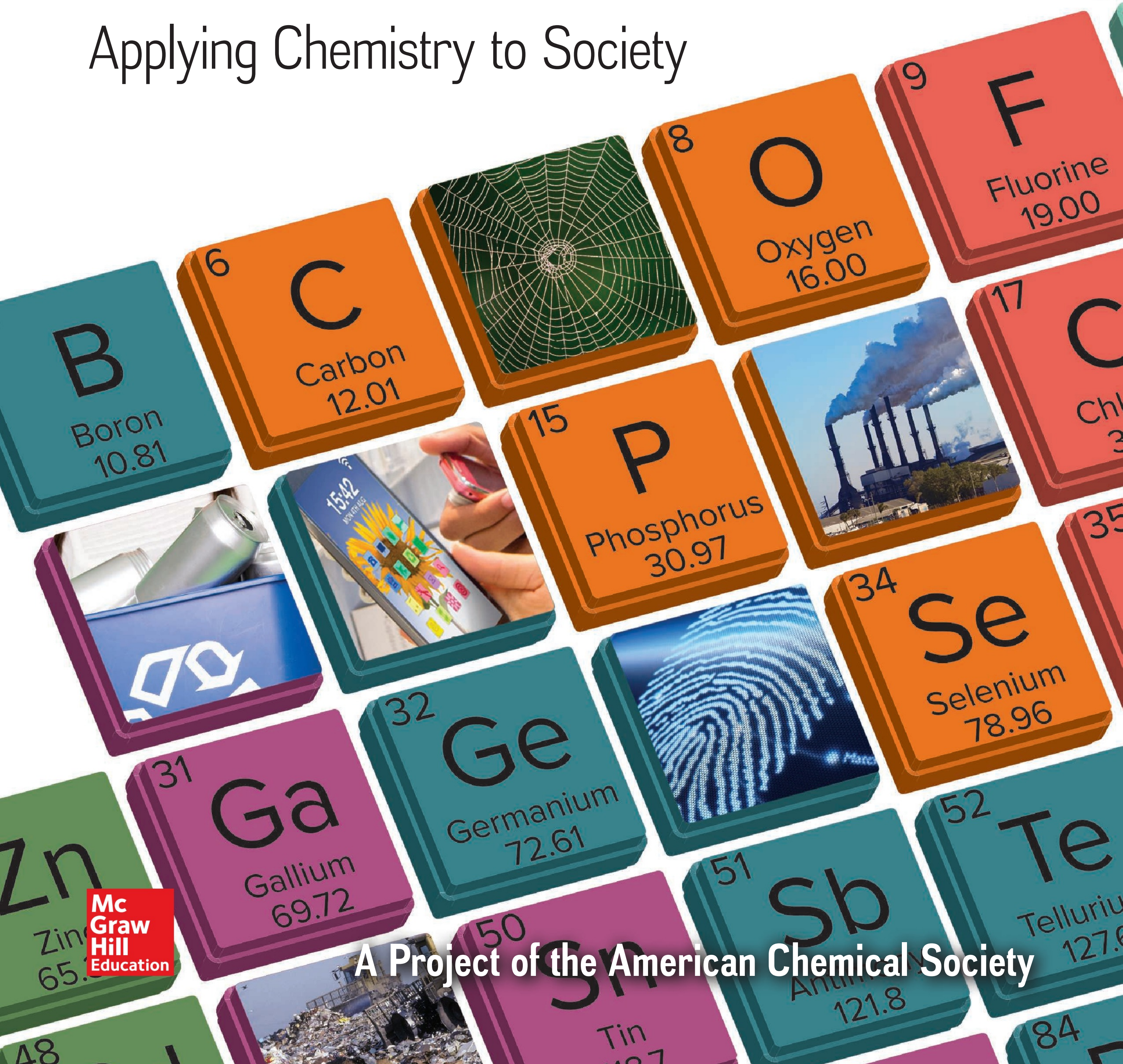
CHEMISTRY IN CONTEXT

Ninth Edition

Applying Chemistry to Society



A Project of the American Chemical Society

Mc Graw Hill Education

Chemistry in Context

Applying Chemistry to Society

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Chemistry for Life®

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Ninth Edition

Chemistry in Context

Applying Chemistry to Society

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CHEMISTRY IN CONTEXT: APPLYING CHEMISTRY TO SOCIETY, NINTH EDITION

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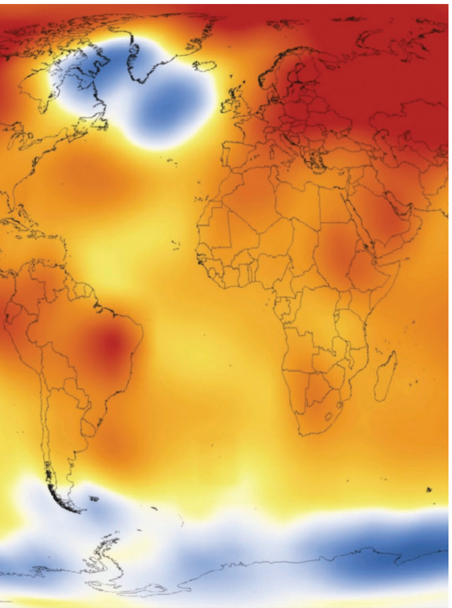

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Preface

Climate change. Water contamination. Air pollution. Food shortages. These and other societal issues are regularly featured in the media. However, did you know that chemistry plays a crucial role in addressing these challenges? A knowledge of chemistry is also essential to improve the quality of our lives. For instance, faster electronic devices, stronger plastics, and more effective medicines and vaccines all rely on the innovations of chemists throughout the world. With our world so dependent on chemistry, it is unfortunate that most chemistry textbooks do not provide significant details regarding real-world applications. Enter *Chemistry in Context*—"the book that broke the mold." Since its inception in 1993, *Chemistry in Context* has focused on the presentation of chemistry fundamentals within a contextual framework.

So, what is "context," and how will this make your study of chemistry more interesting and relevant?

Context! This word is derived from the Latin word meaning "to weave." Hence, *Chemistry in Context* weaves together connections between chemistry and society. In the absence of societal issues, there could be no *Chemistry in Context*. Similarly, without teachers and students who are willing (and brave enough) to engage in these issues, there could be no *Chemistry in Context*. As the "Central Science," chemistry is woven into the fabric of practically every issue that our society faces today.

Context! Do you enjoy good stories about the world in which you live? If so, look inside this book for stories that intrigue, challenge, and possibly even motivate you to act in new or different ways. In almost all contexts—local, regional, and global—parts of these stories are still unfolding. The ways in which you and others make choices today will determine the nature of the stories told in the future.

Context! Are you aware that using a real-world context to engage people is a high-impact practice backed up by research on how people learn? *Chemistry in Context* offers real-world contexts through which to engage learners on multiple levels: personal, societal, and global. Given the rapidly changing nature of these contexts, *Chemistry in Context* also offers teachers the opportunity to become learners alongside their students.

Sustainability—The Ultimate Context

Global sustainability is not just a challenge. Rather, it is *the* defining challenge of our century. Accordingly, the ninth edition of *Chemistry in Context* continues to focus on this challenge, both as a topic worth studying and as a problem worth solving. As a topic, sustainability provides an important source of content for students to master. For example, the tragedy of the commons, the Triple Bottom Line, and the concept of cradle-to-cradle are all part of this essential content. As a problem worth solving, sustainability generates new questions for students to ask—ones that help them to imagine and achieve a sustainable future. For example, students will find questions about the risks and benefits of acting (or not acting) to reduce emissions of greenhouse gases.

