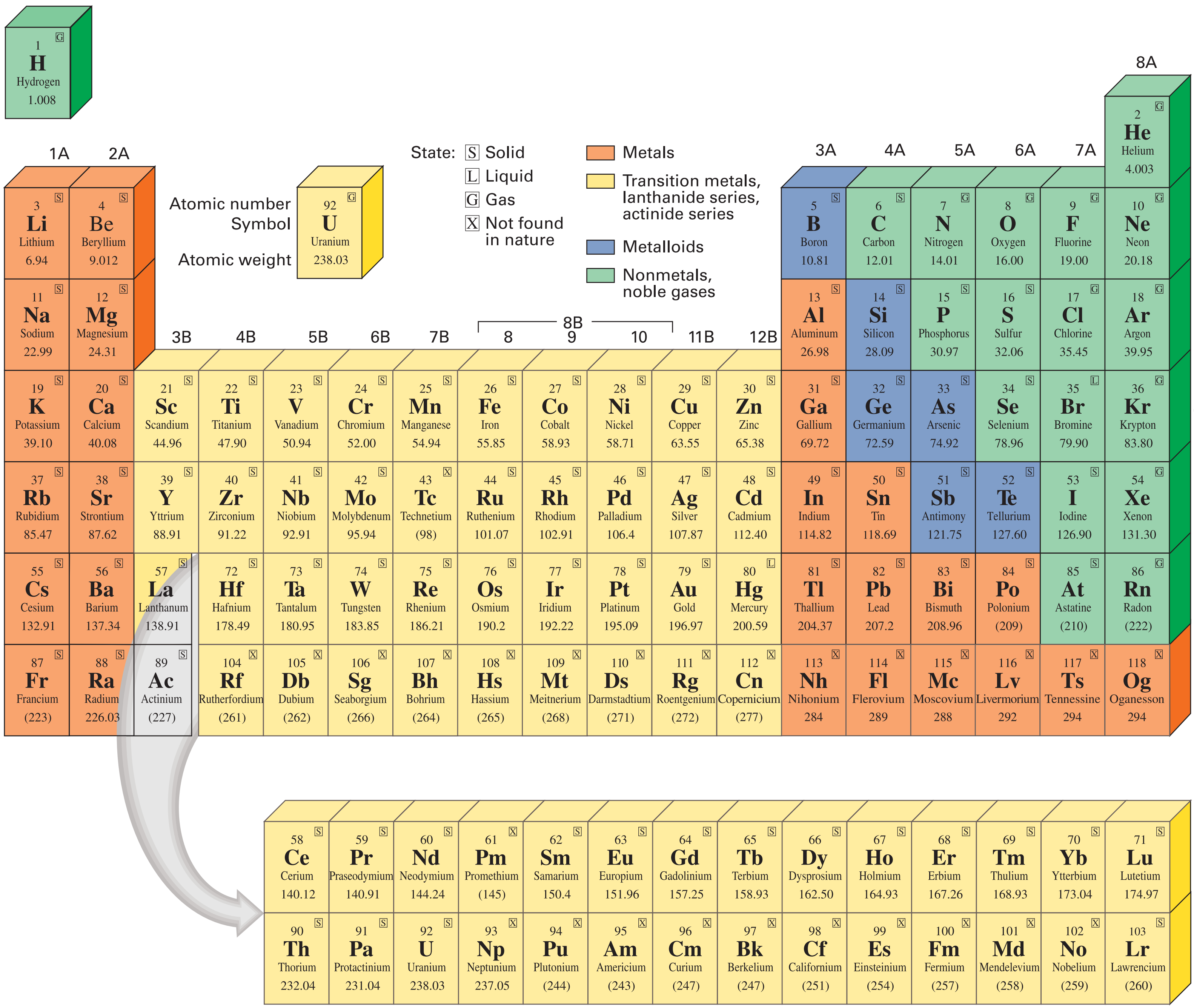
CHEMISTRY IN FOCUS

A Molecular View of Our World 7e

NIVALDO J. TRO

Periodic Table of the Elements



Atomic number 92 G
Symbol U
Uranium
Atomic weight 238.03

State: S Solid
L Liquid
G Gas
X Not found in nature

🟧 Metals
🟨 Transition metals, lanthanide series, actinide series
🟦 Metalloids
🟩 Nonmetals, noble gases

1A	2A	3B	4B	5B	6B	7B	8B 8	8B 9	8B 10	11B	12B	3A	4A	5A	6A	7A	8A	
1 G **H** Hydrogen 1.008																	2 G **He** Helium 4.003	1
3 S **Li** Lithium 6.94	4 S **Be** Beryllium 9.012											5 S **B** Boron 10.81	6 S **C** Carbon 12.01	7 G **N** Nitrogen 14.01	8 G **O** Oxygen 16.00	9 G **F** Fluorine 19.00	10 G **Ne** Neon 20.18	2
11 S **Na** Sodium 22.99	12 S **Mg** Magnesium 24.31											13 S **Al** Aluminum 26.98	14 S **Si** Silicon 28.09	15 S **P** Phosphorus 30.97	16 S **S** Sulfur 32.06	17 G **Cl** Chlorine 35.45	18 G **Ar** Argon 39.95	3
19 S **K** Potassium 39.10	20 S **Ca** Calcium 40.08	21 S **Sc** Scandium 44.96	22 S **Ti** Titanium 47.90	23 S **V** Vanadium 50.94	24 S **Cr** Chromium 52.00	25 S **Mn** Manganese 54.94	26 S **Fe** Iron 55.85	27 S **Co** Cobalt 58.93	28 S **Ni** Nickel 58.71	29 S **Cu** Copper 63.55	30 S **Zn** Zinc 65.38	31 S **Ga** Gallium 69.72	32 S **Ge** Germanium 72.59	33 S **As** Arsenic 74.92	34 S **Se** Selenium 78.96	35 L **Br** Bromine 79.90	36 G **Kr** Krypton 83.80	4
37 S **Rb** Rubidium 85.47	38 S **Sr** Strontium 87.62	39 S **Y** Yttrium 88.91	40 S **Zr** Zirconium 91.22	41 S **Nb** Niobium 92.91	42 S **Mo** Molybdenum 95.94	43 X **Tc** Technetium (98)	44 S **Ru** Ruthenium 101.07	45 S **Rh** Rhodium 102.91	46 S **Pd** Palladium 106.4	47 S **Ag** Silver 107.87	48 S **Cd** Cadmium 112.40	49 S **In** Indium 114.82	50 S **Sn** Tin 118.69	51 S **Sb** Antimony 121.75	52 S **Te** Tellurium 127.60	53 S **I** Iodine 126.90	54 G **Xe** Xenon 131.30	5
55 S **Cs** Cesium 132.91	56 S **Ba** Barium 137.34	57 S **La** Lanthanum 138.91	72 S **Hf** Hafnium 178.49	73 S **Ta** Tantalum 180.95	74 S **W** Tungsten 183.85	75 S **Re** Rhenium 186.21	76 S **Os** Osmium 190.2	77 S **Ir** Iridium 192.22	78 S **Pt** Platinum 195.09	79 S **Au** Gold 196.97	80 L **Hg** Mercury 200.59	81 S **Tl** Thallium 204.37	82 S **Pb** Lead 207.2	83 S **Bi** Bismuth 208.96	84 S **Po** Polonium (209)	85 S **At** Astatine (210)	86 G **Rn** Radon (222)	6
87 S **Fr** Francium (223)	88 S **Ra** Radium 226.03	89 S **Ac** Actinium (227)	104 X **Rf** Rutherfordium (261)	105 X **Db** Dubium (262)	106 X **Sg** Seaborgium (266)	107 X **Bh** Bohrium (264)	108 X **Hs** Hassium (265)	109 X **Mt** Meitnerium (268)	110 X **Ds** Darmstadtium (271)	111 X **Rg** Roentgenium (272)	112 X **Cn** Copernicium (277)	113 X **Nh** Nihonium 284	114 X **Fl** Flerovium 289	115 X **Mc** Moscovium 288	116 X **Lv** Livermorium 292	117 X **Ts** Tennessine 294	118 X **Og** Oganesson 294	7

58 S **Ce** Cerium 140.12	59 S **Pr** Praseodymium 140.91	60 S **Nd** Neodymium 144.24	61 X **Pm** Promethium (145)	62 S **Sm** Samarium 150.4	63 S **Eu** Europium 151.96	64 S **Gd** Gadolinium 157.25	65 S **Tb** Terbium 158.93	66 S **Dy** Dysprosium 162.50	67 S **Ho** Holmium 164.93	68 S **Er** Erbium 167.26	69 S **Tm** Thulium 168.93	70 S **Yb** Ytterbium 173.04	71 S **Lu** Lutetium 174.97
90 S **Th** Thorium 232.04	91 S **Pa** Protactinium 231.04	92 S **U** Uranium 238.03	93 X **Np** Neptunium 237.05	94 X **Pu** Plutonium (244)	95 X **Am** Americium (243)	96 X **Cm** Curium (247)	97 X **Bk** Berkelium (247)	98 X **Cf** Californium (251)	99 X **Es** Einsteinium (254)	100 X **Fm** Fermium (257)	101 X **Md** Mendelevium (258)	102 X **No** Nobelium (259)	103 S **Lr** Lawrencium (260)

CHEMISTRY IN FOCUS 7e

A Molecular View of Our World

Nivaldo J. Tro
WESTMONT COLLEGE

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Brief Contents

To access the following online-only material, enter ISBN 978-1-337-39969-2 at **www.cengagebrain.com** and visit this book's companion website.

