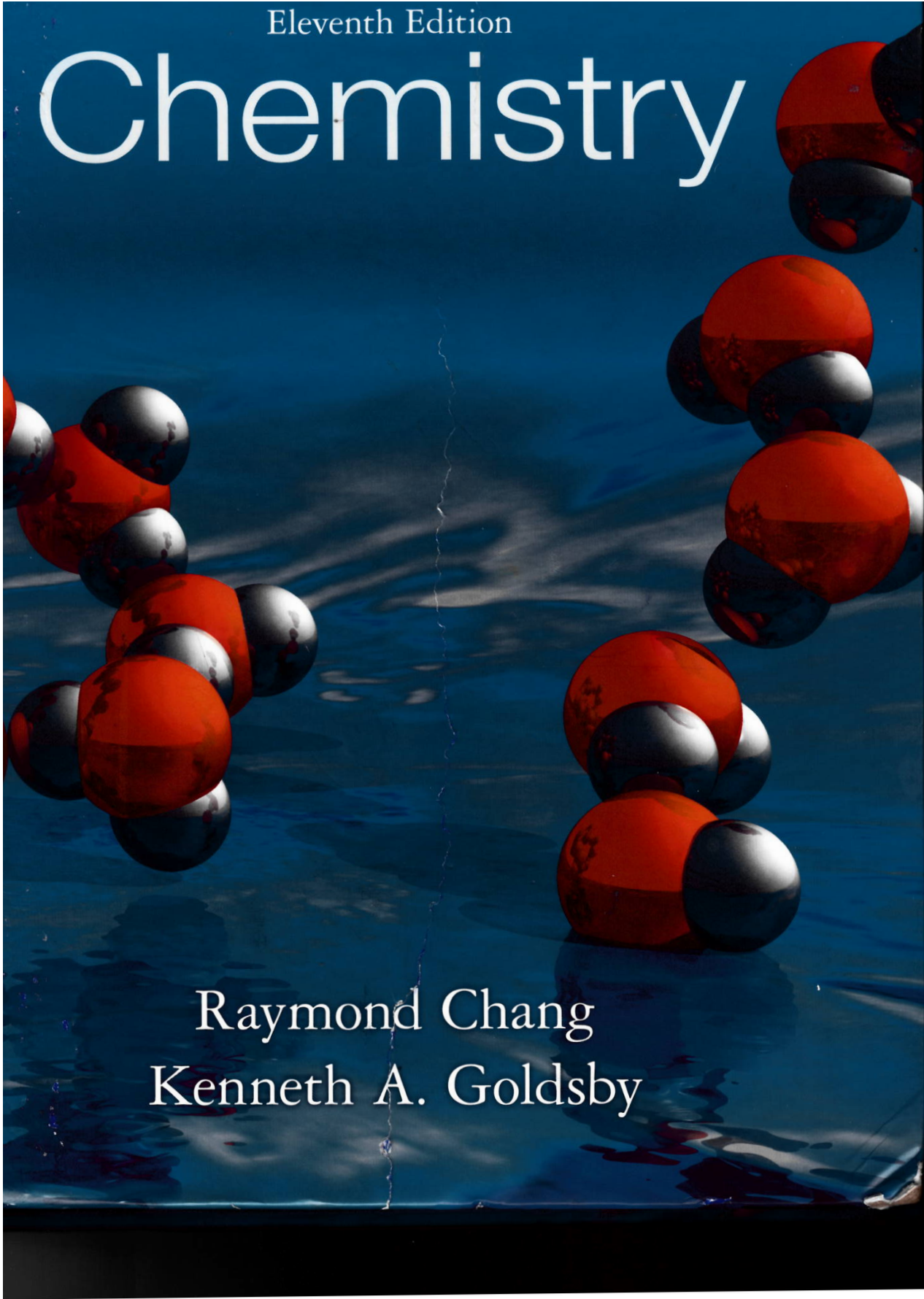


Eleventh Edition

Chemistry

The background of the cover is a deep blue, textured surface that resembles water. Several molecular models are depicted as if floating on this surface. Each model consists of two large red spheres (oxygen) and one smaller white sphere (hydrogen), representing water molecules (H2O). Some models are partially submerged, with their reflections visible on the rippling surface. The lighting creates highlights and shadows on the spheres, giving them a three-dimensional appearance.