Chemistry for a Sustainable World

Incorporating sustainability requires more than a casual rethinking of the curriculum. Unlike most general chemistry texts, *Chemistry in Context* is context rich. In essence, you can think of our coverage as a "Citizens First" approach that is context-driven, rather than the content-driven "Atoms First" approach used in many general chemistry curricula. Thus, unlike any other textbook, we provide interesting real-world scenarios about energy, materials, food, water, and health in order to convey essential chemistry content alongside the key concepts of sustainability.

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Green chemistry, a means to sustainability, continues to be an important theme in *Chemistry in Context*. As in previous editions, examples of green chemistry are highlighted in each chapter. In this new edition, we provide even more examples. This expanded coverage offers the reader a better sense of the need for, and importance of, greening our chemical processes.

Updates to Existing Content

People sometimes ask us, "Why do you release new editions so often?" Indeed, we are on a fast publishing cycle, turning out a new version every three years. We do this because the content in *Chemistry in Context* is time sensitive.

The ninth edition of *Chemistry in Context* represents a significant update, which is reflected by a change in cover art from previous editions. We now feature new contexts: portable electronics (Chapter 1) and "kitchen" chemistry (Chapter 10). A third new context, forensics, represents the final capstone chapter of the textbook (Chapter 14), and is written as a "whodunit" storyline. Concepts from all of the previous 13 chapters are woven into the story, which takes students through the process of investigating crime scenes and employing appropriate techniques for evidence collection and analyses.

All other chapters have been extensively revised in order to improve the flow of topics while incorporating new scientific developments, changes in policies, energy trends, and current world events. Some highlights of updates to *Chemistry in Context,* 9e, include:

- Chapter 2 (air quality) and Chapter 4 (climate change): updated data and environmental contexts, policies, and regulations are woven throughout each chapter.
- Chapter 3 (radiation from the Sun): more details are provided regarding the role of nanoparticles in sunscreen formulations.
- Chapter 5 (energy from combustion): more details are given for the properties of fuels, and contextual comparisons are provided for various energy values. New information regarding current oil reserves is included, as well as the processes involved to obtain fossil fuels from underground reservoirs, including fracking. A thorough discussion of London dispersion intermolecular forces is also provided.
- Chapter 6 (alternative energies): the original chapter placement has been moved to immediately follow the hydrocarbon-fuel chapter. More details regarding solar, wind, and thermoelectric sources of energy are now included.
- Chapter 7 (energy storage): new details are provided regarding supercapacitors *versus* batteries for electric vehicle applications.
- Chapter 8 (water quality): discussions of water contamination issues from Flint, Michigan, and Durango, Colorado, are included, as well as more details regarding acid–base equilibria.
- Chapter 9 (polymers): updated statistics and new information regarding plastics recycling are provided.
- Chapter 11 (nutrition): an introduction to issues in food safety and food security are included.
- Chapter 12 (health and medicine): this heavily revised chapter now includes new details regarding the role of equilibria on the health of our bodies and the processes involved in modern drug design.
- Chapter 13 (genetics): additional information and references are added regarding GMOs, as well as more details on how synthetic insulin is produced via genetic engineering.

Each chapter has available online, an introductory video that introduce the overall topic to be discussed, with a "Reflection" activity for students to ponder before reading the chapter. This is immediately followed by a new section "The Big Picture", which clearly identifies the main questions that are addressed in the chapter. Every chapter then concludes with a "Learning Outcomes" section that outlines the important concepts that were introduced, with citations to their particular section(s).

A number of interactive simulations are also included in various chapters. The digital edition of *Chemistry in Context,* 9e, features embedded videos and activities, whereas the print version provides these experiences via pointing to the **Connect** website. Relative to previous editions, more activities are woven throughout each chapter that direct students to search the Internet to find appropriate data or reports in order to draw their own conclusions regarding current worldwide issues.

Teaching and Learning in Context

This new edition of *Chemistry in Context* continues with the organizational scheme used in previous editions. However, a new introductory chapter focusing on portable electronics is used to introduce the periodic table, elements, and compounds. Subsequent chapters delve into other real-world themes that provide a foundation of chemistry concepts that is built upon in later chapters.

A variety of embedded in-chapter question types—"Skill Building" (basic review, more traditional, "Scientific Practices" (critical thinking), and "You Decide" (analytical reasoning—also includes questions that directly use the Internet. The questions are plentiful and varied. They range from simpler practice exercises focusing on traditional chemical principles to those requiring more thorough analysis and integration of applications. Some of the questions are the basis for small group work, class discussions, or individual projects. These activities will afford students the opportunity to explore interests, as time permits, beyond the core topics.

Web-based activities found on the **Connect** site are integrated throughout the text. These web-based activities help students develop critical thinking and analytical problem-solving skills based on real-time information.

Many chapters include a figure that "comes alive" through interactivity. This feature resides on the **Connect** site and can be assigned by the instructor.

Chemistry in Context, 9e—A Team Effort

Once again, we have the pleasure of offering our readers a new edition of *Chemistry in Context*. But the work is not done by just one individual; rather, it is the work of a talented team. The ninth edition builds on the legacy of prior author teams led by Cathy Middlecamp, A. Truman Schwartz, Conrad L. Stanitski, and Lucy Pryde Eubanks, all leaders in the chemical education community.

This new edition was prepared by Bradley Fahlman, Kathleen Purvis-Roberts, John Kirk, Anne Bentley, Patrick Daubenmire, Jamie Ellis, and Michael Mury. The accompanying laboratory manual was extensively revised by Jennifer Tripp and Lallie McKenzie. Each author brought their own experiences and expertise to the project, which helped to greatly expand the depth and breadth of the contexts in order to reach a variety of audiences. Stephanie Ryan and Jaclyn Trate also did an amazing job with writing solutions to all in-chapter activities, which were greatly expanded from previous editions.

At the American Chemical Society, leadership was provided by Mary Kirchhoff, Director of the Education Division. She supported the writing team, cheering on its efforts to "connect the dots" between chemistry contexts and the underlying fundamental chemistry content. Terri Taylor, Assistant Director for K–12 Science at the American Chemical Society, provided superior support throughout the project, with great insights regarding the effective use of *CiC* in the classroom. Former production manager, Michael Mury, and current production manager, Emily Bones, were also instrumental in the successful completion of this edition. Michael was able to effectively bring together all of the parties involved—the author team, the publisher, and the American Chemical Society, which was no small feat. Emily's attention to detail and extensive experience in the classroom significantly improved the flow and readability of this edition. The introductory videos for each chapter were completed by an extremely talented videographer at the American Chemical Society, Janali Thompson. Input from Terri Taylor, Kevin McCue, and Adam Dylewski at ACS was also instrumental in achieving professional-quality videos in record time.

The many pedagogical improvements offered in *CiC,* 9e were greatly assisted through input from an Editorial Advisory Board: Renee Cole (University of Iowa), Max Houck (Forensic and Intelligence Services, LLC), Andy Jorgensen (University of Toledo), Steve Keller (University of Missouri-Columbia), Resa Kelly (San Jose State University), Kasi Kiehlbaugh (University of Arizona), Peter Mahaffy (King's University), and Ted Picciotto (Portland Community College). The feedback obtained from this exceptional group substantially improved the quality of the completed work.