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Preface

To the Instructor

The two main goals of this book are for students to understand the molecular world and to understand the scientific issues that face society.

Chemistry in Focus is a text designed for a one-semester college chemistry course for students not majoring in the sciences. This book has two main goals: the first is to develop in students an appreciation for the molecular world and the fundamental role it plays in daily life; the second is to develop in students an understanding of the major scientific and technological issues affecting our society.

A MOLECULAR FOCUS

The first goal is essential. Students should leave this course understanding that the world is composed of atoms and molecules and that everyday processes—water boiling, pencils writing, soap cleaning—are caused by atoms and molecules. After taking this course, a student should look at water droplets, salt crystals, and even the paper and ink of their texts in a different way. They should know, for example, that beneath the surface of a water droplet or a grain of salt lie profound reasons for each of their properties. From the opening example to the closing chapter, this text maintains this theme through a consistent focus on explaining the macroscopic world in terms of the molecular world.


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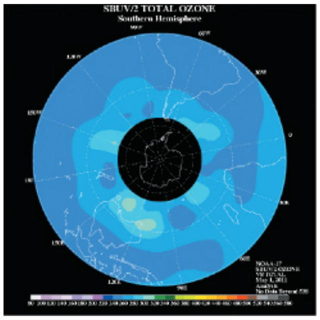
The art program, a unique component of this text, emphasizes the connection between what we see—the macroscopic world—and what we cannot see—the molecular world. Throughout the text, photographs of everyday objects or processes are magnified to show the molecules and atoms responsible for them. The molecules within these magnifications are depicted using space-filling models to help students develop the most accurate picture of the molecular world. Similarly, many molecular formulas are portrayed not only with structural formulas but with space-filling drawings as well. Students are not meant to understand every detail of these formulas—because they are not scientists, they do not need to. Rather, they should begin to appreciate the beauty and form of the molecular world. Such an appreciation will enrich their lives as it has enriched the lives of those of us who have chosen science and science education as our career paths.

CHEMISTRY IN A SOCIETAL AND ENVIRONMENTAL CONTEXT

The other primary goal of this text is to develop in students an understanding of the scientific, technological, and environmental issues facing them as citizens and consumers. They should leave this course with an understanding of the impact of chemistry on society and on humankind's view of itself. Topics such as global warming, ozone depletion, acid rain, drugs, medical technology, and consumer products are covered in detail. In the early chapters, which focus primarily on chemical and molecular concepts, many of the box features introduce these applications and environmental concerns. The later chapters focus on these topics directly and in more detail.


NOAA

MAKING CONNECTIONS

Throughout the text, I have made extensive efforts to help students make connections, both between the molecular and macroscopic world and between principles and applications. The chapter summaries are designed to reinforce those connections, particularly between chemical concepts and societal impact. The chapter summaries consist of two columns, one summarizing the major molecular concepts of the chapter and the other, the impacts of those concepts on society. By putting these summaries side by side, the student can clearly see the connections.


Key Terms 225

SUMMARY

Molecular Concept

Radioactivity, discovered by Becquerel and the Curies, consists of energetic particles emitted by unstable nuclei **(8.1, 8.2)**. *Alpha radiation* consists of helium nuclei that have high ionizing power but low penetrating power. *Beta radiation* consists of electrons emitted when a neutron within an atomic nucleus converts into a proton. Beta particles have lower ionizing power than alpha particles, but higher penetrating power. *Gamma radiation* is high-energy electromagnetic radiation with low ionizing power but high penetrating power **(8.3)**. Unstable nuclei radioactively decay according to their *half-life*, the time it takes for one-half of the nuclei in a given sample to decay **(8.4)**.

Some heavy elements, such as U-235 and Pu-239, can become unstable and undergo *fission* when bombarded with neutrons **(8.5)**. The atom splits to form lighter elements, neutrons, and energy. If fission is kept under control, the emitted energy can be used to generate electricity. If fission is forced to escalate, it results in an atomic bomb **(8.6, 8.7)**. *Hydrogen bombs*, similar to the Sun, employ a different type of nuclear reaction called *fusion* in which the nuclei of lighter elements combine to form heavier ones. In all nuclear reactions that produce energy, some mass is converted to energy in the reaction **(8.8, 8.9)**.

By measuring the levels of certain radioactive elements in fossils or rocks, radioactivity can be used to date objects. The age of Earth is estimated to be 4.5 billion years based on the ratio of uranium to lead in the oldest rocks **(8.10, 8.12)**. High levels of radioactivity can kill human life. Lower levels can be used in therapeutic fashion to either diagnose or treat disease **(8.13)**.

Societal Impact

➡ The discovery of radiation has had many impacts on our society. It ultimately led to the *Manhattan Project*, the construction and detonation of the first atomic bomb in 1945. For the first time, in a very tangible way, society could see the effects of the power that science had given to it **(8.5, 8.6)**. Yet science itself did not drop the bomb on Japan; it was the people of the United States who did that, and the question remains—how do we use the power that technology can give? Since then, our society has struggled with the ethical implications of certain scientific discoveries. For the past decade, nuclear weapons have been disarmed at the rate of 2000 bombs per year. Today, we live in an age when the threat of nuclear annihilation is less severe.

➡ Nuclear fission is used to generate electricity without the harmful side effects associated with fossil-fuel combustion. Yet nuclear power has its own problems, namely the potential for accidents and waste disposal **(8.7)**. Will the United States build a permanent site for nuclear waste disposal? Will we turn to nuclear power as the fossil fuel supply dwindles away? How many resources will we put into the development of fusion as a future energy source? These are all questions that our society faces as we begin this new millennium.

➡ Nuclear processes have been able to tell us how old we are. Archaeological discoveries are fitted into a chronological puzzle that tells about human history from the very earliest times. We know that billions of years passed on Earth before humans ever existed. We know how certain humans began to use tools, and how they migrated and moved around on Earth. We can date specific items such as the Shroud of Turin and determine if they are genuine **(8.11, 8.12)**. What effect does this scientific viewpoint have on our society? On religion? What does it tell us about who we are?

KEY TERMS

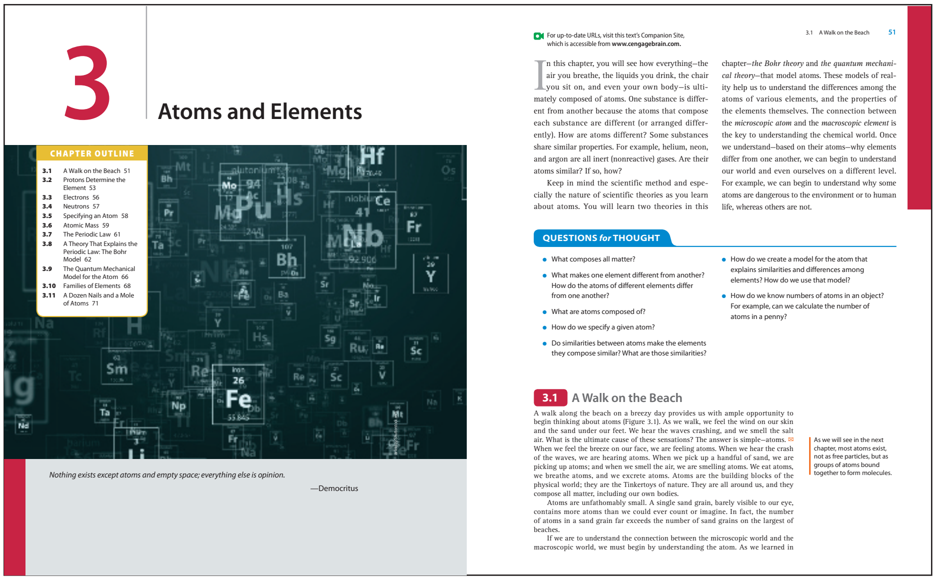
Antoine-Henri Becquerel
critical mass
Marie Sklodowska Curie
Pierre Curie
Albert Einstein
Enrico Fermi
fission
fusion
Otto Hahn
half-life
ionizing power
mass defect
Lise Meitner
nuclear binding energy
nuclear equation
J. R. Oppenheimer
radon
Sievert (Sv)
Fritz Strassmann
Leo Szilard

A Tour of the Text

GENERAL CHAPTER STRUCTURE

Each chapter opens with a brief paragraph introducing the chapter's main topics and explaining to students why these topics are relevant to their lives. These openers pose questions to help students understand the importance of the topics. For example, the opening paragraphs to Chapter 1 state, "As you read these pages, think about the scientific method—its inception just a few hundred years ago has changed human civilization. What are some of those changes? How has the scientific method directly impacted the way you and I live?"

