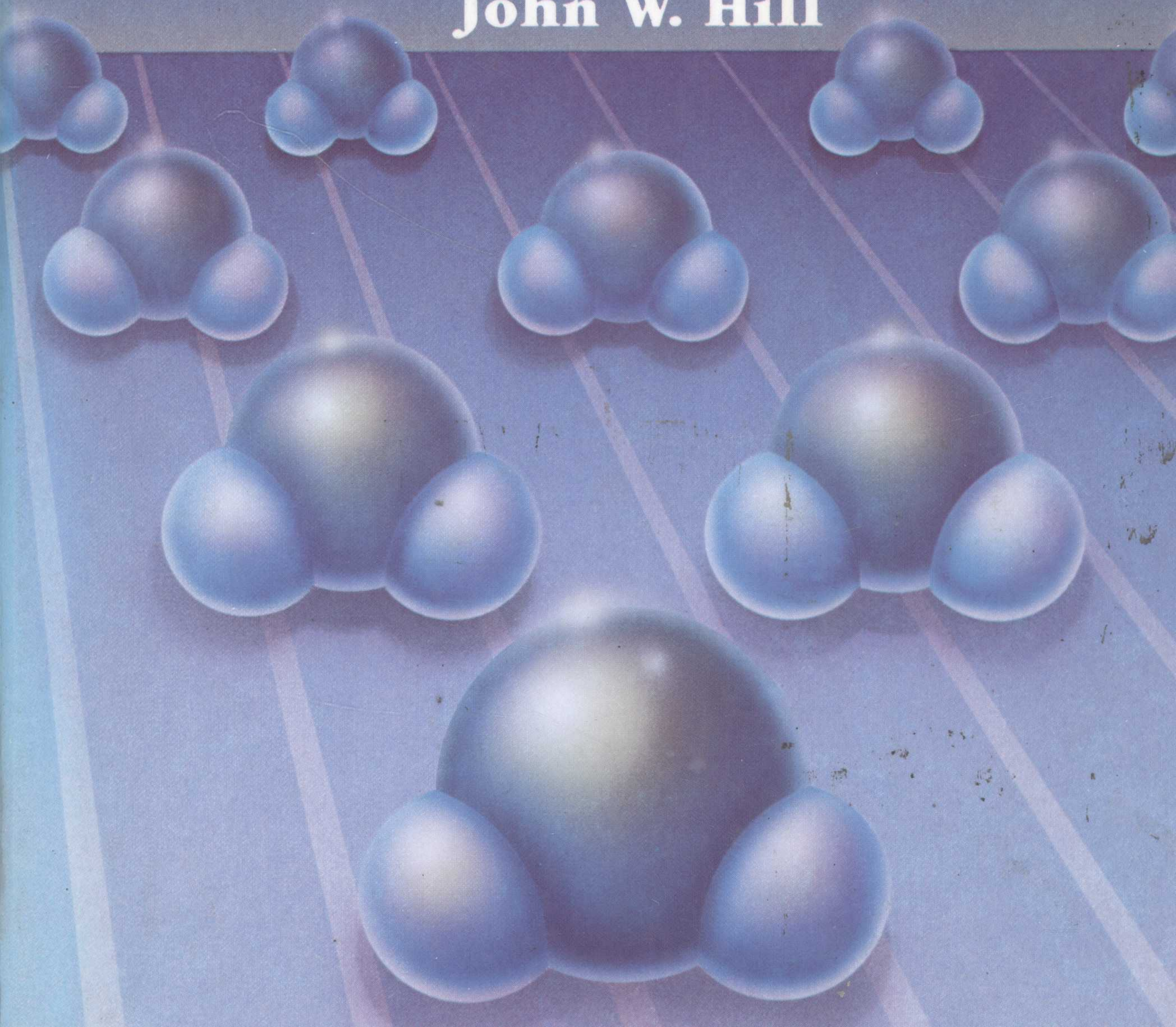
Chemistry for Changing Times

Fourth Edition

John W. Hill



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Preface

TO THE STUDENT

Welcome to Our Chemical World

Chemistry is fun. Through this book, I would like to share with you some of the excitement of chemistry and some of the joy in learning about it. I hope to convince you that chemistry does not need to be excluded from your learning experiences. Learning chemistry will enrich your life—now and long after this course is over—through a better understanding of the natural world, the technological questions now confronting us, and the choices we must face as citizens within a scientific and technological society.