The McGraw-Hill team was superb in all aspects of this project, with special thanks to Jodi Rhomberg and Sherry Kane for shepherding the project to the finish line. Marty Lange (Vice President and General Manager), Thomas Timp (Managing Director), David Spurgeon, PhD (Director of Chemsitry), Rose Koos (Director of Development), Shirley Hino, PhD (Director of Digital Content Development), Matthew Garcia (Marketing Manager), Tami Hodge (Director of Marketing), and Jodi Rhomberg (Senior Product Developer), Sherry Kane and Tammy Juran (Content Project Managers), Carrie Burger and Lori Slattery (Content Licensing Specialists), Tara McDermott (Designer), Laura Fuller (Buyer), Patrick Diller (Digital Product Analyst) and Lora Neyens (Program Manager).

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Bronx Community College
Butler University
Cerritos College
Chandler-Gibert Community College
Claremont McKenna, Pitzer & Scripps Colleges
Clemson University
College of DuPage
College of the Canyons
Columbia Secondary School
Delta College
DePaul University
Durham Public Schools
Eastern Maine Community College
Florida International University—Biscayne Bay
Florida Southern College
Florida SouthWestern State College
Florida State College at Jacksonville
Gateway Technical College
Georgia Gwinnett College
Georgia Southwestern State University
Harold Washington College
Hueneme High School
J.D. Clement Early College High School
Johns Hopkins University
LaGuardia Community College
Lake Michigan College
Lake–Sumter State College
Lancaster High School
Merrimack College
Misericordia University
Montgomery College
Moorpark College
Neosho County Community College
New Jersey City University
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University of Abuja (Nigeria)
University of Baltimore
University of Central Florida
University of Southern Indiana
University of Tennessee
University of Toledo
University of Wisconsin—Milwaukee
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Washington College

We are very excited by the new contexts and features provided in this edition. As you explore these contexts, we hope that your study of the underlying fundamental chemistry concepts will become more relevant in your life. We believe that the chemistry contexts and content provided in this edition, alongside the interactive and thought-provoking activities embedded throughout, will make you think differently about the world around you and the challenges we face. The solutions to current and future societal problems will require an interdisciplinary approach. Whether you decide to continue your studies in chemistry, or transition to other fields of study, we believe that the critical thinking skills fostered in *Chemistry in Context,* 9e will be of value to all of your future endeavors.

Sincerely, on behalf of the author team,

Bradley D. Fahlman

Senior Author and Editor-in-Chief
August, 2016

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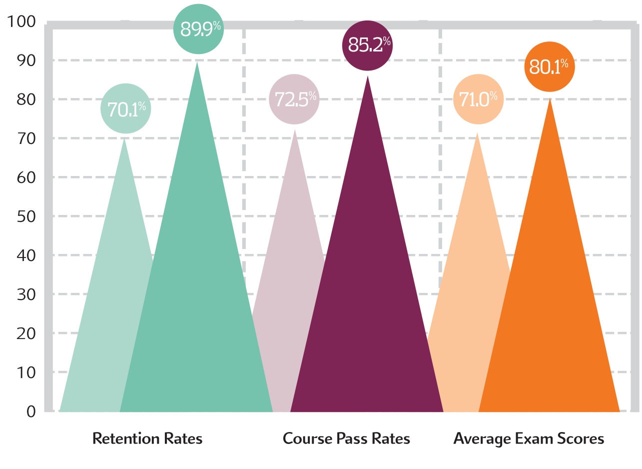

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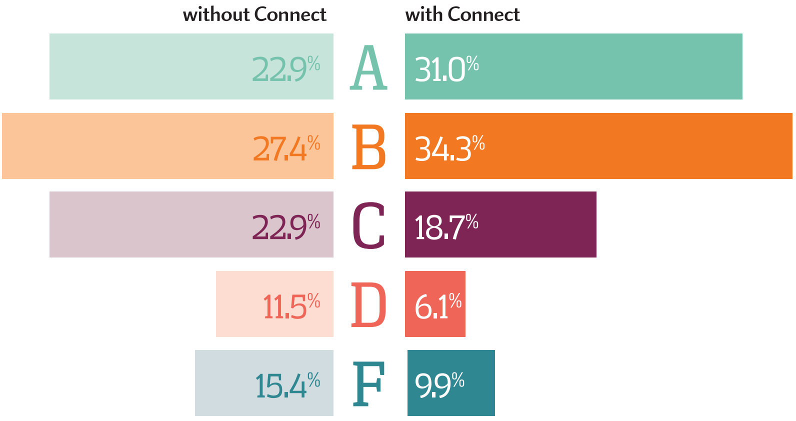

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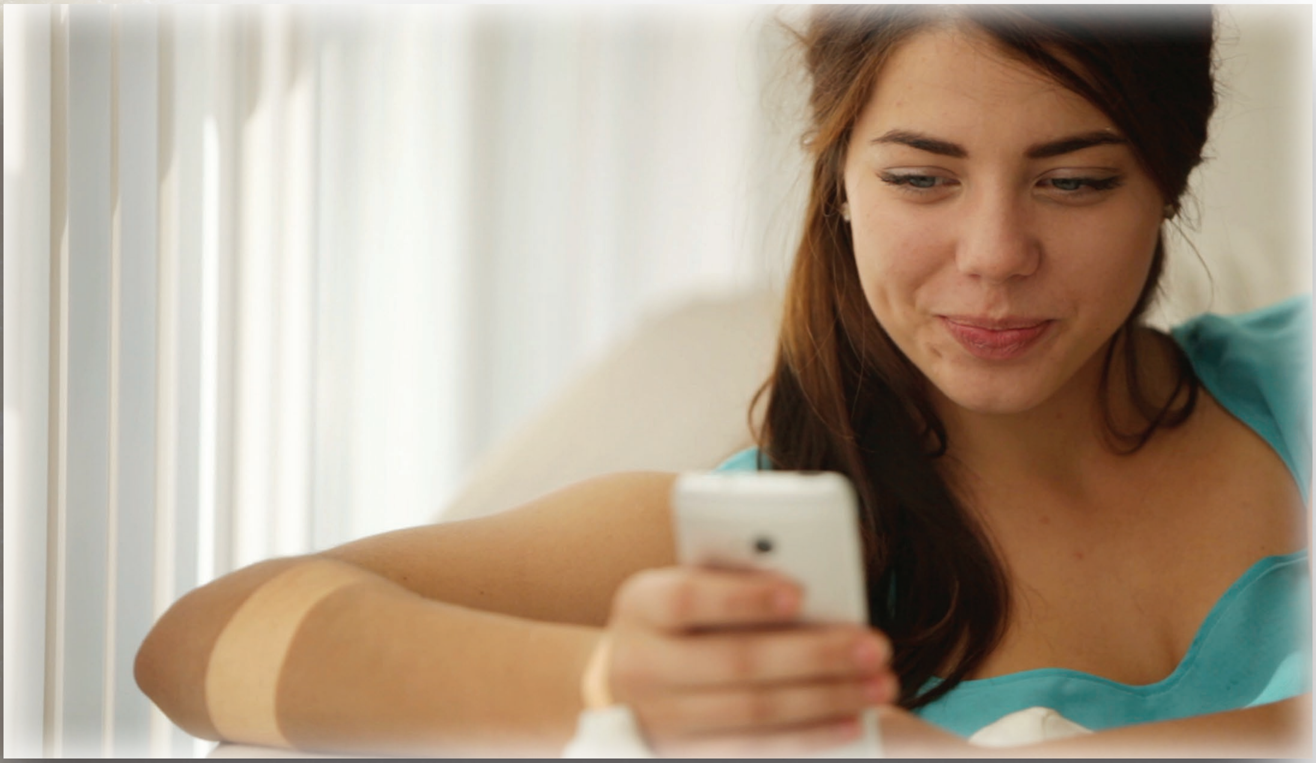
CHAPTER 1