Each chapter introduces the material with *Questions for Thought.*


3

Atoms and Elements

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Nothing exists except atoms and empty space; everything else is opinion.

—Democritus

For up-to-date URLs, visit this text's Companion Site, which is accessible from **www.cengagebrain.com.**

3.1 A Walk on the Beach 51

In this chapter, you will see how everything—the air you breathe, the liquids you drink, the chair you sit on, and even your own body—is ultimately composed of atoms. One substance is different from another because the atoms that compose each substance are different (or arranged differently). How are atoms different? Some substances share similar properties. For example, helium, neon, and argon are all inert (nonreactive) gases. Are their atoms similar? If so, how?

Keep in mind the scientific method and especially the nature of scientific theories as you learn about atoms. You will learn two theories in this chapter—*the Bohr theory* and *the quantum mechanical theory*—that model atoms. These models of reality help us to understand the differences among the atoms of various elements, and the properties of the elements themselves. The connection between the *microscopic atom* and the *macroscopic element* is the key to understanding the chemical world. Once we understand—based on their atoms—why elements differ from one another, we can begin to understand our world and even ourselves on a different level. For example, we can begin to understand why some atoms are dangerous to the environment or to human life, whereas others are not.

QUESTIONS *for* THOUGHT

- What composes all matter?
- What makes one element different from another? How do the atoms of different elements differ from one another?
- What are atoms composed of?
- How do we specify a given atom?
- Do similarities between atoms make the elements they compose similar? What are those similarities?
- How do we create a model for the atom that explains similarities and differences among elements? How do we use that model?
- How do we know numbers of atoms in an object? For example, can we calculate the number of atoms in a penny?

3.1 A Walk on the Beach

A walk along the beach on a breezy day provides us with ample opportunity to begin thinking about atoms (Figure 3.1). As we walk, we feel the wind on our skin and the sand under our feet. We hear the waves crashing, and we smell the salt air. What is the ultimate cause of these sensations? The answer is simple—atoms. ✉ When we feel the breeze on our face, we are feeling atoms. When we hear the crash of the waves, we are hearing atoms. When we pick up a handful of sand, we are picking up atoms; and when we smell the air, we are smelling atoms. We eat atoms, we breathe atoms, and we excrete atoms. Atoms are the building blocks of the physical world; they are the Tinkertoys of nature. They are all around us, and they compose all matter, including our own bodies.

As we will see in the next chapter, most atoms exist, not as free particles, but as groups of atoms bound together to form molecules.

Atoms are unfathomably small. A single sand grain, barely visible to our eye, contains more atoms than we could ever count or imagine. In fact, the number of atoms in a sand grain far exceeds the number of sand grains on the largest of beaches.

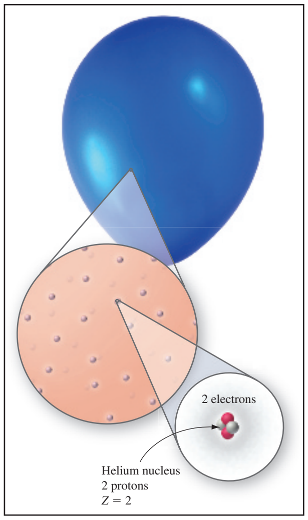
If we are to understand the connection between the microscopic world and the macroscopic world, we must begin by understanding the atom. As we learned in

The opening paragraphs of each chapter are followed by *Questions for Thought* directly related to chapter content. These questions are answered in the main body of each chapter; presenting them early provides a context for the chapter material.

Most chapters, as appropriate, follow with a description or thought experiment about an everyday experience. The observations of the thought experiment are then explained in molecular terms. For example, a familiar experience may be washing a greasy dish with soapy water. Why does plain water not dissolve the grease? The molecular reason is then given, enhanced by artwork that shows a picture of a soapy dish and a magnification showing what happens with the molecules.

Continuing this theme, the main body of each chapter introduces chemical principles in the context of discovering the molecular causes behind everyday observations. What is it about helium *atoms* that makes it possible to breathe small amounts of helium *gas*—as in a helium balloon—without adverse side effects? What is it about chlorine *atoms* that makes breathing chlorine *gas* dangerous? What happens to water *molecules* when water boils? These questions have molecular answers that teach and illustrate chemical principles. The text develops the chemical principles and concepts involved in a molecular understanding of the macroscopic observations.

Once the student is introduced to basic concepts, consumer applications and environmental problems follow. The text, however, does not separate principles and applications. Early chapters involving basic principles also contain applications, and later chapters with more emphasis on applications build on and expand basic principles.



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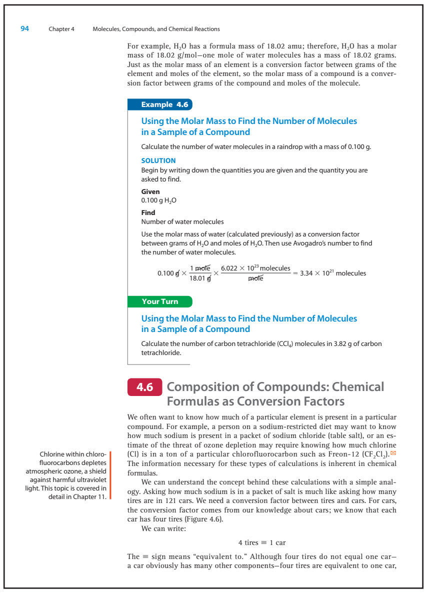
EXAMPLES AND YOUR TURN EXERCISES

Example problems are included throughout the text, followed by related *Your Turn* exercises for student practice. In designing the text, I made allowances for different instructor preferences on quantitative material. Although a course for nonmajors is not usually highly quantitative, some instructors prefer more quantitative material than others. To accommodate individual preferences, many quantitative sections, including some *Examples* and *Your Turn* exercises, can be easily omitted. These are often placed toward the end of chapters for easy omission. Similarly, exercises in the back of each chapter that rely on quantitative material can also be easily omitted. Instructors desiring a more quantitative course should include these sections, whereas those wanting a more qualitative course can skip them. The answers to the *Your Turn* exercises can be found in Appendix 3.



94 Chapter 4 Molecules, Compounds, and Chemical Reactions

For example, H_2O has a formula mass of 18.02 amu; therefore, H_2O has a molar mass of 18.02 g/mol—one mole of water molecules has a mass of 18.02 grams. Just as the molar mass of an element is a conversion factor between grams of the element and moles of the element, so the molar mass of a compound is a conversion factor between grams of the compound and moles of the molecule.

Example 4.6

Using the Molar Mass to Find the Number of Molecules in a Sample of a Compound

Calculate the number of water molecules in a raindrop with a mass of 0.100 g.

SOLUTION

Begin by writing down the quantities you are given and the quantity you are asked to find.

Given

0.100 g H_2O

Find

Number of water molecules

Use the molar mass of water (calculated previously) as a conversion factor between grams of H_2O and moles of H_2O. Then use Avogadro's number to find the number of water molecules.

$$0.100\,\cancel{g} \times \frac{1\,\cancel{mole}}{18.01\,\cancel{g}} \times \frac{6.022 \times 10^{23}\,\text{molecules}}{\cancel{mole}} = 3.34 \times 10^{21}\,\text{molecules}$$

Your Turn

Using the Molar Mass to Find the Number of Molecules in a Sample of a Compound

Calculate the number of carbon tetrachloride (CCl_4) molecules in 3.82 g of carbon tetrachloride.

4.6 Composition of Compounds: Chemical Formulas as Conversion Factors

We often want to know how much of a particular element is present in a particular compound. For example, a person on a sodium-restricted diet may want to know how much sodium is present in a packet of sodium chloride (table salt), or an estimate of the threat of ozone depletion may require knowing how much chlorine (Cl) is in a ton of a particular chlorofluorocarbon such as Freon-12 (CF_2Cl_2). ✉ The information necessary for these types of calculations is inherent in chemical formulas.

Chlorine within chlorofluorocarbons depletes atmospheric ozone, a shield against harmful ultraviolet light. This topic is covered in detail in Chapter 11.

We can understand the concept behind these calculations with a simple analogy. Asking how much sodium is in a packet of salt is much like asking how many tires are in 121 cars. We need a conversion factor between tires and cars. For cars, the conversion factor comes from our knowledge about cars; we know that each car has four tires (Figure 4.6).

We can write:

$$4 \text{ tires} \equiv 1 \text{ car}$$

The ≡ sign means "equivalent to." Although four tires do not equal one car—a car obviously has many other components—four tires are equivalent to one car,

BOXED FEATURES

Molecular Thinking

Molecular Thinking boxes describe an everyday observation related to the chapter material. The student is then asked to explain the observation based on what the molecules are doing. For example, in Chapter 4, when chemical equations and combustion are discussed, the *Molecular Thinking* box describes how a fire will burn hotter in the presence of wind. The student is then asked to give a molecular reason—based on what was just learned about chemical equations and combustion—to explain this observation.