Chemistry Directly Affects Our Lives

How does the human body work? Are potatoes fattening? Why do most weight-loss diets seem to work in the short run but fail in the long run? Does fasting "cleanse" the body? Why do our moods swing from happy to sad? Can a chemical test on urine predict possible suicide attempts? How does penicillin kill bacteria without harming our healthy body cells? Chemists have found answers to questions like these and continue to seek the knowledge that will unlock still other secrets of our universe. As these mysteries are resolved, the direction of our lives often changes—sometimes dramatically.

We live in a chemical world—a world of nuclear wastes, dwindling petroleum reserves, drugs, biocides, food additives, fertilizers, detergents, plastics and pollutants. Knowledge of chemistry will help you to better understand the benefits and hazards of this world and enable you to make intelligent decisions in the future.

Chemistry Is Life

Our bodies are intricate chemical factories. They are durable but delicate systems. A myriad of chemical reactions are constantly taking place within us which allow our bodies to function properly. Thinking, learning, exercising, feeling happy or sad, putting on too much weight or not gaining enough, and virtually all life processes are made possible by these chemical reactions. Everything that we ingest is part of a complex process that determines whether our bodies work effectively or not. The consumption of some substances can initiate chemical reactions that will stop body functions altogether. Other substances, if consumed, can cause permanent handicaps, and others can make living less comfortable. A proper balance of the right foods provides the chemicals and generates the reactions we need in order to function at our best. The knowledge of chemistry that you will soon be gaining will help you to better understand how your body works so that you will be able to take proper care of it.

Changing Times

We live in a world of increasingly rapid change. It has been said that the only constant is change itself. At present, we are facing some of the greatest problems that humans have ever encountered, and the dilemmas with which we are now confronted seem to have no perfect solutions. We are sometimes forced to make a best choice among only bad alternatives, and our decisions often provide only temporary solutions to our problems. Nevertheless, if we are to choose properly, we must understand what our choices are. Mistakes can be costly and they cannot always be rectified. It is easy to pollute, but cleaning up pollution once it is there is enormously expensive. We can best avoid mistakes by collecting as much information as possible before making critical decisions. Science is a means of gathering and evaluating information, and chemistry is central to all the sciences.

Chemistry and the Human Condition

Above all else, my hope is that you will learn that chemistry need not be dull and difficult. Rather, it can enrich your life in so many ways—through a better understanding of your body, your mind, and your environment, and through enhanced understanding of the world in which we live. After all, the search to understand the universe is an essential part of what it means to be human.

TO THE INSTRUCTOR

The Revision

The previous editions of *Chemistry for Changing Times* were written with the firm conviction that chemistry can be presented in an intellectually honest way to students who have little background and no prior interest in chemistry. That assumption also underlies this revision, as does the belief that a course for students not majoring in science must be taught differently than a course taught to science majors.

Our Goals

We can no longer feel we have done our duty to nonscience students and to society by teaching only traditional chemistry courses. A traditional course will not stimulate a typical nonscience student's interest or kindle much of a desire to know more about the world. Most of the world's problems won't be solved without intelligent applications of chemistry, and if we fail to motivate our students or if we allow them to complete our courses without having gained an understanding of or an appreciation for the chemical world, all of society loses. We are living in an age where difficult daily decisions that affect our health and the future of the world prevail, and the stakes are enormously high. Three-fourths of all legislation considered by the United States Congress involves scientific or technological questions. Our government is now committed to improving science education, especially for those who will not become scientists. If we who teach chemistry fail to take advantage of our present opportunities, we will be contributing to the very maladies we hope to correct.

Our Students

Generally, students enrolled in this course are not interested in the austere abstractness and the elegant mathematics of the physical theories that we scientists find so beautiful. If they were, they would most likely be science majors. Because of their temperament and training these students are not prepared to understand the awesome mathematical theories of quantum mechanics and thermodynamics. Even the simplest stoichiometric relationships inspire fear in many of these students. The essential quantitative nature of chemistry must be presented to students with care to avoid intimidation.

