°C; **1.3A** (a) 14 g/mol, (b)  $1.6 \times 10^3$  g, **1.3B** (a) 9.25 g/cm<sup>3</sup>, (b)  $3.76 \times 10^3$  g, **1.4** (a) 4, (b) 1, (c) 4, (d) 2, (e) 2 or 3, (f) 4; **1.5A** (a) 116.21, (b) 80.71 m, (c)  $3.813 \times 10^3$  atoms, (d) 31 dm<sup>3</sup>, (e) 516 g/mol, **1.5B** (a) 32.44 cm<sup>3</sup>, (b)  $4.2 \times 10^3$  kg/m<sup>3</sup>, (c)  $1.008 \times 10^3$  kg, (d) 40.75 mL, (e) 227 cm<sup>3</sup>, **1.6A** 0.8120 g/cm<sup>3</sup>, **1.6B** 95.3 cm<sup>3</sup>, **1.7A** 0.0101 oz, **1.7B** 0.8513 oz, **1.8A**  $1.05 \times 10^3$  kg/m<sup>3</sup>, **1.8B** 13.6 g/cm<sup>3</sup>

#### Checkpoints

**1.1.1** c, **1.1.2** a, **1.3.1** b, **1.3.4** d, **1.5.1** d, **1.5.2** e, **1.5.3** a, **1.5.4** e, **1.6.1** b, **1.6.2** c, **1.6.3** a, **1.6.4** e

#### Applying What You've Learned

**a)** The recommended storage temperature range for cidofovir is 20°C–25°C. **b)** The density of the fluid in a vial is 1.18 g/mL. (The density should be reported to three significant figures.) **c)** The recommended dosage of cidofovir for a 177-lb man is  $4 \times 10^3$  mg or 0.4 g.

### QUESTIONS AND PROBLEMS

#### Section 1.1: The Study of Chemistry

##### Review Questions

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

##### Problems

- Classify each of the following statements as a hypothesis, law, or theory: (a) Boyle's contribution to science would have been much greater if he had married. (b) An autumn leaf gradually turns red and the ground beneath it is an attractive brown between the leaf and Earth. (c) All matter is composed of very small particles called atoms.
- 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.
- Identify the elements present in the following molecules (see Table 1.1):
  - 
  - 
  - 
  -

- Identify the elements present in the following molecules (see Table 1.1):
  - 
  - 
  - 
  -

#### Section 1.2: Classification of Matter

##### Review Questions

- Give an example for each of the following terms: (a) matter, (b) substance, (c) mixture.
- Give an example of a homogeneous mixture and an example of a heterogeneous mixture.
- Give an example of an element and a compound. How do elements and compounds differ?
- What is the number of known elements?

##### Problems

- Give the names of the elements represented by the chemical symbols: (a) Fe, (b) Cu, (c) Zn, (d) Cl, (e) P, (f) Mg, (g) U, (h) Si, (i) Ne (see the table inside the back cover).
- Give the chemical symbols for the following elements: (a) potassium, (b) tin, (c) chromium, (d) boron, (e) barium, (f) platinum, (g) sulfur, (h) argon, (i) mercury (see the table inside the back cover).

- Classify each of the following substances as an element or a compound: (a) hydrogen, (b) water, (c) gold, (d) sugar.
- Classify each of the following as an element, a compound, a homogeneous mixture, or a heterogeneous mixture: (a) seawater, (b) helium gas, (c) sodium chloride (salt), (d) a bottle of soft drink, (e) a milkshake, (f) air in a bottle, (g) concrete.
- Identify each of the diagrams shown here as a solid, liquid, gas, or mixture of two substances.
  - 
  - 
  - 
  -

- Identify each of the diagrams shown here as an element or a compound.
  - 
  - 
  - 
  -

- Identify each of the diagrams shown here as an element or a compound.
  - 
  - 
  - 
  -

#### Section 1.3: Scientific Measurement

##### Review Questions

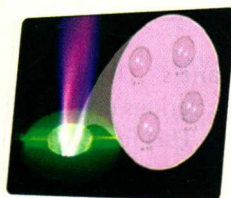
- Name the SI base units that are important in chemistry, and give the SI units for expressing the following: (a) length, (b) volume, (c) mass, (d) time, (e) temperature.
- Write the numbers represented by the following prefixes: (a) mega-, (b) kilo-, (c) deci-, (d) centi-, (e) milli-, (f) micro-, (g) nano-, (h) pico-.
- What units do chemists normally use for the density of liquids and solids? For the density of gas? Explain the differences.
- What is the difference between mass and weight? If a person weighs 150 lb on Earth, about how much would the person weigh on the moon?
- Describe the three temperature scales used in the laboratory and in everyday life: the Fahrenheit, Celsius, and Kelvin scales.