6.14 A Look at a Label 169

Molecular Thinking

What Happens When We Smell Something

Air contains primarily two kinds of molecules, oxygen (about 20% of air) and nitrogen (about 80% of air). These molecules move at high speeds and collide with each other and everything else. The collective effect of these collisions is what we call pressure.

We are constantly inhaling and exhaling billions of billions of nitrogen and oxygen molecules, all of which rush through our nose and into our lungs, and most of which rush back out again when we exhale.

If we walk into a blooming rose garden, however, we immediately notice something different when we inhale—a pleasant smell. What causes it? The molecules in the rose garden are not much different from those in ordinary air—20% oxygen and 80% nitrogen. However, there is a small difference—about 1 molecule in every 100 million is *geraniol* or *2-phenylethanol*, the molecules responsible for the smell of roses.

When we inhale these molecules, even in concentrations as small as 1 in 100 million, receptors in our noses grab them. Olfactory receptors are extremely sensitive to molecular shapes and can pick out the one geraniol molecule out of the 100 million nitrogen and oxygen molecules (Figure 6.11). When the geraniol interacts with the receptor in our nose, a nerve signal travels to our brain, which we interpret as *the smell of roses*.

QUESTION: Explain, in molecular terms, why you can stand 2 ft upwind from rotting fish and not smell a thing, whereas 20 ft downwind the odor is unbearable.

David Woolley/Getty Images

Figure 6.11 Geraniol and 2-phenylethanol are the main components of rose scent. The flowers emit these molecules into the air, which is inhaled through the nose.

Geraniol $CH_3C{=}CHCH_2CH_2C{=}CHCH_2OH$ (with CH_3 above each C)

2–Phenylethanol CH_2-CH_2OH

✔ Self-Check 6.7

To what family does the molecule CH_3COOCH_3 belong?

a. carboxylic acid
b. alcohol
c. ether
d. ester

6.14 A Look at a Label

Although we have invested only a small amount of time in our study of organic chemistry, we can now identify several important kinds of organic compounds. For example, the shaving cream Edge Gel lists as its contents deionized water, palmitic acid, triethanolamine, pentane, fatty acid esters, sorbitol, and isobutane.

Boxed features show relevance and ask students to interact with the material.

4.4 Naming Compounds 91

Molecular Focus

Calcium Carbonate

Within most chapters of this text, we will highlight a "celebrity" compound in a Molecular Focus box. You have probably encountered these compounds in your life in some way or another. We begin with calcium carbonate, an ionic compound that is abundant in nature.

Formula: $CaCO_3$
Molar mass: 100.09 g/mol
Melting point: 1339°C (calcite form)

Calcium carbonate is an example of an ionic compound containing a polyatomic ion (CO_3^{2-}). Calcium carbonate is common in nature, occurring in eggshells, seashells, limestone, and marine sediments. It occurs most dramatically in stalactites and stalagmites in limestone caves. These formations develop over time because rainwater, containing atmospheric CO_2 that makes it acidic (more on this in Chapter 13), dissolves calcium carbonate from soils and rocks. As the calcium carbonate–saturated water seeps into the ground, some of the CO_2 escapes, lowering the acidity of the rainwater and causing the calcium carbonate to deposit as a solid. When this occurs in an underground cave, the dripping water forms structures called *stalactites*, which hang down from the ceiling of a cave, and *stalagmites*, which protrude up from the floor of a cave.

Calcium carbonate is used in many consumer products because of its low toxicity, structural stability, and tendency to neutralize acids. It is the main ingredient in a number of building materials, including cement and marble. It also is the main component of popular over-the-counter antacids such as Tums and is commonly used to remove excess acidity from wines.

The stalactites and stalagmites of limestone caves are composed of calcium carbonate.

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Example 4.2

Naming Ionic Compounds

Give the name for the compound MgF_2.

SOLUTION

The cation is *magnesium*. The anion is fluorine, which becomes *fluoride*. The correct name is magnesium fluoride.

Your Turn

Naming Ionic Compounds

Give the name for the compound KBr.

Example 4.3

Naming Ionic Compounds That Contain a Polyatomic Ion

Give the name for the compound NaOH.

(continued)

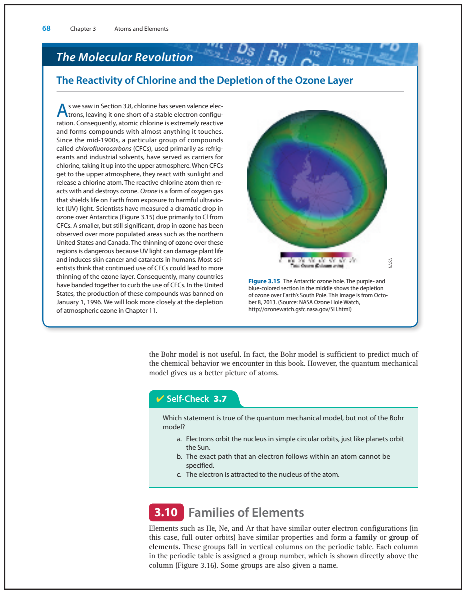
Molecular Focus

Molecular Focus boxes highlight a "celebrity" compound related to the chapter's material. The physical properties and structure of the compound are given and its use(s) described. Featured compounds include calcium carbonate, hydrogen peroxide, ammonia, AZT, retinal, sulfur dioxide, ammonium nitrate, and others.

Celebrity compounds are highlighted.

The Molecular Revolution

The Molecular Revolution boxes highlight topics of modern research and recent technology related to the chapter's material. Examples include measuring global temperatures, imaging atoms with scanning tunneling microscopy, and the development of fuel cell and hybrid electric vehicles.



68 Chapter 3 Atoms and Elements

The Molecular Revolution

The Reactivity of Chlorine and the Depletion of the Ozone Layer

As we saw in Section 3.8, chlorine has seven valence electrons, leaving it one short of a stable electron configuration. Consequently, atomic chlorine is extremely reactive and forms compounds with almost anything it touches. Since the mid-1900s, a particular group of compounds called *chlorofluorocarbons* (CFCs), used primarily as refrigerants and industrial solvents, have served as carriers for chlorine, taking it up into the upper atmosphere. When CFCs get to the upper atmosphere, they react with sunlight and release a chlorine atom. The reactive chlorine atom then reacts with and destroys ozone. *Ozone* is a form of oxygen gas that shields life on Earth from exposure to harmful ultraviolet (UV) light. Scientists have measured a dramatic drop in ozone over Antarctica (Figure 3.15) due primarily to Cl from CFCs. A smaller, but still significant, drop in ozone has been observed over more populated areas such as the northern United States and Canada. The thinning of ozone over these regions is dangerous because UV light can damage plant life and induces skin cancer and cataracts in humans. Most scientists think that continued use of CFCs could lead to more thinning of the ozone layer. Consequently, many countries have banded together to curb the use of CFCs. In the United States, the production of these compounds was banned on January 1, 1996. We will look more closely at the depletion of atmospheric ozone in Chapter 11.

NASA

Figure 3.15 The Antarctic ozone hole. The purple- and blue-colored section in the middle shows the depletion of ozone over Earth's South Pole. This image is from October 8, 2013. (Source: NASA Ozone Hole Watch, http://ozonewatch.gsfc.nasa.gov/SH.html)

the Bohr model is not useful. In fact, the Bohr model is sufficient to predict much of the chemical behavior we encounter in this book. However, the quantum mechanical model gives us a better picture of atoms.

✔ Self-Check 3.7

Which statement is true of the quantum mechanical model, but not of the Bohr model?

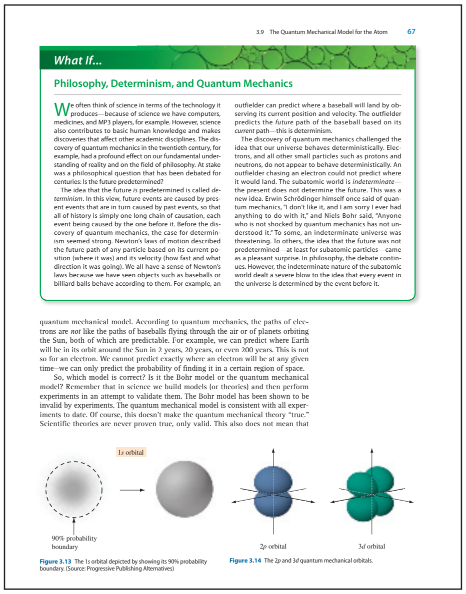
a. Electrons orbit the nucleus in simple circular orbits, just like planets orbit the Sun.
b. The exact path that an electron follows within an atom cannot be specified.
c. The electron is attracted to the nucleus of the atom.

3.10 Families of Elements

Elements such as He, Ne, and Ar that have similar outer electron configurations (in this case, full outer orbits) have similar properties and form a **family** or **group of elements.** These groups fall in vertical columns on the periodic table. Each column in the periodic table is assigned a group number, which is shown directly above the column (Figure 3.16). Some groups are also given a name.