Our Objectives

The principal objectives in a chemistry course for nonscience students are these:

- Design your chemistry course to attract as many students as possible. If they don't enroll, you won't have the opportunity to teach them.
- Have students study examples of current topics in chemistry so that they will incorporate into their lives a sense for how chemists approach and solve problems.
- Induce students to relate chemical problems to their own lives so that they will be better able to appreciate the significance of such problems.
- Instill in students an appreciation for chemistry as an open-ended learning experience that will continue throughout their lives. Chemistry should not be a subject that is memorized before the final exam and then quickly forgotten.
- Acquaint students with scientific methods so that they will be able to distinguish between science and technology.

These objectives have been met to a most gratifying extent in my own course. Course enrollment rose sharply during the early years of the course, and it has continued to rise more rapidly than overall university enrollment.

Major Changes in This Revision

The entire book has been updated. One new chapter, "Sports: The Chemical Connection," has been added in response to increased student interest in athletics and fitness. A section on alcoholic beverages is now included in the "Foods" chapter. A section on the risks and benefits of science and technology has been added to the first chapter, and this theme is continued in many subsequent chapters. Also, there is a section on chemical wastes in the last chapter.

A new section discussing the use of the mole in chemical calculations—with several examples—has been added at the end of Chapter 6.

Virtually no portion of the previous edition has been left unchanged, but this revision still retains the spirit of that work.

Readability

A chemistry text need not be stodgy in order to present its subject well. Learning chemistry is not always easy, but it can be rewarding if the information is conveyed in a clear and understandable way. With this thought in mind, we have tried to create a chemistry textbook that is both clearly readable and thoroughly enjoyable—and we believe we have succeeded in doing so.

Units of Measurement

The metric system has been adopted by most of the world, and the modern version, the International System of Units (SI), is used in many countries, especially by scientists. What units of measurement should be used in a chemistry text designed for use by students of the humanities and the social sciences? We feel that students will encounter both the old metric system and the new SI version, in addition to the English system, in their everyday lives. Therefore, we have used the units that they are most likely to encounter—Calories, not joules, when discussing weight loss or gain, for example. Nevertheless, we have used SI units in the presentation of most chemical principles, and we have used the SI spellings (litre, not liter) and symbols (K, not °K) where they do not present a barrier to learning.

Complicated Chemical Structures

Structures of complicated molecules are presented in the text, particularly toward the end, but students should not feel that they are expected to memorize them. They have been presented merely to emphasize the fact that these structures are known and that molecular properties depend upon them. Students may, however, come to recognize familiar functional groups, even with respect to the most complicated molecules.

Glossary

No separate glossary is provided, for I believe that definitions are best learned in context. Access to these terms is provided through the index, where the page on which a word is defined is indicated with **boldface.** Defined terms are also in boldface in the text itself.

Problems

In response to surveys conducted by the publisher, previous users of this book have expressed a desire for more study problems. Consequently, I have added problems to each chapter. In addition, detailed worked-out examples are interspersed in the text, particularly in the earlier, more quantitative chapters (Chapters 1 through 6). Instructors should assign the problems at their own discretion. You should present problems and exercises of your own if you want students to develop skills in special areas. Answers to selected problems are given in the appendix. Detailed, worked-out answers to all of the problems are given in the study guide.

References and Suggested Readings

At the end of each chapter, you will find a list of recommended books and articles. Students whose interest and enthusiasm have been sparked can delve more deeply into those subjects about which they are curious. Instructors will also find this information helpful.

SUPPLEMENTARY MATERIALS

The most important teaching aid in any course is the teacher. To make your task a bit easier as you teach the course, we have provided a variety of supplementary materials. These will also serve to enrich and round out the education of your students.

The Study Guide

A revised study guide is available to help students learn the material more effectively. For each chapter of the text, this guide provides an overview, a list of objectives, and a series of short-answer questions. The guide also provides additional problems as well as worked-out sample problems where appropriate. Use your own judgment to make additions to and deletions from the lists of objectives. The study guide contains worked-out solutions to all of the problems presented in the text.