Portable Electronics: The Periodic Table in the Palm of Your Hand



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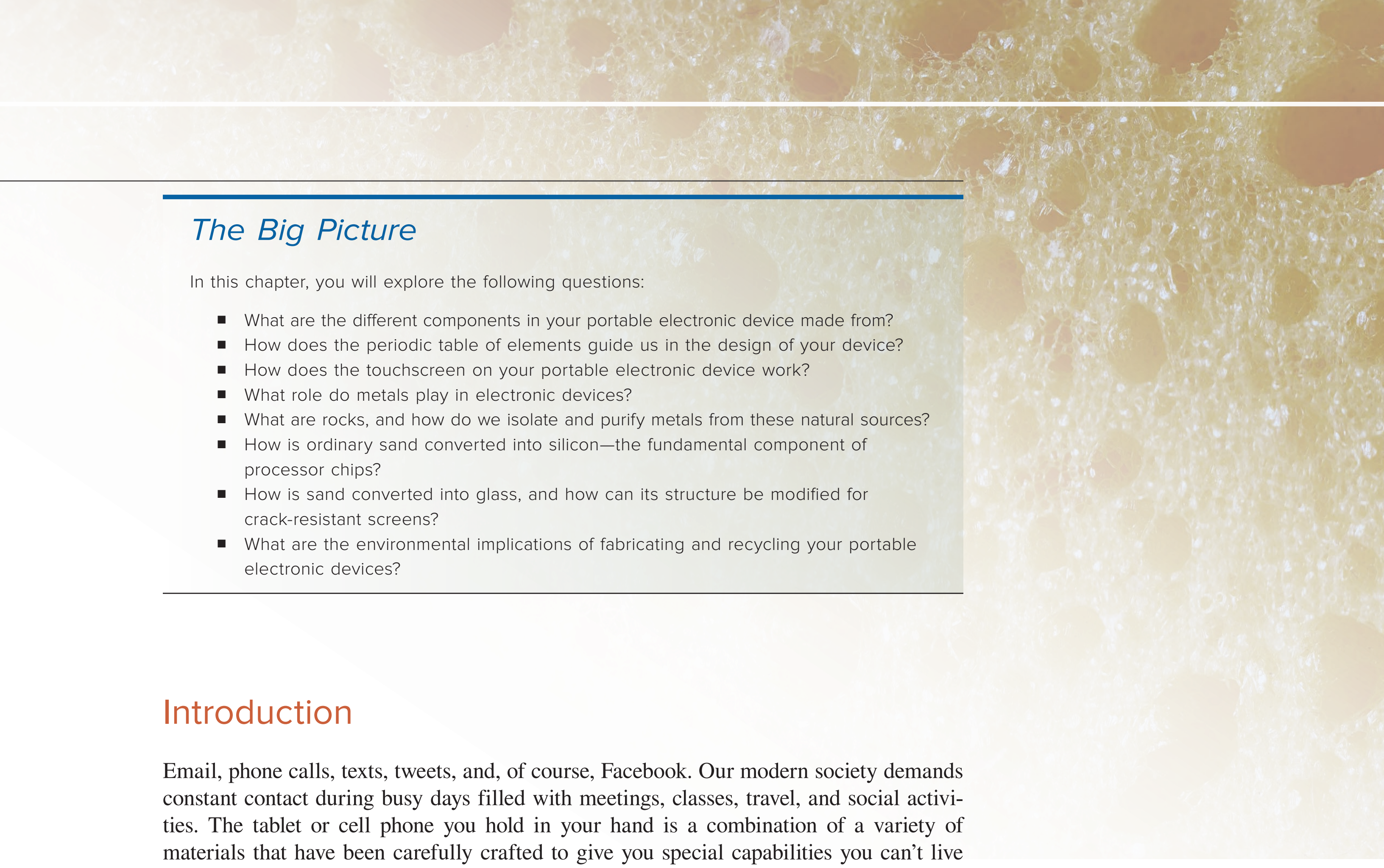
REFLECTION

What's in Your Cell Phone?

As you will see in this chapter, chemistry plays a central role in controlling the properties of electronic devices.

- **a.** List some desirable attributes of a cell phone, and some that you would like to see in the future.
- **b.** The majority of materials that comprise your cell phone may be classified as metals, plastics, or glass. Using the Web as a resource, describe where these materials come from (both the region(s) of the world where they are produced, and the raw materials used in their fabrication).
- **c.** Cite two elements that combine to form a substance important to your cell phone.
- **d.** What is the expected lifespan of your cell phone?



The Big Picture

In this chapter, you will explore the following questions:

- What are the different components in your portable electronic device made from?
- How does the periodic table of elements guide us in the design of your device?
- How does the touchscreen on your portable electronic device work?
- What role do metals play in electronic devices?
- What are rocks, and how do we isolate and purify metals from these natural sources?
- How is ordinary sand converted into silicon—the fundamental component of processor chips?
- How is sand converted into glass, and how can its structure be modified for crack-resistant screens?
- What are the environmental implications of fabricating and recycling your portable electronic devices?

Introduction

Email, phone calls, texts, tweets, and, of course, Facebook. Our modern society demands constant contact during busy days filled with meetings, classes, travel, and social activities. The tablet or cell phone you hold in your hand is a combination of a variety of materials that have been carefully crafted to give you special capabilities you can't live without.

In order to satisfy the ever-rigorous demands of today's consumer, the latest portable electronics must be lightweight, thin, durable, multifunctional, and easily synced with computers and next-generation wearable devices. Such complex designs are only possible by putting together the elements of the periodic table in many different ways to form materials with the above physical properties that we need or desire.

In this chapter, you will learn about the various components that make up your cell phone, tablet, or other portable electronic device. Perhaps most importantly, you will discover where these components came from and what happens to them after their lifetime is finished. Throughout this book, you will see that the world around us may be described by various length scales. Let's now begin our discovery into the submicroscopic depths of your electronic device. You will never look at your cell phone the same way again ...

Your Turn 1.1 Scientific Practices How Small?!

The smallest building blocks inside your cell phone are about *1000 times* smaller than the diameter of a human hair fiber!

a. What is a typical diameter of an individual hair fiber?
b. Using the answer found in question **a**, how many hair-fiber widths would it take to span the length your cell phone?

1.1 What's the Matter with Materials? A Survey of the Periodic Table

It's wintertime and you need to respond to an urgent text on your smartphone. You touch the screen with a gloved finger and get no response. The hassle of removing your gloves and risking frostbite, just to operate your cell phone or tablet, is an all-too-common occurrence for those who live in cold climates. However, there are now a variety of commercially available gloves that use a special thread or have pads sewn into them, which allow a user to seamlessly control their touchscreen device. Most smartphones and tablets will also respond to a special pen-like object known as a stylus. Nevertheless, this begs the question: Why are touchscreens so restrictive in responding to only a small number of stimuli?

Your Turn 1.2 Scientific Practices Touchscreen Response

Taking care not to damage your screen, use a variety of materials to touch the screen of your portable electronic device. In addition to your finger, items that may be used include a paper clip, plastic pen, key, battery, fabrics, pencil lead, sponge (wet and dry), pencil eraser, coin, glass marble, paper, cardboard, or any other items. Did any of these materials other than your finger cause a response? We will revisit this question later in the chapter.