What If . . .

What If . . . boxes discuss topics with societal, political, or ethical implications. At the end of the discussion there are one or more open-ended questions for group discussion. Topics include the Manhattan Project, government subsidies for the development of alternative fuels, stem cell research, and others.



3.9 The Quantum Mechanical Model for the Atom 67

What If...

Philosophy, Determinism, and Quantum Mechanics

We often think of science in terms of the technology it produces—because of science we have computers, medicines, and MP3 players, for example. However, science also contributes to basic human knowledge and makes discoveries that affect other academic disciplines. The discovery of quantum mechanics in the twentieth century, for example, had a profound effect on our fundamental understanding of reality and on the field of philosophy. At stake was a philosophical question that has been debated for centuries: Is the future predetermined?

The idea that the future *is* predetermined is called *determinism*. In this view, future events are caused by present events that are in turn caused by past events, so that all of history is simply one long chain of causation, each event being caused by the one before it. Before the discovery of quantum mechanics, the case for determinism seemed strong. Newton's laws of motion described the future path of any particle based on its current position (where it was) and its velocity (how fast and what direction it was going). We all have a sense of Newton's laws because we have seen objects such as baseballs or billiard balls behave according to them. For example, an outfielder can predict where a baseball will land by observing its current position and velocity. The outfielder predicts the *future* path of the baseball based on its *current* path—this is determinism.

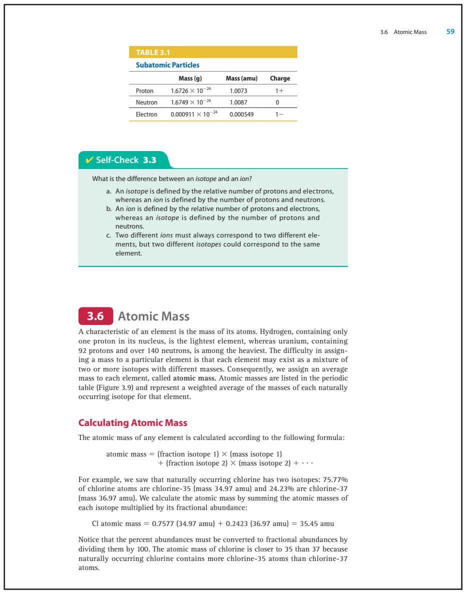
The discovery of quantum mechanics challenged the idea that our universe behaves deterministically. Electrons, and all other small particles such as protons and neutrons, do not appear to behave deterministically. An outfielder chasing an electron could not predict where it would land. The subatomic world is *indeterminate*—the present does not determine the future. This was a new idea. Erwin Schrödinger himself once said of quantum mechanics, "I don't like it, and I am sorry I ever had anything to do with it," and Niels Bohr said, "Anyone who is not shocked by quantum mechanics has not understood it." To some, an indeterminate universe was threatening. To others, the idea that the future was not predetermined—at least for subatomic particles—came as a pleasant surprise. In philosophy, the debate continues. However, the indeterminate nature of the subatomic world dealt a severe blow to the idea that every event in the universe is determined by the event before it.

quantum mechanical model. According to quantum mechanics, the paths of electrons are *not* like the paths of baseballs flying through the air or of planets orbiting the Sun, both of which are predictable. For example, we can predict where Earth will be in its orbit around the Sun in 2 years, 20 years, or even 200 years. This is not so for an electron. We cannot predict exactly where an electron will be at any given time—we can only predict the probability of finding it in a certain region of space.

So, which model is correct? Is it the Bohr model or the quantum mechanical model? Remember that in science we build models (or theories) and then perform experiments in an attempt to validate them. The Bohr model has been shown to be invalid by experiments. The quantum mechanical model is consistent with all experiments to date. Of course, this doesn't make the quantum mechanical theory "true." Scientific theories are never proven true, only valid. This also does not mean that

Figure 3.13 The 1*s* orbital depicted by showing its 90% probability boundary. (Source: Progressive Publishing Alternatives)

Figure 3.14 The 2*p* and 3*d* quantum mechanical orbitals.



3.6 Atomic Mass 59

TABLE 3.1

Subatomic Particles

	Mass (g)	Mass (amu)	Charge
Proton	1.6726×10^{-24}	1.0073	1+
Neutron	1.6749×10^{-24}	1.0087	0
Electron	0.000911×10^{-24}	0.000549	1−

✓ Self-Check 3.3

What is the difference between an *isotope* and an *ion*?

a. An *isotope* is defined by the relative number of protons and electrons, whereas an *ion* is defined by the number of protons and neutrons.
b. An *ion* is defined by the relative number of protons and electrons, whereas an *isotope* is defined by the number of protons and neutrons.
c. Two different *ions* must always correspond to two different elements, but two different *isotopes* could correspond to the same element.

3.6 Atomic Mass

A characteristic of an element is the mass of its atoms. Hydrogen, containing only one proton in its nucleus, is the lightest element, whereas uranium, containing 92 protons and over 140 neutrons, is among the heaviest. The difficulty in assigning a mass to a particular element is that each element may exist as a mixture of two or more isotopes with different masses. Consequently, we assign an average mass to each element, called **atomic mass.** Atomic masses are listed in the periodic table (Figure 3.9) and represent a weighted average of the masses of each naturally occurring isotope for that element.

Calculating Atomic Mass

The atomic mass of any element is calculated according to the following formula:

$$\text{atomic mass} = (\text{fraction isotope 1}) \times (\text{mass isotope 1}) \\ + (\text{fraction isotope 2}) \times (\text{mass isotope 2}) + \cdots$$

For example, we saw that naturally occurring chlorine has two isotopes: 75.77% of chlorine atoms are chlorine-35 (mass 34.97 amu) and 24.23% are chlorine-37 (mass 36.97 amu). We calculate the atomic mass by summing the atomic masses of each isotope multiplied by its fractional abundance:

$$\text{Cl atomic mass} = 0.7577\ (34.97\text{ amu}) + 0.2423\ (36.97\text{ amu}) = 35.45\text{ amu}$$

Notice that the percent abundances must be converted to fractional abundances by dividing them by 100. The atomic mass of chlorine is closer to 35 than 37 because naturally occurring chlorine contains more chlorine-35 atoms than chlorine-37 atoms.

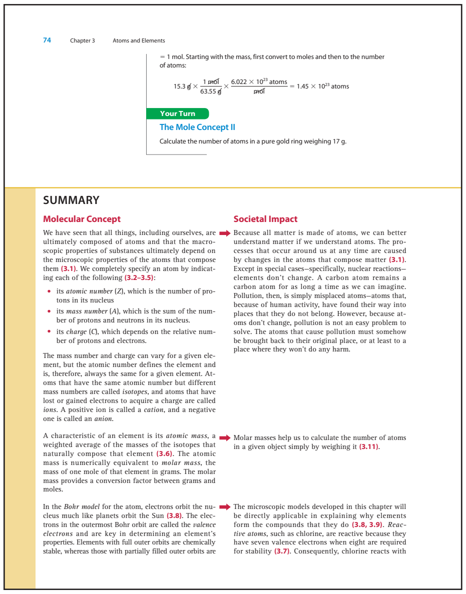
Self-Check

The *Self-Check* boxes consist of questions that allow students to periodically check their comprehension. The questions reinforce the key concepts in the text, develop students' critical thinking skills, and help them relate the material to the world around them.

CHAPTER SUMMARIES

Chapters end with a two-column summary of the ideas presented in the main body of the chapter. In this summary, students get a side-by-side review of the chapter, with molecular concepts in one column and the coinciding societal impact in the other. The chapter summary allows the student to get an overall picture of the chapter and strengthens the connection between principles and applications.

Chapter summaries review main molecular concepts and their societal impacts.



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= 1 mol. Starting with the mass, first convert to moles and then to the number of atoms:

$$15.3\,\cancel{\text{g}} \times \frac{1\,\cancel{\text{mol}}}{63.55\,\cancel{\text{g}}} \times \frac{6.022 \times 10^{23}\text{ atoms}}{\cancel{\text{mol}}} = 1.45 \times 10^{23}\text{ atoms}$$

Your Turn

The Mole Concept II

Calculate the number of atoms in a pure gold ring weighing 17 g.