The Instructor's Guide

An instructor's guide has also been prepared in conjunction with the text. This guide suggests course outlines for courses ranging in length from one quarter to one full year. The flexibility of these outlines will enable you to choose the material that best suits the particular needs of your students. The guide also lists sources of other printed educational material, audiovisual aids, and lecture demonstrations. Teaching strategies for presenting difficult material are also provided. New in this edition is a set of master sheets for making overhead transparencies. Many of the suggestions that have come from you, the users of *Chemistry for Changing Times,* have been incorporated in this guide, and additional suggestions are welcome anytime.

The Laboratory Manual

The laboratory manual, *Chemical Investigations for Changing Times,* is also available in a new, fourth edition. You will find shorter, cheaper, and safer experiments in this revised manual. You will discover that this greater number of experiments enables you to select experiments that are best suited to your style of teaching.

Test Bank

A bank of multiple-choice test items on $8\frac{1}{2} \times 5\frac{1}{2}$ inch cards is available from the publisher for adopters of *Chemistry for Changing Times,* fourth edition.

ACKNOWLEDGMENTS

I wish to thank everyone who has contributed suggestions in the preparation of this work. Glenn Vogel and Frank Darrow of Ithaca College were especially helpful, particularly with the chapter on sports chemistry. Ann Lemley, Mary Purchase, Kay Obendorf, C. C. Chu, and others in the Department of Design and Environmental Analysis at Cornell University were gracious hosts during my sabbatical in 1981 and contributed generously of their time and expertise.

For this edition, the following people provided penetrating, challenging, and greatly helpful prepublication reviews: Frank Fazio, Indiana University of Pennsylvania; Norman Fogel, University of Oklahoma at Norman; Keith J. Harper, North Texas State University; Stanley N. Johnson, Orange Coast College; James L. Lambert, Spring Hill College; Paul G. Seybold, Wright State University; Glenn Vogel, Ithaca College; and Ralph A. Zingaro, Texas A & M University.

We are also indebted to the respondents to the users' survey for the third edition. I especially want to acknowledge the contributions of Salvatore Russo of Western Washington University and V. P. Wystrach of Sacred Heart University who went beyond the confines of the survey to provide innumerable helpful suggestions.

I am indebted beyond measure to Cynthia S. Hill, R.D., for help with much of the book, especially the new material on diet and exercise, the chemistry of muscles, and alcoholic beverages. She also provided ideas for many of the new illustrations.

Above all, though, I would like to thank the many students who with zest and enthusiasm have gone on to learn for themselves more about chemistry than I ever taught them. Teaching is a joy, but learning is a real celebration. I have learned far more from my students than I can ever teach them; for that I am eternally grateful. Comments, corrections, suggestions, and criticisms are always welcome.

John W. Hill
River Falls, Wisconsin

Contents

chapter 1

Chemistry

A Science for All Seasons

Chemistry on the evening news—they call it a materials shortage. Chemistry in the newspapers—they call it an energy crisis.

You didn't know that was chemistry? Consider the usual definition: **chemistry** is a study of matter and the changes it undergoes. What is **matter?** It is the stuff of which all material things are made. We change matter to make it more useful. Most changes in matter are accompanied by changes in energy. Some matter we change to extract a part of its energy; for example, we burn gasoline to get energy to propel our automobiles.

More about matter and energy later. Indeed, matter and energy are what this book—and all of chemistry—is about. But chemistry isn't just something you hear or read about. You are a chemist. You practice chemistry every day.

You practice chemistry in the kitchen when you cook. You practice chemistry when you clean your house, wash your car, or paint a fence. You practice chemistry in the bathroom when you bathe and apply cosmetics. You practice chemistry when you take medicine or treat an injury. Indeed, some remarkable chemistry occurs while you eat or breathe and even while you sleep. Your body is the most miraculous of all the chemical factories on Earth. It takes the food you eat and turns it into muscle and blood and skin and bones and brains and a myriad of other marvelous things. Your body takes oxygen from the air and combines it with part of the food you eat to provide you with energy for every activity you undertake.