The properties of a device are governed by what it is made of—its **composition**. What compositions are required for a touchscreen to be transparent, crack-resistant, and touch-sensitive? This is no minor feat, and requires scientists to constantly explore the world around them in order to select the most appropriate constituents.

Chemistry is the branch of science that focuses on the composition, structure, properties, and changes of matter.

Everything around you—the air you breathe, the water you drink, and the mobile device in your hand—is defined as **matter**. Matter is considered to be anything that occupies space and has a mass. This consists of solids, liquids, gases, or plasmas that exist as either pure substances or mixtures (Figure 1.1).

Plasmas are seen in superheated conditions, such as a lightning strike.

For instance, in dissolving sugar in water, both the solid sugar and liquid water are considered pure substances—each composed of a single substance. The mixing together of these separate pure substances will result in a **homogeneous mixture**,

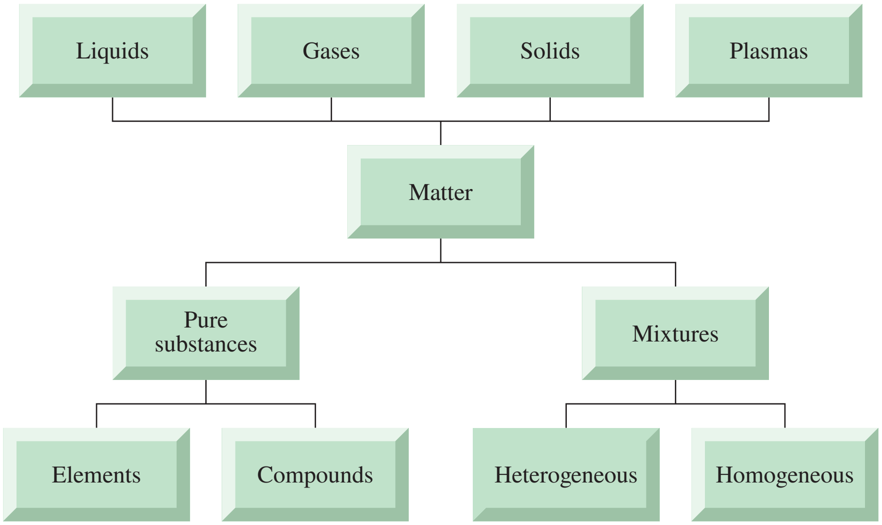


Figure 1.1

A classification scheme for matter.

which will be uniform in composition throughout. Quite often, a homogeneous mixture is referred to as a **solution**. If we take a few spoonfuls of a sugar solution, each one would contain the same ratio of sugar and water. In contrast, if one digs up a handful of soil, you will discover a complicated mixture of sand, particles of varying shapes and colors, liquid water within the pores, and perhaps even some resident earthworms. This is known as a **heterogeneous mixture**, because it is not uniform in composition throughout. That is, the relative amounts of sand, dirt, rocks, etc., will vary from one handful to the next.

As we will see shortly, the smallest building blocks of matter are known as **atoms**. An **element** is composed of many atoms of the same type. Every day, we take for granted the use of pure elements such as copper in household pipes, aluminum in home exteriors, lithium in batteries, and carbon in pencil nibs. In contrast, a **compound** is a pure substance that is made up of two or more different types of atoms in a fixed, characteristic chemical combination. Reconsidering a sugar solution, water (H_2O) is a compound consisting of oxygen and hydrogen atoms. Sugar ($C_{12}H_{22}O_{11}$) is also a compound, but instead contains carbon, hydrogen, and oxygen atoms. Even though the types of atoms in compounds and elements are identical, they are bonded to one another in a different manner within each substance. For instance, the oxygen atoms in sugar are exactly identical to the oxygen atoms that comprise elemental oxygen gas (O_2). However, it would take a chemical reaction to break apart the atoms within sugar to return the oxygen atoms to their elemental form—gaseous oxygen.

Chemical symbols are one- or two-letter abbreviations for the elements. These symbols, established by international agreement, are used throughout the world. Some of them make immediate sense to those who speak English or related languages. For example, oxygen is O, aluminum is Al, lithium is Li, and silicon is Si. However, other symbols have their origin in other languages, such as some metals that were discovered by ancient civilizations and given Latin names long ago. For example, argentum (Ag) is silver, ferrum (Fe) is iron, plumbum (Pb) is lead, and hydrargyrum (Hg) is mercury.

Chemical symbols sometimes also are referred to as atomic symbols.

Did You Know? Pluto was discovered in 1930, and for over 75 years was considered a planet. However, in 2006, Pluto was reclassified as a dwarf planet. Regardless of this reclassification, the name plutonium still appears in the periodic table.

Elements have been named for properties, planets, places, and people. Hydrogen (H) means "water former," because hydrogen and oxygen gases burn in a flame to form the compound water (H_2O). Neptunium (Np) and plutonium (Pu) were named after two planets in our solar system. Berkelium (Bk) and californium (Cf) honor the University of California, Berkeley, lab in which they were first produced. Flerovium (Fl) and livermorium (Lv) were both named after the laboratories in which the elements were discovered. Only a few atoms of each have been produced by nuclear fusion reactions.

Plutonium can fuel both nuclear reactors and nuclear bombs. See Chapter 6 for details.

It is fitting that Russian chemist Dmitri Mendeleev (1834–1907) has his own element (Mendelevium, Md), because the most common way of arranging the elements—the periodic table—reflects the system he developed. This is an orderly arrangement of all the elements based on similarities in their reactivities and properties.