SUMMARY

Molecular Concept	Societal Impact
We have seen that all things, including ourselves, are ultimately composed of atoms and that the macroscopic properties of substances ultimately depend on the microscopic properties of the atoms that compose them **(3.1)**. We completely specify an atom by indicating each of the following **(3.2–3.5)**: • its *atomic number* (*Z*), which is the number of protons in its nucleus • its *mass number* (*A*), which is the sum of the number of protons and neutrons in its nucleus. • its *charge* (*C*), which depends on the relative number of protons and electrons. The mass number and charge can vary for a given element, but the atomic number defines the element and is, therefore, always the same for a given element. Atoms that have the same atomic number but different mass numbers are called *isotopes*, and atoms that have lost or gained electrons to acquire a charge are called *ions*. A positive ion is called a *cation*, and a negative one is called an *anion*.	➡ Because all matter is made of atoms, we can better understand matter if we understand atoms. The processes that occur around us at any time are caused by changes in the atoms that compose matter **(3.1)**. Except in special cases—specifically, nuclear reactions—elements don't change. A carbon atom remains a carbon atom for as long a time as we can imagine. Pollution, then, is simply misplaced atoms—atoms that, because of human activity, have found their way into places that they do not belong. However, because atoms don't change, pollution is not an easy problem to solve. The atoms that cause pollution must somehow be brought back to their original place, or at least to a place where they won't do any harm.
A characteristic of an element is its *atomic mass*, a weighted average of the masses of the isotopes that naturally compose that element **(3.6)**. The atomic mass is numerically equivalent to *molar mass*, the mass of one mole of that element in grams. The molar mass provides a conversion factor between grams and moles.	➡ Molar masses help us to calculate the number of atoms in a given object simply by weighing it **(3.11)**.
In the *Bohr model* for the atom, electrons orbit the nucleus much like planets orbit the Sun **(3.8)**. The electrons in the outermost Bohr orbit are called the *valence electrons* and are key in determining an element's properties. Elements with full outer orbits are chemically stable, whereas those with partially filled outer orbits are	➡ The microscopic models developed in this chapter will be directly applicable in explaining why elements form the compounds that they do **(3.8, 3.9)**. *Reactive atoms*, such as chlorine, are reactive because they have seven valence electrons when eight are required for stability **(3.7)**. Consequently, chlorine reacts with

KEY TERMS

Each chapter has a set of key terms from within that chapter for review and study. Each of the key terms is defined in the Glossary at the end of the text.

STUDENT EXERCISES

All chapters contain exercises of four types: *Questions*, *Problems*, *Points to Ponder*, and *Feature Problems and Projects*. The *Questions* ask students to recall many of the key concepts from the chapter. The *Problems* ask students to apply what they have learned to solve problems similar to those in the chapter *Examples* and *Your Turn* boxes. The *Points to Ponder* consist primarily of open-ended short-essay questions in which students are asked about the ethical, societal, and political implications of scientific issues. The *Feature Problems and Projects* contain problems with graphics and short projects, often involving Web-based inquiry.

NEW TO THIS EDITION

The art program has been updated including every chapter opening image to better communicate the excitement and relevance of chemistry to our daily lives.

Since CHEMISTRY IN FOCUS emphasizes relevance and connection to current environmental and technological issues, all of the data relevant to these issues have been updated and made current. For example, data such as Earth's temperature, atmospheric carbon dioxide concentrations, rain acidity, and pollution levels have been thoroughly researched and made as current as possible.

Interest boxes (Molecular Thinking, Molecular Focus, Molecular Revolution, and What If) have been updated to reflect the progress and current issues.

The self-check questions have been revised extensively to enhance student learning and make them adaptable to a digital environment that automatically tells the student whether or not they answered correctly.

A new set of instructional and interactive videos entitled, BIG PICTURE VIDEOS, have been created for the new edition. These videos are designed to be assigned to students outside of class to introduce important topics in each chapter. The videos encourage active learning because each video stops in about the middle and asks the student to answer a question. The video continues after the student answers the question, forcing them to participate in the learning process.

Supporting Materials

Please visit http://www.cengage.com/chemistry/tro/cheminfocus6e for information about student and instructor resources for this text.

Acknowledgments

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Thanks also to those who supported me personally while writing this book. I am particularly grateful to my wife, Ann, whose love healed a broken man. Thanks to my children, Michael, Ali, Kyle, and Kaden—they are my raison d'être. I come from a large and close extended Cuban family who have stuck by me through all manner of difficult circumstances. I thank my parents, Nivaldo and Sara, and my siblings, Sarita, Mary, and Jorge.

I am greatly indebted to the reviewers of each of the editions of this book, who are listed below. They have all left marks on the work you are now holding. Lastly, I thank my students, whose lives energize me and whose eyes continually provide a new way for me to see the world.

—Nivaldo J. Tro
Westmont College

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1

Molecular Reasons

CHAPTER OUTLINE

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Science, like art, is fun, a playing with truths. . . .

—W. H. Auden

For up-to-date URLs, visit this text's Companion Site, which is accessible from **www.cengagebrain.com**.

In this book, you will learn about chemistry, the science that investigates the small to understand the large. You will, in my opinion, be a deeper and better-educated person if you understand one simple fact: *All that is happening around you has a molecular cause*. When you understand the molecular realm that lies behind everyday processes, the world becomes a larger and richer place.

In this chapter, you will learn about the scientific method—the method that chemists use to learn about the molecular realm. Contrary to popular thought, the scientific method is creative, and the work of the scientist is not unlike the work of the artist. As you read these pages, think about the modern scientific method—its inception just a few hundred years ago has changed human civilization. What are some of those changes? How has the scientific method directly impacted the way you and I live?

We will then move on to some fundamental chemical principles that help us make sense of the vast variety of substances that exist in the world. As you learn the details of atoms, elements, compounds, and mixtures, keep in mind the central role that science plays in our society today. Also remember that you don't need to go into the laboratory or look to technology to see chemistry because—even as you sit reading this book—*all that is happening around you has a molecular cause.*

QUESTIONS *for* THOUGHT

- What is chemistry?
- How do scientists learn about the world?
- How did science and chemistry develop?
- What is matter and how do we classify it?
- What is matter composed of?
- What is the structure of an atom?

1.1 Firesticks

Flames are fascinating. From the small flicker of a burning candle to the heat and roar of a large campfire, flames captivate us. Children and adults alike will stare at a flame for hours—its beauty and its danger demand attention. My children have a beloved campfire ritual they call "firesticks." They find dry tree branches, two to three feet long, and ignite the tips in the campfire. They then pull the flaming branches out of the fire and wave them in the air, producing a trail of light and smoke. My reprimands about the danger of this practice work for only several minutes, and then waving wands of fire find their way back into their curious little hands.

As fascinating as flames are, an unseen world—even more fantastic—lies beneath the flame. This unseen world is the world of molecules, the world I hope you see in the pages of this book. We will define molecules more carefully later; for now think of them as tiny particles that make up matter—so tiny that a single flake of ash from a fire contains one million trillion of them. The flame on my children's firesticks and in the campfire is composed of molecules, billions of billions of them rising upward and emitting light (Figure 1.1).

The molecules in the flame come from an extraordinary transformation—called a **chemical reaction**—in which the molecules within the wood combine with certain molecules in air to form new molecules. The new molecules have excess energy that they shed as heat and light as they escape in the flame. Some of them, hopefully after cooling down, might find their way into your nose, producing the smell of the fire.

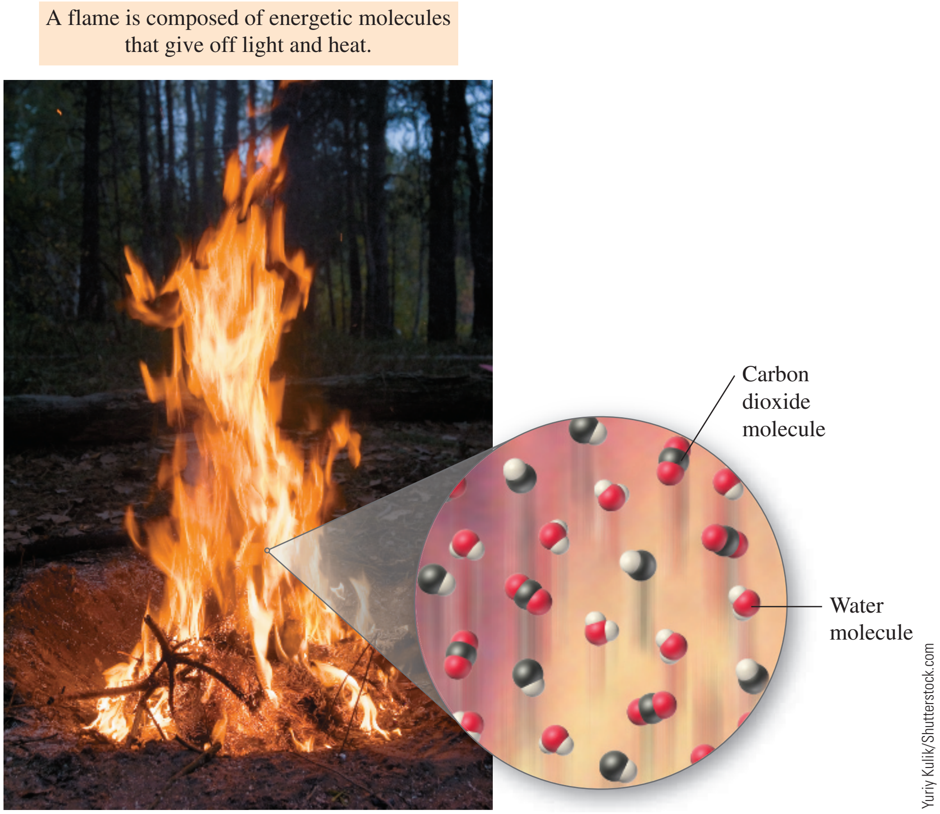

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Figure 1.1 The energetic molecules that compose a flame form from the reaction between the molecules within the log and the molecules in the air. They move upward, away from the log, giving off heat and light as they travel.