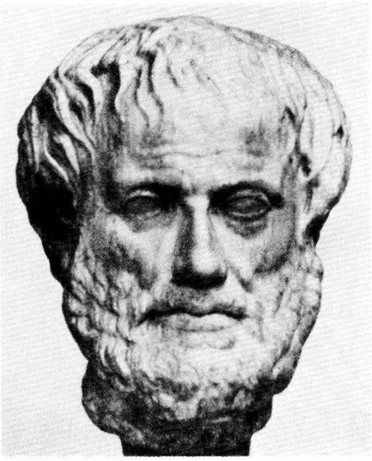

Figure 1.1 Aristotle (384–322 B.C.), Greek philosopher and tutor of Alexander the Great, believed that we could understand nature through logic. The idea of experimental science did not triumph over Aristotelian logic until about A.D. 1500. (Courtesy of the Smithsonian Institution, Washington, D.C.)

What is chemistry? It is a science that touches your life every moment. It deals with matter from the tiniest parts of atoms to the minutest materials of the complex human body. It goes beyond the individual to affect society as a whole, and it shapes our civilization.

Science and Technology: The Roots of Knowledge

Chemistry is a *science,* but what is a science? Let's examine the roots of science. Our study of the material universe has two facets: the *technological,* or *factual,* and the *philosophical,* or *theoretical.*

Technology arose long before science, having its origins in antiquity. The ancients used fire to bring about chemical changes. For example, they cooked food, baked pottery, and smelted ores to produce metals such as copper. They made beer and wine by fermentation, and obtained dyes and drugs from plant materials. These things—and many others—were accomplished without an understanding of the scientific principles involved.

The Greek philosophers, about 2500 years ago, were perhaps the first to formulate theories explaining the behavior of matter. They generally did not test their theories by experimentation, however. Nevertheless, their view of nature—attributed mainly to Aris-

Figure 1.2 *The Alchemist,* a painting done by the Dutch artist Cornelis Bega around 1660, depicts a laboratory of the seventeenth century. (Courtesy of Aldrich Chemical Company, Milwaukee.)

totle—was consistent internally, and it dominated natural philosophy for 2000 years.

The experimental roots of chemistry are firmly planted in alchemy, a mystical chemistry that flourished in Europe during the Middle Ages (about A.D. 500 to 1500). Modern chemists inherited from the alchemists an abiding interest in human health and the quality of life. Consider, for example, that alchemists not only searched for a philosophers' stone that would turn cheaper metals into gold but also sought an elixir that would confer immortality on those exposed to it. Alchemists never achieved these goals, but they discovered many new chemical substances and perfected techniques such as distillation and extraction that are still used today.

Technology also developed rapidly during the Middle Ages in Europe, in spite of the generally nonproductive Aristotelian philosophy that prevailed. The beginnings of modern science were more recent, however, coming with the emergence of the experimental method. What we now call science grew out of natural philosophy, that is, out of philosophical speculation about nature. Science had its true beginnings in the seventeenth century, when the work of astronomers, physicists, and physiologists was characterized by a reliance on experimentation.

Figure 1.3 Sir Francis Bacon (1561–1626), English philosopher and Lord Chancellor to James I. (Courtesy of the Smithsonian Institution, Washington, D.C.)

The Baconian Dream

It was a philosopher, Sir Francis Bacon (1561–1626), who first dreamed about how science could enrich human life with new inventions and increased prosperity. By the middle of the twentieth century, it appeared that science and its application in technology had made the Baconian dream come true. Many dread diseases—smallpox, polio, plague—had been virtually eliminated. Fertilizers, pesticides, and scientific animal breeding had increased and enriched our food supply. Transportation was swift, communication nearly instantaneous. New power sources had been discovered. Nuclear energy seemed to promise an unlimited quantity of power for our every need. New materials—plastics, fibers, metals, ceramics—were developed to improve our clothing and shelter.

Much of twentieth-century technology has grown out of scientific discoveries, and technological developments are used by scientists as tools for even more discoveries. These developments in science and technology are, to a considerable extent, the base of what we mean by the "modern" world.

The Carsonian Nightmare

The Baconian dream lost much of its lustre during the last two decades. People learned that the products of science were not an unmitigated good. Some people began to predict that science might

Figure 1.4 Rachel Carson at Woods Hole, Massachusetts, in 1951. (Edwin Gray Studio, copyright © 1951).

bring not wealth and happiness but death and destruction. Perhaps most noteworthy among these critics of modern technology was Rachel Carson, a biologist who had written several popular science books. In 1962, her poetic and polemic book *Silent Spring* was published. The book's main theme is that, through our use of chemicals to control insects, we are threatening the destruction of all life, including ourselves.