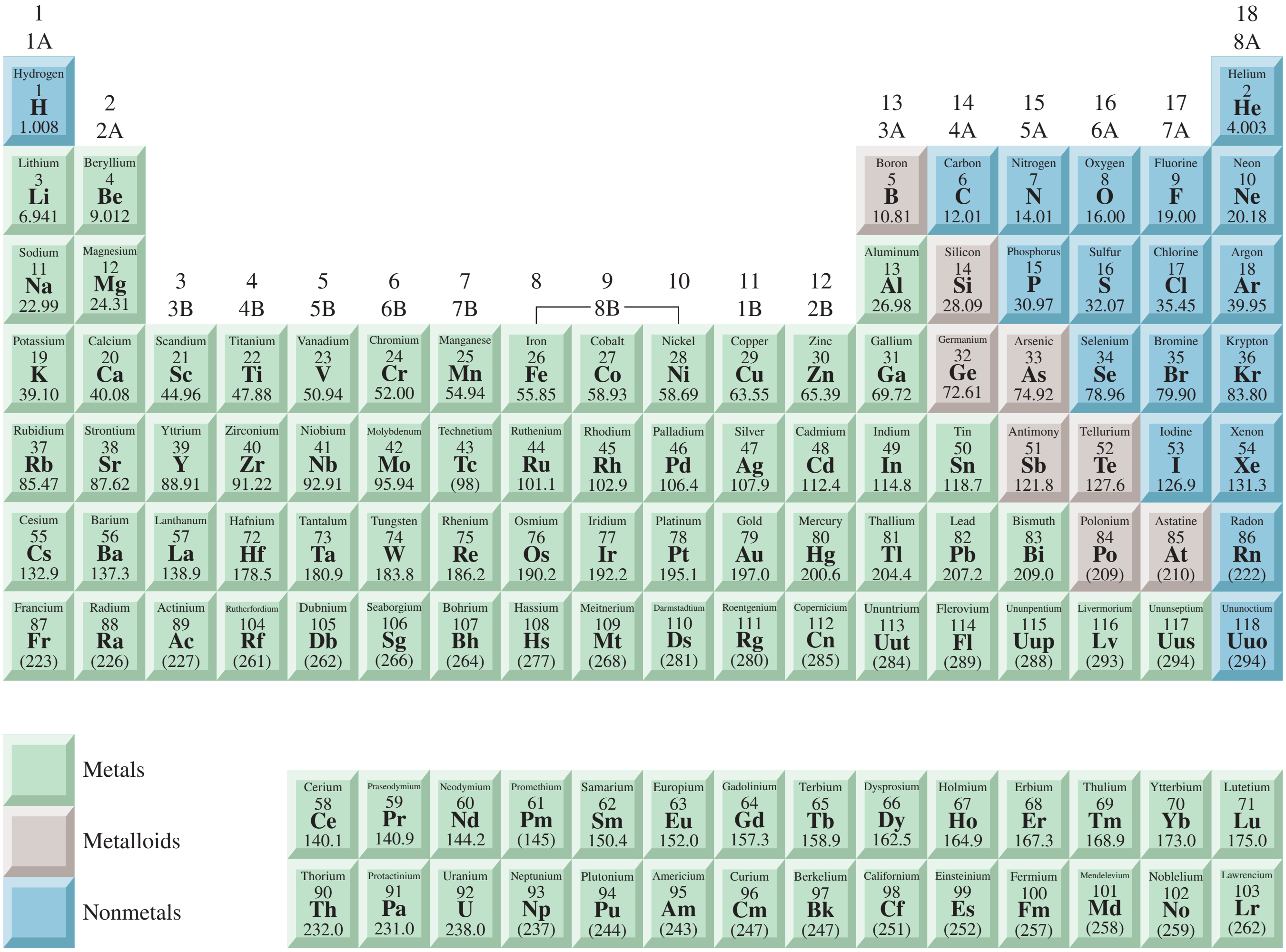
About 90 elemental substances occur naturally on Earth and, as far as we know, elsewhere in the universe. The other two dozen or so elements, including those most recently discovered, have been created from existing elements through nuclear reactions. Plutonium is probably the best known of the synthetic elements, although it does occur in trace amounts in nature.

Four new elements were recognized in 2015 after being discovered years earlier. Elements 113, 115, 117, and 118 have been named Nihonium (Nh; one of two ways to say Japan in Japanese), Moscovium (Mc; to recognize a laboratory in Moscow, Russia), Tennessine (Ts; to recognize laboratories in Tennessee in the U.S.), and Oganesson (Og; to recognize the Russian nuclear physicist Yuri Oganessian), respectively.

Among all known elements, the vast majority are solids at room temperature. At room temperature, nitrogen ($N_2(g)$), oxygen ($O_2(g)$), argon ($Ar(g)$), and eight other elements are gases; in contrast, only bromine ($Br_2(l)$) and mercury ($Hg(l)$) are liquids.

Throughout the text, we will use italics to indicate the phase of the substance; *(s)* indicates a solid, *(l)* a liquid, and *(g)* a gas. In Section 1.4, we will describe why only some elements need a "2" subscript.

The modern periodic table shown in Figure 1.2 lists the elements by number. The green shading indicates the *metals*, which represent most of the periodic table. These elements are usually solid at room temperature, shiny in appearance, may be permanently deformed without breaking or cracking, and are effective conductors of electricity and heat. Ancient civilizations used some metallic elements (iron, copper, tin, lead, gold, and silver) for weaponry, currency, and decoration. Today, the cases of portable electronic devices sometimes employ the metal aluminum, and the circuitry that powers the device utilizes metals such as gold, copper, and tin.



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1A	2A	3B	4B	5B	6B	7B	8B			1B	2B	3A	4A	5A	6A	7A	8A
Hydrogen 1 **H** 1.008																	Helium 2 **He** 4.003
Lithium 3 **Li** 6.941	Beryllium 4 **Be** 9.012											Boron 5 **B** 10.81	Carbon 6 **C** 12.01	Nitrogen 7 **N** 14.01	Oxygen 8 **O** 16.00	Fluorine 9 **F** 19.00	Neon 10 **Ne** 20.18
Sodium 11 **Na** 22.99	Magnesium 12 **Mg** 24.31											Aluminum 13 **Al** 26.98	Silicon 14 **Si** 28.09	Phosphorus 15 **P** 30.97	Sulfur 16 **S** 32.07	Chlorine 17 **Cl** 35.45	Argon 18 **Ar** 39.95
Potassium 19 **K** 39.10	Calcium 20 **Ca** 40.08	Scandium 21 **Sc** 44.96	Titanium 22 **Ti** 47.88	Vanadium 23 **V** 50.94	Chromium 24 **Cr** 52.00	Manganese 25 **Mn** 54.94	Iron 26 **Fe** 55.85	Cobalt 27 **Co** 58.93	Nickel 28 **Ni** 58.69	Copper 29 **Cu** 63.55	Zinc 30 **Zn** 65.39	Gallium 31 **Ga** 69.72	Germanium 32 **Ge** 72.61	Arsenic 33 **As** 74.92	Selenium 34 **Se** 78.96	Bromine 35 **Br** 79.90	Krypton 36 **Kr** 83.80
Rubidium 37 **Rb** 85.47	Strontium 38 **Sr** 87.62	Yttrium 39 **Y** 88.91	Zirconium 40 **Zr** 91.22	Niobium 41 **Nb** 92.91	Molybdenum 42 **Mo** 95.94	Technetium 43 **Tc** (98)	Ruthenium 44 **Ru** 101.1	Rhodium 45 **Rh** 102.9	Palladium 46 **Pd** 106.4	Silver 47 **Ag** 107.9	Cadmium 48 **Cd** 112.4	Indium 49 **In** 114.8	Tin 50 **Sn** 118.7	Antimony 51 **Sb** 121.8	Tellurium 52 **Te** 127.6	Iodine 53 **I** 126.9	Xenon 54 **Xe** 131.3
Cesium 55 **Cs** 132.9	Barium 56 **Ba** 137.3	Lanthanum 57 **La** 138.9	Hafnium 72 **Hf** 178.5	Tantalum 73 **Ta** 180.9	Tungsten 74 **W** 183.8	Rhenium 75 **Re** 186.2	Osmium 76 **Os** 190.2	Iridium 77 **Ir** 192.2	Platinum 78 **Pt** 195.1	Gold 79 **Au** 197.0	Mercury 80 **Hg** 200.6	Thallium 81 **Tl** 204.4	Lead 82 **Pb** 207.2	Bismuth 83 **Bi** 209.0	Polonium 84 **Po** (209)	Astatine 85 **At** (210)	Radon 86 **Rn** (222)
Francium 87 **Fr** (223)	Radium 88 **Ra** (226)	Actinium 89 **Ac** (227)	Rutherfordium 104 **Rf** (261)	Dubnium 105 **Db** (262)	Seaborgium 106 **Sg** (266)	Bohrium 107 **Bh** (264)	Hassium 108 **Hs** (277)	Meitnerium 109 **Mt** (268)	Darmstadium 110 **Ds** (281)	Roentgenium 111 **Rg** (280)	Copernicium 112 **Cn** (285)	Ununtrium 113 **Uut** (284)	Flerovium 114 **Fl** (289)	Ununpentium 115 **Uup** (288)	Livermorium 116 **Lv** (293)	Ununseptium 117 **Uus** (294)	Ununoctium 118 **Uuo** (294)
				Cerium 58 **Ce** 140.1	Praseodymium 59 **Pr** 140.9	Neodymium 60 **Nd** 144.2	Promethium 61 **Pm** (145)	Samarium 62 **Sm** 150.4	Europium 63 **Eu** 152.0	Gadolinium 64 **Gd** 157.3	Terbium 65 **Tb** 158.9	Dysprosium 66 **Dy** 162.5	Holmium 67 **Ho** 164.9	Erbium 68 **Er** 167.3	Thulium 69 **Tm** 168.9	Ytterbium 70 **Yb** 173.0	Lutetium 71 **Lu** 175.0
				Thorium 90 **Th** 232.0	Protactinium 91 **Pa** 231.0	Uranium 92 **U** 238.0	Neptunium 93 **Np** (237)	Plutonium 94 **Pu** (244)	Americium 95 **Am** (243)	Curium 96 **Cm** (247)	Berkelium 97 **Bk** (247)	Californium 98 **Cf** (251)	Einsteinium 99 **Es** (252)	Fermium 100 **Fm** (257)	Mendelevium 101 **Md** (258)	Nobelium 102 **No** (259)	Lawrencium 103 **Lr** (262)