Let's suppose for a moment that we could see the molecules within the burning wood—we would witness a frenzy of activity. A bustling city during rush hour would appear calm by comparison. The molecules in the wood, all vibrating and jostling trillions of times every second, rapidly react with molecules in the air. The reaction of a single molecule with another occurs within a split second, and the newly produced molecules fly off in a trail of heat and light, only to reveal the next molecule in the wood—ready to react. This process repeats itself trillions of times every second as the wood burns. Yet on the macroscopic scale—the scale that we see—the process looks calm. The wood disappears slowly, and the flame from a few good logs lasts several hours.

Big Picture Video: Molecular Reasons

1.2 Molecular Reasons

All that is happening around you has a molecular cause. When you write, eat, think, move, or breathe, molecules are in action, undergoing changes that make these things happen. The world that you can see—that of everyday objects—is determined by the world you cannot see—that of atoms, molecules, and their interactions. **Chemistry** is *the science that investigates the molecular reasons for the processes occurring in our macroscopic world*. Why are leaves green? Why do colored fabrics fade on repeated exposure to sunlight? What happens when water boils? Why does a pencil leave a mark when dragged across a sheet of paper? These basic questions can be answered by considering atoms and molecules and their interactions with each other.

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Chemists investigate the molecular reasons for physical phenomena.

For example, over time you might see a red shirt fade as it is exposed to sunlight. The molecular cause is energy from the sun, which decomposes the molecules that gave the shirt its red color. You may notice that nail polish remover accidentally spilled on your hand makes your skin feel cold as it evaporates. The molecular cause is molecules in your skin colliding with the evaporating molecules in the nail polish remover, losing energy to them, and producing the cold sensation. You may see that sugar stirred into coffee readily dissolves (Figure 1.2). The sugar seems to disappear in the coffee. However, when you drink the coffee, you know the sugar is still there because you can taste its sweetness. The molecular cause is that a sugar molecule has a strong attraction for water molecules and prefers to leave its neighboring

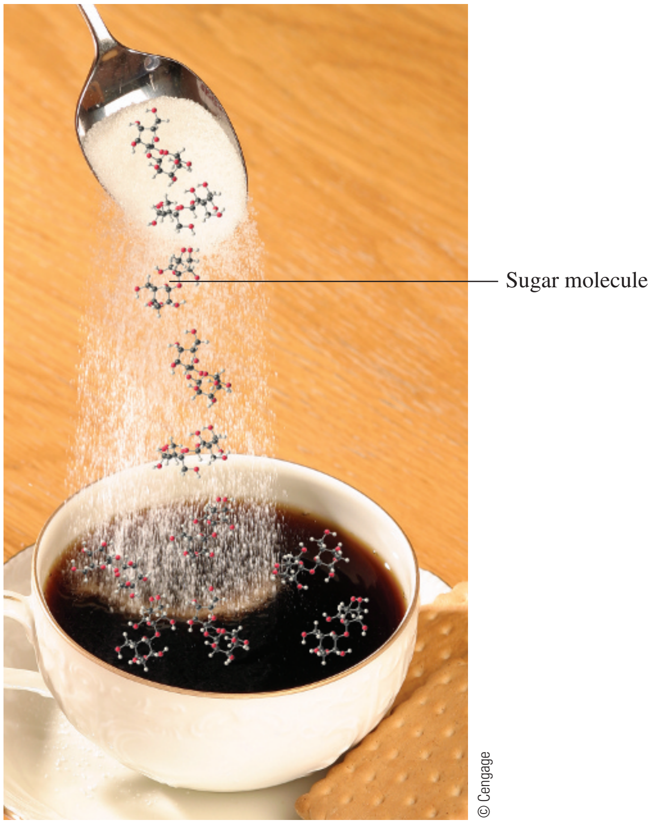


Figure 1.2 When sugar dissolves into coffee, the sugar molecules mix with the water molecules.

sugar molecules and mingle with the water. You see this as the apparent disappearing of the solid sugar, but it is not disappearing at all, just mixing on the molecular level. Chemists, by using the scientific method, investigate the molecular world; they examine the molecular reasons for our macroscopic observations.

1.3 The Scientist and the Artist

Science and art are often perceived as different disciplines, attracting different types of people. Artists are often perceived to be highly creative and uninterested in facts and numbers. Scientists, in contrast, are perceived to be uncreative and interested only in facts and numbers. Both images are false, however, and the two professions have more in common than is generally imagined.

We can begin to understand the nature of scientific work by studying the **scientific method**, outlined in Figure 1.3. The first step in the scientific method is

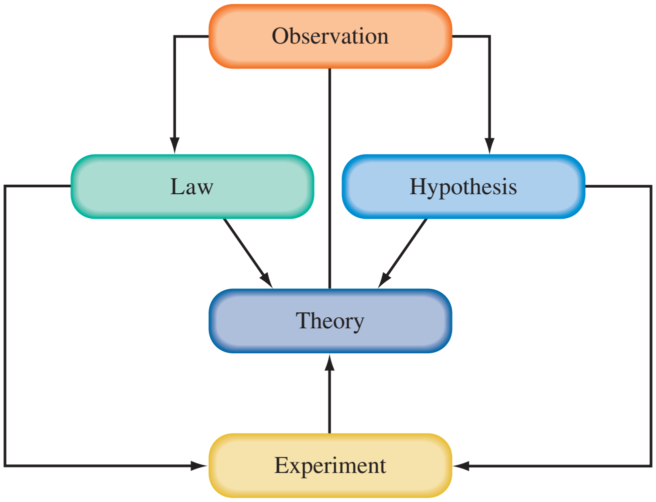


Figure 1.3 The scientific method.

What If…

Why Should Nonscience Majors Study Science?

You may be reading this book because it is required reading in a required course. You are probably not a science major and might be wondering why you should study science. I propose three reasons why you should study science, specifically because you are not a science major.

First, modern science influences culture and society in profound ways and raises ethical questions that only society as a whole can answer. For example, in the early part of this century, scientists at a biotechnology company in Massachusetts succeeded for the first time in cloning (making a biological copy of) a human embryo. Their reason for cloning the embryo was *not* human reproduction (they were not trying to make a race of superhumans or clones of themselves) but rather to cure and treat diseases. This kind of cloning, called *therapeutic cloning* (as opposed to *reproductive cloning*), holds as its goal the creation of specialized cells (called *stem cells*) to be used, for example, to cure diabetes or to mend damaged spinal cords. The potential benefits of this research are significant, but it also carries some moral risk. Does the benefit of curing serious disease outweigh the risk of creating human embryos? Only society as a whole can answer that question. If our society is to make intelligent decisions on issues such as this, we, as citizens of that society, should have a basic understanding of the scientific principles at work.

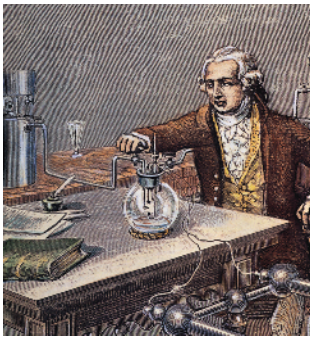
Second, decisions involving scientific principles are often made by nonscientists. Politicians are generally not trained in science, nor are the people electing the politicians. Yet politicians make decisions concerning science policy, science funding, and environmental regulation. A clever politician could impose unsound scientific policy on an uninformed electorate. For example, Adolf Hitler proposed his own versions of Nazi genetics on the German people. He wrongly proposed that the Aryan race could make itself better by isolating itself from other races. According to Hitler, Aryans should only reproduce with other Aryans to produce superior human beings. However, any person with a general knowledge of genetics would know that Hitler was wrong. Excessive inbreeding actually causes genetic weaknesses in a population. For this reason, purebred dogs have many genetic problems, and societal taboos exist for intrafamily marriages. History demonstrates other examples of this sort of abuse. Agriculture in the former Soviet Union still suffers from years of misdirected policies based on communistic ideas of growing crops, and South America has seen failures in *land use* policies that were scientifically ill informed. If you are at all interested in the sustainability of our planet, you need to have a basic understanding of science so that you can help make intelligent decisions about its future.

Third, science is a fundamental way to understand the world around us and therefore reveals knowledge not attainable by other means. Such knowledge will deepen and enrich your life. For example, an uninformed observer of the night sky may marvel at its beauty but will probably not experience the awe that comes from knowing that even the closest star is trillions of miles away or that stars produce light in a process that could only start at temperatures exceeding millions of degrees. For the uninformed, the world is a two-dimensional, shallow place. For the informed, the world becomes a deeper, richer, and more complex place. In chemistry, we learn about the world that exists behind the world we see, a world present all around us and even inside of us. Through its study we are better able to understand our world and better able to understand ourselves.

the **observation** or measurement of some aspect of nature. This may involve only one person making visual observations, or it may require a large team of scientists working together with complex and expensive instrumentation. A series of related observations or measurements may be combined to formulate a broadly applicable generalization called a **scientific law**. As an example, consider the work of **Antoine Lavoisier (1763–1794)**, a French chemist who studied combustion, a type of chemical reaction. Lavoisier carefully measured the weights of objects before and after burning them in closed containers. He noticed that the initial weight of the substance being burned and the final weight of the substances that were formed during burning were always equal. As a result of these observations, he formulated the **law of conservation of mass**, which states the following:

> In a chemical reaction matter is neither created nor destroyed.