Raymond Chang
Kenneth A. Goldsby

Eleventh Edition

Chemistry

Raymond Chang

Williams College

Kenneth A. Goldsby

Florida State University





CHEMISTRY, ELEVENTH EDITION

Published by McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020. Copyright © 2013 by The McGraw-Hill Companies, Inc. All rights reserved. Printed in the United States of America. Previous editions © 2010, 2007, and 2005. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of The McGraw-Hill Companies, Inc., including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

5 6 7 8 9 0 DOW/DOW 1 0 9 8 7 6 5 4

ISBN 978-0-07-340268-0

MHID 0-07-340268-0

Vice President, Editor-in-Chief: *Marty Lange*

Vice President, EDP: *Kimberly Meriwether David*

Senior Director of Development: *Kristine Tibbetts*

Publisher: *Ryan Blankenship*

Executive Editor: *Jeff Huettman*

Senior Developmental Editor: *Shirley R. Oberbroeckling*

Executive Marketing Manager: *Tamara L. Hodge*

Senior Project Manager: *Sandy Wille*

Senior Buyer: *Kara Kudronowicz*

Lead Media Project Manager: *Judi David*

Senior Designer: *David W. Hash*

Cover/Interior Designer: *Jamie E. O'Neal*

Cover Image: *The Structure of the First Coordination Shell in Liquid Water, Hirohito Ogasawara, Ph.D.*

Senior Photo Research Coordinator: *John C. Leland*

Photo Research: *Toni Michaels/PhotoFind, LLC*

Compositor: *Aptara[®], Inc.*

Typeface: *10/12 Times Roman*

Printer: *R. R. Donnelley*

All credits appearing on page C-1 or at the end of the book are considered to be an extension of the copyright page.

Library of Congress Cataloging-in-Publication Data

Chang, Raymond.

Chemistry / Raymond Chang.—11th ed.

p. cm.

Includes index.

ISBN 978-0-07-340268-0 — ISBN 0-07-340268-0 (hard copy : alk. paper) 1. Chemistry—

Textbooks. I. Title.

QD31.3.C38 2013

540—dc23

2011020441

www.mhhe.com

2.4 The Periodic Table

More than half of the elements known today were discovered between 1800 and 1900. During this period, chemists noted that many elements show strong similarities to one another. Recognition of periodic regularities in physical and chemical behavior and the need to organize the large volume of available information about the structure and properties of elemental substances led to the development of the **periodic table**, a chart in which elements having similar chemical and physical properties are grouped together. Figure 2.10 shows the modern periodic table in which the elements are arranged by atomic number (shown above the element symbol) in horizontal rows called **periods** and in vertical columns known as **groups** or **families**, according to similarities in their chemical properties. Note that elements 113–118 have recently been synthesized, although they have not yet been named.

The periodic table can be divided into three categories—metals, nonmetals, and metalloids. Metals are located on the left side of the table, while a nonmetal is located on the right side.

The elements can be divided into three categories—metals, nonmetals, and metalloids. A **metal** is a good conductor of heat and electricity while a **nonmetal** is usually a poor conductor of heat and electricity. A **metalloid** has properties that are intermediate between those of metals and nonmetals. Figure 2.10 shows that the majority of known elements are metals; only 17 elements are nonmetals, and 8 elements are metalloids. From left to right across any period, the physical and chemical properties of the elements change gradually from metallic to nonmetallic.

Figure 2.10 The modern periodic table. The elements are arranged according to the atomic numbers above their symbols. With the exception of hydrogen (H), nonmetals appear at the far right of the table. The two rows of metals beneath the main body of the table are conventionally set apart to keep the table from being too wide. Actually, cerium (Ce) should follow lanthanum (La), and thorium (Th) should come right after actinium (Ac). The 1–18 group designation has been recommended by the International Union of Pure and Applied Chemistry (IUPAC) but is not yet in wide use. In this text, we use the standard U.S. notation for group numbers (1A–8A and 1B–8B). No names have yet been assigned to elements 113–118.