People in the pesticide industry (and their allies) roundly denounced Carson as a "propagandist," while other scientists rallied to her support. The scientific community divided into hostile camps. By the late 1960s, though, we had experienced massive fish kills, the threatened extinction of several species of birds, and the disappearance of fish from rivers, lakes, and areas of the ocean that had long been productive. The majority of scientists had moved into Carson's camp. Most of the remainder had moderated their criticism or become silent. Popular support for Carson's views was overwhelming.

Carson was not the first prophet of doom. As early as 1798, Thomas Malthus, in his "Essay upon the Principles of Population," had predicted that an increase in population more rapid than the increase in the food supply would lead to great famine. During the nineteenth century and for more than half of the twentieth, science and technology seemed to make a fool of Malthus. Food was abundant, at least in developed countries, and scientific discoveries and technological developments enabled us to increase food production as rapidly as the population grew.

The last few decades have brought changes, however. Population growth now threatens to outpace even the most optimistic projections of food production. Fuel shortages have caused what we have come to know as the energy crisis. Materials shortages have driven prices ever higher. Some scientists, and some outside the scientific community, project a dismal future; others confidently predict that science and technology, properly applied, will save us from disaster.

Science: Testable, Explanatory, and Tentative

What *is* science if scientists dispute what is and what will be? Is science merely a guessing game in which one guess is as good as another? We cannot *define* science precisely. Rather, we must resort to *describing* it.

One essential characteristic of science is that its tenets are *testable.* Scientists make **hypotheses** (guesses) that can be tested by **experiment.** This is the main characteristic that distinguishes science from the arts and humanities. We can learn from individual experience, and we can learn about historical events, but the knowledge gained through science is different: it depends upon phenomena that can be verified through repeated testing. Even educated guesses are of little value to scientists unless they can devise experiments to test their guesses. You may be elated over a good grade in chemistry, but that experience is uniquely yours; others might not be at all pleased with the same grade. Scientific **facts**—such as the boiling point of water and the speed of light—remain the same, however, no matter who does the measuring. These facts are verified by repeated testing.

Scientists must make careful observations and accurate measurements. They record facts based upon their observations, but nothing really counts as science until those observations have been verified by others. If something is patently false, a scientist can't get away for long with saying that it is true.

Experimental observations are only a bare (but necessary) beginning to the intellectual processes of science. Science is not a straightforward and logical process for cranking out discoveries. It is a way of *explaining* nature, but the explanations must be tested against a sometimes less-than-agreeable reality. The most beautiful hypothesis can be destroyed by one ugly fact. Our ideas about the universe must correspond to our observations. Scientists test ideas by predicting what they should observe if the ideas are true. Their understanding of nature is refined constantly by the interplay of ideas and observations.

Science is a body of knowledge, but that knowledge is always *tentative.* Detailed explanations, called **theories,** are quite useful as a framework for the organization of scientific knowledge. Sometimes, though, a theory has to be modified or discarded in the light of new observations. The body of knowledge we call science is alive, ever changing, and rapidly growing.

Scientists often use **models** to help explain complicated phenomena. The word *model* has a somewhat different meaning in science than in everyday life. A scientific model can be used to visualize the invisible. For example, when a glass of water stands for a period of time, the water disappears (Figure 1.5). The process is called evaporation. Scientists explain this phenomenon by the kinetic-molecular theory. According to the kinetic-molecular model, the liquid (water, in this case) is made up of small, invisible particles called *molecules.* The molecules are in constant motion and, in the bulk of the liquid, are held together by forces of attraction. Some molecules near the surface of the liquid gain sufficient energy (through collisions with other molecules) to break the attraction of their neighbors, escape from the liquid, and disperse among the widely spaced air molecules. Thus, the water in the glass disappears. For the scientist, understanding evaporation is much more satisfying than merely having a name for it.

What *is* science, then? We can only state some of its characteristics: it is *testable, explanatory,* and *tentative.* Contrary to a popu-