Unfortunately, Lavoisier was part of the establishment at a time when the establishment was extremely unpopular. He was guillotined in 1794 by French revolutionists. His controlled observations, however, led to a general law of nature that applies not only to combustion but also to every known chemical reaction. The burning log discussed in the opening section of this book, for example, does not disappear into nothing; it is transformed into ash and gas. The weight lost by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Antoine Lavoisier, also known as the father of modern chemistry.

the log while burning and the weight of the oxygen that it reacted with exactly equal the weight of the ash and gas formed. Laws like these do not automatically fall out of a series of measurements. The measurements must be carefully controlled. But then the scientist must be creative in seeing a pattern that others have missed and formulating a scientific law from that pattern.

Scientific laws summarize and predict behavior, but they do not explain the underlying cause. A **hypothesis** is an initial attempt to explain the underlying causes of observations and laws. A hypothesis is a tentative model (educated by observation) that is then tested by an **experiment**, a controlled observation specifically designed to test a hypothesis. One or more confirmed hypotheses (possibly with the additional support of observations and laws) may evolve into an overarching model of reality called a **theory**. A good theory often predicts behavior far beyond the observations and laws from which it was formulated. For example, John Dalton, an English chemist, used the law of conservation of mass along with other laws and observations to formulate his atomic theory, which asserts that all matter is composed of small particles called atoms. Dalton took a creative leap from the law of conservation of mass to a theory about atoms. ▶ His ingenuity led to a theory that explained the law of conservation of mass by predicting the existence of microscopic particles, the building blocks of all matter.

The atomic theory is described in more detail in Section 1.9.

✔ Self-Check 1.1

A chemist observes the behavior of a gas by filling a balloon and measuring its volume at different temperatures. After making many measurements, he concludes that the volume of a gas always increases with increasing temperature. The chemist's conclusion is best classified as an:

a. observation
b. law
c. theory

You can find the answers to Self-Check questions at the end of the chapter.

Example 1.1

The Scientific Method

Suppose you are an astronomer mapping the galaxies in the sky for the very first time. You discover that all galaxies are moving away from Earth at high speeds. As part of your studies, you measure the speed and distance from Earth of a number of galaxies. Your results are shown here.

Distance from Earth	**Speed Relative to Earth**
5.0 million light-years	600 miles/second (mi/s)
8.4 million light-years	1000 mi/s
12.3 million light-years	1500 mi/s
20.8 million light-years	2500 mi/s

Formulate a law based on your observations.
Because laws summarize a number of related observations, you can formulate the following law from the tabulated observations:

The farther away a galaxy is from Earth, the faster its speed.

Devise a hypothesis or theory that might explain the law.
You may devise any number of hypotheses or theories consistent with the preceding law. Your hypotheses must, however, give the underlying reasons behind the law. One possible hypothesis:

(continued)

> Earth has a slowing effect on all galaxies. Those galaxies close to Earth experience this effect more strongly than those that are farther away and therefore travel more slowly.

Another possible hypothesis:

> Galaxies were formed in an expansion that began sometime in the past and are therefore moving away from each other at speeds that depend on their separation.

What kinds of experiments would help validate or disprove these hypotheses? For the first hypothesis, you might devise experiments that try to measure the nature of the slowing effect that Earth exerts on galaxies. For example, the force responsible for the slowing may also affect the Moon's movement, which might be measured by experiment. For the second hypothesis, experiments that look for other evidence of an expansion would work. For example, you might try to look for remnants of the heat or light given off by the expansion. Experimental confirmation of your hypothesis could result in the evolution of the hypothesis into a theory for how the universe came to exist in its present form.

Finally, like a hypothesis, a theory is subject to experiments. A theory is valid if it is consistent with, or predicts the outcome of, experiments. If an experiment is inconsistent with a particular theory, that theory must be revised, and a new set of experiments must be performed to test the revision. A theory is never proved, only validated by experimentation. The constant interplay between theory and experiment gives science its excitement and power.

The process by which a set of observations leads to a model of reality is *the scientific method*. It is similar, in some ways, to the process by which a series of observations of the world leads to a magnificent painting. Like the artist, the scientist must be creative. Like the artist, the scientist must see order where others have seen only chaos. Like the artist, the scientist must create a finished work that imitates the world. The difference between the scientist and the artist lies in the stringency of the imitation. The scientist must constantly turn to experiment to determine whether his or her ideas about the world are valid.

1.4 The First People to Wonder About Molecular Reasons

The Greek philosophers are the first people on record to have thought deeply about the nature of matter. As early as 600 B.C., these scholars wanted to know the *why* of things. However, they were immersed in the philosophical thought of their day that held that physical reality is an imperfect representation of a more perfect reality. As a result, they did not emphasize experiments on the imperfect physical world as a way to understand it. According to **Plato** (428–348 B.C.), *reason alone* was the superior way to unravel the mysteries of nature. Remarkably, Greek ideas about nature led to some ideas similar to modern ones.

Democritus (460–370 B.C.), for example, theorized that matter was ultimately composed of small, indivisible particles he called *atomos,* or atoms, meaning "not to cut." Democritus believed that if you divided matter into smaller and smaller pieces, you would eventually end up with tiny particles (atoms) that could not be divided any further. He is quoted as saying, "Nothing exists except atoms and empty space; everything else is opinion." Although Democritus was right by modern standards, most Greek thinkers, especially Aristotle and Plato, rejected his atomistic viewpoint.

Thales (624–546 B.C.) reasoned that any substance could be converted into any other substance, so that all substances were in reality one basic material. Thales believed that the one basic material was water. He said, "Water is the principle, or the element of things. All things are water." **Empedocles** (490–430 B.C.), on the other hand, suggested that all matter was composed of four basic materials or elements: air, water, fire, and earth. This idea was accepted by **Aristotle** (384–321 B.C.), who added a fifth element—the heavenly ether—perfect, eternal, and incorruptible. In Aristotle's mind, the five basic elements composed all matter, and this idea reigned for 2000 years.

1.5 Immortality and Endless Riches

The predecessor of chemistry, called **alchemy**, flourished in Europe during the Middle Ages. Alchemy was a partly empirical, partly magical, and entirely secretive pursuit with two main goals: the transmutation of ordinary materials into gold and the discovery of the "elixir of life," a substance that would grant immortality to any who consumed it. In spite of what might today appear as misdirected goals, alchemists made some progress in our understanding of the chemical world. Through their obsession with turning metals into gold, they learned much about metals. They were able to form *alloys*—mixtures of metals—with unique properties. They also contributed to the development of laboratory separation and purification techniques that are still used today. In addition, alchemists made advances in the area of pharmacology by isolating natural substances and using them to treat ailments. Because of the mystical nature of alchemy and the preoccupation with secrecy, however, knowledge was not efficiently propagated, and up to the sixteenth century, progress was slow.

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Alchemists sought to turn ordinary materials into gold and to make "the elixir of life," a substance that would grant immortality.

1.6 The Beginning of Modern Science

The publication of two books in 1543 marks the beginning of what is now called **the scientific revolution**. The first book was written by **Nicholas Copernicus** (1473–1543), a Polish astronomer who claimed that the Sun was the center of the universe. In contrast, the Greeks had reasoned that Earth was the center of the universe, with all heavenly bodies, including the Sun, revolving around Earth. Although complex orbits were required to explain the movement of the stars and planets, the Earth-centered universe put humans in the logical center of the created order. Copernicus, by using elegant mathematical arguments and a growing body of astronomical data, suggested exactly the opposite—the Sun stood still and Earth revolved around it. The second book, written by **Andreas Vesalius** (1514–1564), a Flemish anatomist, portrayed human anatomy with unprecedented accuracy.

The uniqueness of these books was their overarching emphasis on observation and experiment as the way to learn about the natural world. The books were revolutionary, and Copernicus and Vesalius laid the foundation for a new way to understand the world. Nonetheless, progress was slow. Copernicus's ideas were not popular among the religious establishment. **Galileo Galilei** (1564–1642), who confirmed and expanded on Copernicus's ideas, was chastised by the Roman Catholic Church for his views. Galileo's Sun-centered universe put man outside of the geometric middle of God's created order and seemed to contradict the teachings of Aristotle and the Church. As a result, the Roman Catholic Inquisition forced Galileo to recant his views. Galileo was never tortured, but he was subject to house arrest until he died.

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Galileo Galilei expanded on Copernicus's ideas of a Sun-centered rather than an Earth-centered universe.