Figure 1.2

The periodic table of elements, showing the locations of metals, metalloids, and nonmetals.

Did You Know? Lothar Meyer (1830–1895), a German chemist, also developed a periodic table at the same time as Mendeleev. Interestingly, both periodic tables were developed independently, but were nearly identical to each other.

Far fewer in number are the *nonmetals*—elements that may be in gaseous, liquid, or solid states at room temperature. The nonmetals are characterized by poor conductivity of heat or electricity, and those in the solid state cannot be deformed without cracking or breaking. A mere eight elements fall into a category known as *metalloids*—elements that lie between metals and nonmetals in the periodic table, and whose properties do not fall cleanly into either category. As a reflection of their intermediate electrical conductivity relative to metals and nonmetals, the metalloids are also often called *semimetals* or *semiconductors*. The metalloid element silicon serves as the key component in all integrated circuits, known as *chips*, that are at the heart of all electronic devices.

Your Turn 1.3 Scientific Practices The Periodic Table Inside Your Cell Phone

Survey the periodic table shown above. Which elements do you think are found in your cell phone?

The elements in the periodic table fall into vertical columns called **groups**. Groups serve to organize elements according to important properties they have in common, and are numbered from left to right. Some groups are given names as well. For example, the metals in the first two columns, Groups 1 and 2, are referred to as the *alkali metals* and *alkaline earth metals*, respectively. Compounds containing metals from either of these groups will give rise to alkaline conditions in soil and water. Additionally, the alkaline earths are mostly responsible for the hard water found in some vicinities.

The nonmetals in Group 17 are known as *halogens*, which include fluorine, chlorine, bromine, and iodine. The final column, Group 18, consists of the *noble gases*—inert elements that undergo few, if any, chemical reactions. You may recognize helium as the noble gas used to make balloons rise, because it is less dense than air. Radon is a noble gas that is radioactive, a characteristic that distinguishes it from the other elements in Group 18.

Chapter 6 will provide more details about radioactivity.

1.2 Atomic Legos—Atoms as Building Blocks for Matter

Elements are made up of *atoms*—the smallest building block that can exist as a stable, independent entity. The word atom comes from the Greek word for "uncuttable." Although today it is possible to "split" atoms using specialized processes, atoms remain indivisible by ordinary chemical or mechanical means.

Atoms are extremely small. Because they are so tiny, we need colossal numbers of them in order to see, touch, or weigh them. For example, a *single drop of water* contains about 5.3×10^{21} atoms. To put this into perspective, this is roughly a trillion times greater than the 7 billion people on Earth—almost enough to give each person a trillion atoms!

Notice a particular format, called *scientific notation*, for '5.3×10^{21} atoms' was used. In decimal notation, that number of atoms would be written as 5,300,000,000,000,000,000,000. More details regarding scientific notation will be provided in Section 1.8.

Although individual atoms are infinitesimally small, we have technology capable of moving them into desired positions and imaging them on a surface. As incredible as this sounds, scientists at Ohio University were able to assemble atoms on a silver surface to create a smiley face (Figure 1.3). **Nanotechnology** refers to the manipulation of matter with at least one dimension sized between 1–100 nanometers, where 1 nanometer (nm) = 1×10^{-9} m. Whereas individual atoms and small molecules are sized in the sub-nanoscopic range, larger biomolecules such as DNA, hemoglobin, and most viruses are nanoscopic in size. Numerous components found in consumer products such as cosmetics, sunscreens, and paints are sized within the nano-regime. The smiley face shown in Figure 1.3 is only a few nanometers tall and wide. At this size, about 250 million smileys could fit on a cross section of a human hair!

Chapter 3 will describe the types of nanoparticles used in sunscreens, as well as their overall benefits and hazards.

In order to convert a quantity into a different unit, a conversion factor must be used. For instance, the conversion of 12 m to nm would be:

$$(12\ \cancel{\text{m}}) \times \left(\frac{1 \times 10^{9}\ \text{nm}}{1\ \cancel{\text{m}}}\right) = 1.2 \times 10^{10}\ \text{nm}$$

When a unit is converted from one form to another, it is often referred to as *dimensional analysis*.

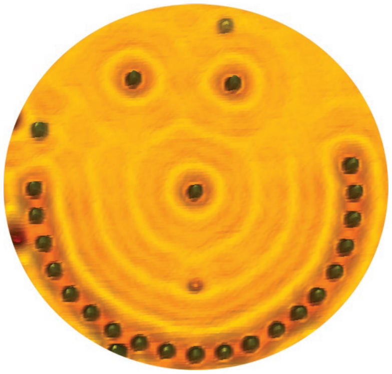


Figure 1.3

A nano-sized smiley face formed by the arrangement of individual silver atoms on a surface, as imaged with a scanning tunneling microscope.

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Your Turn 1.4 Scientific Practices Unit Conversions

In **Your Turn 1.1**, you discovered the extremely small dimensions of an individual hair fiber. Let's now explore other length scales that are in the macroscopic world around us, and the invisible micro- and sub-microscopic worlds that comprise our cell phones.

a. List some examples of macroscopic objects in your surroundings with dimensions (length, width, height, diameter, etc.) on the order of: (i) millimeters, (ii) centimeters, and (iii) meters.
b. Describe the dimensions (length, width, height) of your cell phone or tablet using the three units described in question **a**. Express your answers in standard decimal notation.

1.3 Compounding the Complexity—From Elements to Compounds

Did You Know? Chemists in the late 18th century isolated what they thought were pure Group 2 elements, which were found to be insoluble in water and resistant to heating. The term "earth" was historically used to describe these characteristic properties. However, these chemists had instead isolated *compounds* of the Group 2 elements, such as calcium oxide (CaO) and magnesium oxide (MgO). Years later, it was discovered that pure alkaline earth metals have drastically different properties than these compounds, such as extreme reactivity with water and rapid burning in air with a brilliant-colored flame.

Using the concept of atoms, we can better explain the terms element and compound that are so prevalent in the language of chemistry. Elements are made up of only one kind of atom. For example, the element carbon is made up of carbon atoms only. By contrast, compounds are made up of two or more different kinds of atoms that are chemically bonded to one another. For instance, the compound aluminum oxide (Al_2O_3) contains both aluminum and oxygen atoms in a 2:3 ratio. Silicon dioxide (SiO_2) is made up of silicon and oxygen atoms.