##### Problems

- Bismite is a reddish-brown liquid. Calculate its density (in g/mL) if 586 g of the substance occupies 188 mL.
- The density of ethanol, a colorless liquid that is commonly known as grain alcohol, is 0.789 g/mL. Calculate the mass of 17.4 mL of the liquid.
- Convert the following temperatures to degrees Celsius or Fahrenheit: (a) 99°F, the temperature on a hot summer day; (b) 12°F, the temperature on a cold winter day; (c) a 162°F fever; (d) a furnace operating at 1852°F; (e) 273.15°C (theoretically the lowest attainable temperature).

## Media Study Tools . . .

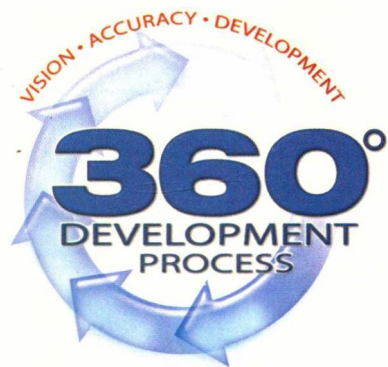
- Reinforce your understanding by viewing animations prepared from the unique Visualizing Chemistry figures.



- Learn on the fly by downloading Media Player or MPEG content to your portable device.



# 360° Development Process



A key principle in developing any general chemistry text is the ability to adapt to teaching specifications in a universal way. The only way to do so is by contacting those universal voices—and learning from their suggestions. Raymond Chang, a veteran author of general chemistry texts, has been involved in the development of this text from the beginning. Raymond's guidance and expertise have proven to be instrumental in the creation of this first-edition text. However, our desire to achieve excellence does not stop with him.

We are confident that our book has the most current content the industry has to offer, thus pushing our desire for accuracy and up-to-date information to the highest standard possible. To accomplish this, we have moved along an arduous road to production. Extensive and open-minded advice is critical in the production of a superior text.

Here is a brief overview of the initiatives included in the 360° Development Process of *Chemistry*, First Edition, by Julia Burdge.

**Board of Advisors** A hand-picked group of trusted teachers active in general chemistry courses served as chief advisors and consultants to the author and editorial team during manuscript development. The Board of Advisors reviewed parts of the manuscript; served as a sounding board for pedagogical, media, and design concerns; consulted on organizational changes; and attended a focus group to confirm the manuscript's readiness for publication.

**Symposia** Every year McGraw-Hill conducts a general chemistry symposium that is attended by instructors from across the country. These events are an opportunity for editors from McGraw-Hill to gather information about the needs and challenges of instructors teaching these courses. This information helped to create the book plan for *Chemistry*. They also offer a forum for the attendees to exchange ideas and experiences with colleagues they might have not otherwise met.

**Focus Groups** In addition to the symposia, we held two specific focus groups for this book—on the overall project and on the art. These selected chemistry professors provided ideas on improvements and suggestions for fine-tuning the content, pedagogy, and art.

**Online Focus Groups** Online focus groups were held with selected reviewers on specific topics, including the coverage of hybridization and orbitals, organic chemistry, and the art program. The author and editorial team used the information gathered to make improvements to the content and art, and to provide accurate user-friendly material.

**Manuscript Review Panels** Over 100 teachers and academics from across the country and internationally reviewed the various drafts of the manuscript to give feedback on content, design, pedagogy, and organization. This feedback was summarized by the book team and used to guide the direction of the text.

**Accuracy Panel** A select group of chemistry experts served as the chief advisors for the accuracy and clarity of the text and solutions manual. These individuals reviewed manuscripts and art in the draft and final forms, reviewed page proofs in the first and revised rounds, and oversaw the writing and accuracy check of the instructor's solutions manuals, test bank, and other ancillary materials.

**Student Focus Groups on Content and Design** Six student class tests and three student focus groups provided the editorial team with an understanding of how content and the design of a textbook impacts students' homework and study habits in the general chemistry course area.



**Developmental Editing** In addition to being influenced by a distinguished chemistry author, the development of this manuscript was impacted by two developmental editors. One with a Ph.D. in Chemistry, John Murdzek, helped to ensure clarity and consistency and to develop the conversational and casual narrative style. His expertise also helped to maximize the positive visual impact of the art and photo placement.

**Art Development** Julia Burdge, along with our designer and editors, worked closely with Precision Graphics, an art development company, to create the visual program within this text. Several personal visits to the Precision offices in Champaign, Illinois, allowed the author and art team to work together and develop the individual art pieces, art-photo combinations, process boxes, and new animations of chemical processes. Out of these dynamics came the author's entirely unique art pieces, the **Visualizing Chemistry** two-page spreads. The end result is a distinctive and innovative visual program that ensures accuracy in relation to textual information, and a style that is uniquely Burdge.

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