CHEMISTRY in Action

Distribution of Elements on Earth and in Living Systems

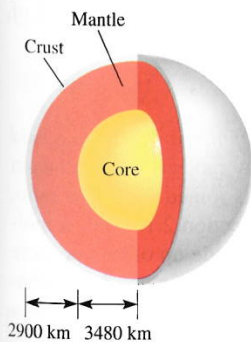
The majority of elements are naturally occurring. How are these elements distributed on Earth, and which are essential to living systems?

Earth's crust extends from the surface to a depth of about 40 km (about 25 mi). Because of technical difficulties, scientists have not been able to study the inner portions of Earth as easily as the crust. Nevertheless, it is believed that there is a solid core consisting mostly of iron at the center of Earth. Surrounding the core is a layer called the *mantle*, which consists of hot fluid containing iron, carbon, silicon, and sulfur.

Of the 83 elements that are found in nature, 12 make up 99.7 percent of Earth's crust by mass. They are, in decreasing order of natural abundance, oxygen (O), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), titanium (Ti), hydrogen (H), phosphorus (P), and manganese (Mn). In discussing the natural abundance of the

elements, we should keep in mind that (1) the elements are not evenly distributed throughout Earth's crust, and (2) most elements occur in combined forms. These facts provide the basis for most methods of obtaining pure elements from their compounds, as we will see in later chapters.

The accompanying table lists the essential elements in the human body. Of special interest are the *trace elements*, such as iron (Fe), copper (Cu), zinc (Zn), iodine (I), and cobalt (Co), which together make up about 0.1 percent of the body's mass. These elements are necessary for biological functions such as growth, transport of oxygen for metabolism, and defense against disease. There is a delicate balance in the amounts of these elements in our bodies. Too much or too little over an extended period of time can lead to serious illness, retardation, or even death.



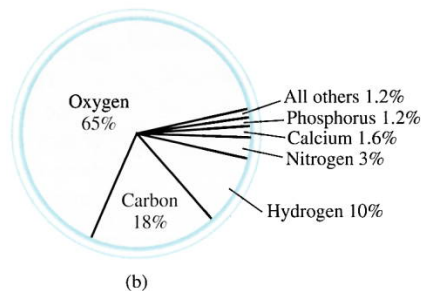
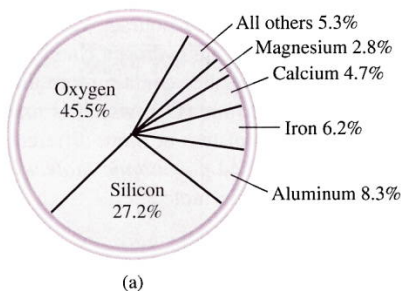
Structure of Earth's interior.

Essential Elements in the Human Body

Element	Percent by Mass*	Element	Percent by Mass*
Oxygen	65	Sodium	0.1
Carbon	18	Magnesium	0.05
Hydrogen	10	Iron	<0.05
Nitrogen	3	Cobalt	<0.05
Calcium	1.6	Copper	<0.05
Phosphorus	1.2	Zinc	<0.05
Potassium	0.2	Iodine	<0.05
Sulfur	0.2	Selenium	<0.01
Chlorine	0.2	Fluorine	<0.01

*Percent by mass gives the mass of the element in grams present in a 100-g sample.

(a) Natural abundance of the elements in percent by mass. For example, oxygen's abundance is 45.5 percent. This means that in a 100-g sample of Earth's crust there are, on the average, 45.5 g of the element oxygen. (b) Abundance of elements in the human body in percent by mass.



may be lost or gained. The loss of one or more electrons from a neutral atom results in a **cation**, an ion with a net positive charge. For example, a sodium atom (Na) can readily lose an electron to become a sodium cation, which is represented by Na^+ :

In Chapter 8 we will see why atoms of different elements gain (or lose) a specific number of electrons.