A **chemical formula** is a symbolic way to represent the elementary composition of a substance. It reveals both the elements present (by chemical symbols) and the atomic ratio of those elements (by the subscripts). For example, in the compound CO_2, the elements C and O are present in a ratio of one carbon atom for every two oxygen atoms. Similarly, H_2O indicates two hydrogen atoms for each oxygen atom. Note that when an atom occurs only once, such as the O in H_2O or the C in CO_2, the subscript of "1" is omitted.

So what about the term **molecule** that is so pervasive in chemistry vocabulary? Are molecules the same as compounds? Are elements also considered molecules? The definition of compounds and molecules is quite similar—both being the combination of more than one atom in a specific spatial arrangement. However, only molecules may feature a single type of atom. For instance, water (H_2O) is considered *both* a compound and a molecule, because it is composed of two different types of atoms—hydrogen and oxygen. In contrast, ozone (O_3) is best referred to as a molecule, but is *not* considered a compound because only oxygen is present.

At this juncture, it would be tempting to say that all compounds could also be defined as molecules (*e.g.*, H_2O, CO_2, SO_2). This is indeed the case for compounds composed of two or more nonmetals, which are commonly denoted as **molecular compounds**. However, this is not accurate if the compound contains a metal and nonmetal. For instance, when the metal sodium combines with the nonmetal chlorine, the compound NaCl is formed. This substance is referred to as an **ionic compound** and should not be designated as a molecule. We will describe more about ions in Section 1.7; however, at this stage, consider ions to be either positively charged or negatively charged species that are held together by their mutual attraction. Hence, the building blocks for these types of compounds are oppositely charged ions instead of neutral atoms. Figure 1.4 provides a summarizing definition scheme for elements, compounds, molecules, and atoms.

Your Turn 1.5 Skill Building Classification of Matter

Use the classification scheme shown in **Figure 1.4** to categorize the following:

a. Your cell phone
b. Aluminum foil
c. Red wine
d. Chlorine gas
e. Stainless steel
f. Table salt
g. Sugar

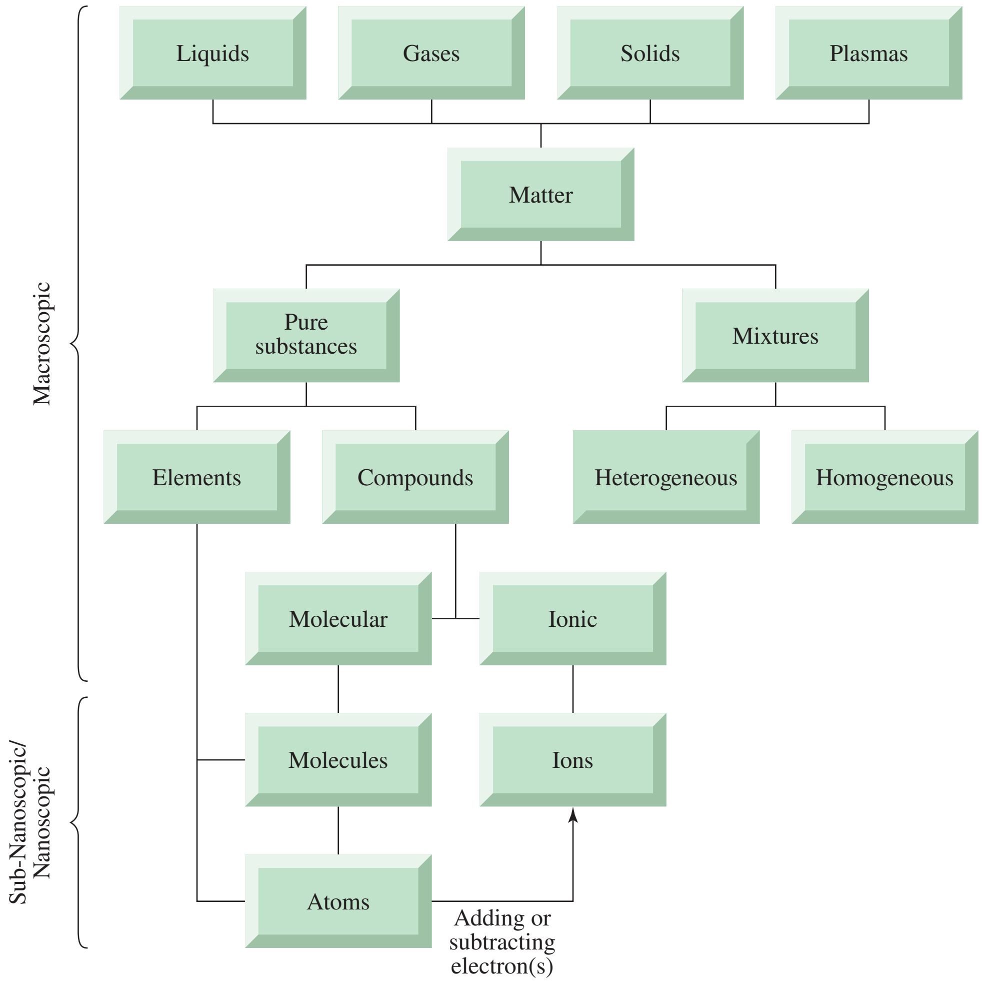

Figure 1.4

An explicit classification scheme for matter, showing the difference between elements and the two types of compounds: ionic and molecular. The formation of ions from atoms will be discussed in Section 1.7.

Although 118 elements exist, over 20 million compounds have been isolated, identified, and characterized. Some are very familiar, naturally occurring substances such as water, table salt, and sucrose (*i.e.,* table sugar). Many known compounds are chemically synthesized by people across our planet. You might be wondering how 20 million compounds could possibly be formed from so few elements. But consider that over 1 million words in the English language can be formed from only 26 letters.

For example, iron and oxygen can combine in a number of different ways. Anyone who has driven extensively on salty roads during the winter has observed the compound Fe_2O_3, or rust, on the metal sides or undercarriages of cars. Pure samples of this compound will contain 69.9% iron and 30.1% oxygen atoms by mass. Thus, 100 grams of rust will always consist of 70 grams of iron atoms and 30 grams of oxygen atoms, which are chemically combined to form this particular compound. These values never vary, no matter where the rust is found. Every compound exhibits a constant characteristic chemical composition.

A small paper clip weighs about a gram.

However, iron atoms may also combine with oxygen atoms to form a different compound, Fe_3O_4, which is referred to as magnetite. A pure sample of Fe_3O_4 contains 72.4% iron atoms and 27.6% oxygen atoms by mass. You might be wondering that if the formula of magnetite contains a 3:4 Fe:O atomic ratio, why isn't the composition expressed as 43% Fe (that is, $\frac{3\text{ Fe atoms}}{7\text{ atoms total}}$) and 57% O (that is, $\frac{4\text{ O atoms}}{7\text{ atoms total}}$)? Similarly, why doesn't the compound Fe_2O_3 above have 40% Fe (that is, $\frac{2\text{ Fe atoms}}{5\text{ atoms total}}$) and 60% O (that is, $\frac{3\text{ O atoms}}{5\text{ atoms total}}$)? If iron and oxygen atoms had the same masses, these calculations would exactly describe the composition of each compound. However, if you compare the weight of a piece of iron relative to a similar-sized piece of aluminum, the iron will be much heavier. Hence, every