Na Atom	Na^+ Ion
11 protons	11 protons
11 electrons	10 electrons

On the other hand, an **anion** is an ion whose net charge is negative due to an increase in the number of electrons. A chlorine atom (Cl), for instance, can gain an electron to become the chloride ion Cl^- :

Cl Atom	Cl^- Ion
17 protons	17 protons
17 electrons	18 electrons

Sodium chloride (NaCl), ordinary table salt, is called an **ionic compound** because it is formed from cations and anions.

An atom can lose or gain more than one electron. Examples of ions formed by the loss or gain of more than one electron are Mg^{2+} , Fe^{3+} , S^{2-} , and N^{3-} . These ions, as well as Na^+ and Cl^- , are called **monatomic ions** because they contain only one atom. Figure 2.11 shows the charges of a number of monatomic ions. With very few exceptions, metals tend to form cations and nonmetals form anions.

In addition, two or more atoms can combine to form an ion that has a net positive or net negative charge. **Polyatomic ions** such as OH^- (hydroxide ion), CN^- (cyanide ion), and NH_4^+ (ammonium ion) are ions containing more than one atom.

Review of Concepts

- What does S_8 signify? How does it differ from 8S ?
- Determine the number of protons and electrons for the following ions:
 - P^{3-} and (b) Ti^{4+} .

1 1A	2 2A																	18 8A
Li^+																		
Na^+	Mg^{2+}	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	Al^{3+}						
K^+	Ca^{2+}				Cr^{2+} Cr^{3+}	Mn^{2+} Mn^{3+}	Fe^{2+} Fe^{3+}	Co^{2+} Co^{3+}	Ni^{2+} Ni^{3+}	Cu^+ Cu^{2+}	Zn^{2+}					Se^{2-}	Br^-	
Rb^+	Sr^{2+}									Ag^+	Cd^{2+}			Sn^{2+} Sn^{4+}		Te^{2-}	I^-	
Cs^+	Ba^{2+}									Au^+ Au^{3+}	Hg_2^{2+} Hg^{2+}			Pb^{2+} Pb^{4+}				

Figure 2.11 Common monatomic ions arranged according to their positions in the periodic table. Note that the Hg_2^{2+} ion contains two atoms.

2.6 Chemical Formulas

Chemists use **chemical formulas** to express the composition of molecules and ionic compounds in terms of chemical symbols. By composition we mean not only the elements present but also the ratios in which the atoms are combined. Here we are concerned with two types of formulas: molecular formulas and empirical formulas.

Molecular Formulas

A **molecular formula** shows the exact number of atoms of each element in the smallest unit of a substance. In our discussion of molecules, each example was given with its molecular formula in parentheses. Thus, H_2 is the molecular formula for hydrogen, O_2 is oxygen, O_3 is ozone, and H_2O is water. The subscript numeral indicates the number of atoms of an element present. There is no subscript for O in H_2O because there is only one atom of oxygen in a molecule of water, and so the number "one" is omitted from the formula. Note that oxygen (O_2) and ozone (O_3) are allotropes of oxygen. An **allotrope** is one of two or more distinct forms of an element. Two allotropic forms of the element carbon—diamond and graphite—are dramatically different not only in properties but also in their relative cost.

Molecular Models

Molecules are too small for us to observe directly. An effective means of visualizing them is by the use of molecular models. Two standard types of molecular models are currently in use: *ball-and-stick* models and *space-filling* models (Figure 2.12). In ball-and-stick model kits, the atoms are wooden or plastic balls with holes in them. Sticks or springs are used to represent chemical bonds. The angles they form between atoms approximate the bond angles in actual molecules. With the exception of the H atom, the balls are all the same size and each type of atom is represented by a specific color. In space-filling models, atoms are represented by truncated balls held together by snap

See back endpaper for color codes for atoms.

	Hydrogen	Water	Ammonia	Methane
Molecular formula	H_2	H_2O	NH_3	CH_4
Structural formula	$H-H$	$H-O-H$	$\begin{array}{c} H-N-H \\ \\ H \end{array}$	$\begin{array}{c} H \\ \\ H-C-H \\ \\ H \end{array}$
Ball-and-stick model				
Space-filling model				

Figure 2.12 Molecular and structural formulas and molecular models of four common molecules.

fasteners, so that the bonds are not visible. The balls are proportional in size to atoms. The first step toward building a molecular model is writing the **structural formula**, which *shows how atoms are bonded to one another in a molecule*. For example, it is known that each of the two H atoms is bonded to an O atom in the water molecule. Therefore, the structural formula of water is $\text{H}-\text{O}-\text{H}$. A line connecting the two atomic symbols represents a chemical bond.

Ball-and-stick models show the three-dimensional arrangement of atoms clearly, and they are fairly easy to construct. However, the balls are not proportional to the size of atoms. Furthermore, the sticks greatly exaggerate the space between atoms in a molecule. Space-filling models are more accurate because they show the variation in atomic size. Their drawbacks are that they are time-consuming to put together and they do not show the three-dimensional positions of atoms very well. We will use both models extensively in this text.

Empirical Formulas

The molecular formula of hydrogen peroxide, a substance used as an antiseptic and as a bleaching agent for textiles and hair, is H_2O_2 . This formula indicates that each hydrogen peroxide molecule consists of two hydrogen atoms and two oxygen atoms. The ratio of hydrogen to oxygen atoms in this molecule is 2:2 or 1:1. The empirical formula of hydrogen peroxide is HO. Thus, the **empirical formula** tells us *which elements are present and the simplest whole-number ratio of their atoms*, but not necessarily the actual number of atoms in a given molecule. As another example, consider the compound hydrazine (N_2H_4), which is used as a rocket fuel. The empirical formula of hydrazine is NH_2 . Although the ratio of nitrogen to hydrogen is 1:2 in both the molecular formula (N_2H_4) and the empirical formula (NH_2), only the molecular formula tells us the actual number of N atoms (two) and H atoms (four) present in a hydrazine molecule.

Empirical formulas are the *simplest* chemical formulas; they are written by reducing the subscripts in the molecular formulas to the smallest possible whole numbers. Molecular formulas are the *true* formulas of molecules. If we know the molecular formula, we also know the empirical formula, but the reverse is not true. Why, then, do chemists bother with empirical formulas? As we will see in Chapter 3, when chemists analyze an unknown compound, the first step is usually the determination of the compound's empirical formula. With additional information, it is possible to deduce the molecular formula.

For many molecules, the molecular formula and the empirical formula are one and the same. Some examples are water (H_2O), ammonia (NH_3), carbon dioxide (CO_2), and methane (CH_4).

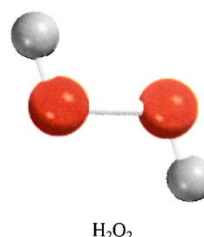
Examples 2.2 and 2.3 deal with writing molecular formulas from molecular models and writing empirical formulas from molecular formulas.

Example 2.2

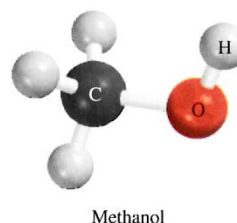
Write the molecular formula of methanol, an organic solvent and antifreeze, from its ball-and-stick model, shown in the margin.

Solution Refer to the labels (also see back endpapers). There are four H atoms, one C atom, and one O atom. Therefore, the molecular formula is CH_4O . However, the standard way of writing the molecular formula for methanol is CH_3OH because it shows how the atoms are joined in the molecule.

Practice Exercise Write the molecular formula of chloroform, which is used as a solvent and a cleansing agent. The ball-and-stick model of chloroform is shown in the margin on p. 54.



The word "empirical" means "derived from experiment." As we will see in Chapter 3, empirical formulas are determined experimentally.



Similar problems: 2.47, 2.48.