Chemistry and Life

An Introduction to General, Organic, and Biological Chemistry

Fifth Edition

John W. Hill Stuart J. Baum Dorothy M. Feigl

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Library of Congress Cataloging-in-Publication Data

Hill, John William.
Chemistry and life : an introduction to general, organic, and biological chemistry. — 5th ed. / John W. Hill, Stuart J. Baum, Dorothy M. Feigl.
p. cm.
Includes index.
ISBN 0-13-569294-6
1. Chemistry. I. Baum, Stuart J. II. Feigl. Dorothy M. III Title.
QD31.2.H56 1997
540—dc20 96-36303
CIP

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Art Studio: *Precision Graphics* and *Thompson Steele Production Services*
Copyediting, Text Composition, and Electronic Page Makeup: *Thompson Steele Production Services*

Printed in the United States of America

10 9 8 7 6 5 4 3 2

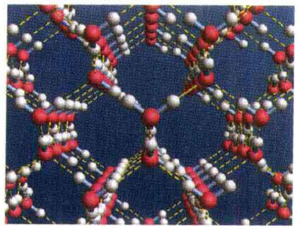
ISBN 0-13-569294-6

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall Hispanoamericana, S.A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Simon & Schuster Asia Pte. Ltd., *Singapore*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*

Preface

Our world has been transformed by science and technology. The impact of science on the quality of human life is profound. Yet, to beginning students, the scientific disciplines that daily influence their lives often seem mysterious and incomprehensible. Those of us who enjoy the study of science, however, find it a fascinating and rewarding experience precisely because it can provide reasonable explanations for seemingly mysterious phenomena.

Chemistry and Life has been written in that spirit. Apparently obscure phenomena are explained in an informal, readable style. We assume that the student has little or no chemistry background and clearly explain each new concept as it is introduced. Chemical principles and biological applications are carefully integrated throughout the text, with liberal use of drawings, diagrams, and photographs.


Hydrogen bonds in ice.

Our selection of topics and choice of examples make the text especially appropriate for students in health and life sciences, but it is also suitable for anyone seeking to become a better-informed citizen of our technological society. The text provides ample material for a full year's course. The 11 Special Topics cover optional material for added flexibility. They may be omitted or assigned as outside reading without loss of continuity. We have also included many short essays that focus on interesting applications of topics presented in the text. We have consciously increased the sophistication of chemical understanding as the student progresses through the chapters.

Changes in the Fifth Edition

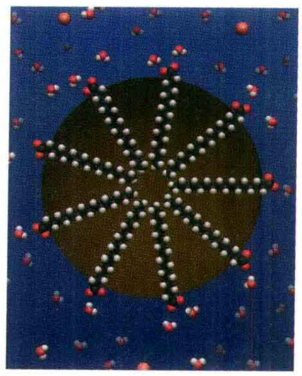
All the text has been updated to reflect the latest scientific knowledge. In addition, we have responded to suggestions of users and reviewers of the fourth edition and used our own writing and teaching experience to make the following changes:

Organization

For this fifth edition, we have included detailed contents on the opening page of each chapter. At the end of each chapter, we have added a list of Key Terms and a chapter Summary. The key terms are boldfaced in the text and are defined in the Glossary (Appendix IV).

We have added a greater number of photos, figures, and margin notes to clarify and enliven the text discussion. Many sections have undergone extensive rewriting, especially in the chapters on lipids and proteins. The discussion of the VSEPR theory and the shapes of molecules has been taken out of Chapter 4; it now makes up new Special Topic B.

The health-related topics from the fourth edition have been retained, and we have included several new essays. For example, arteriosclerosis, lead poisoning, development of cancer, diabetes, hemophilia, blood doping, and blood types.


A microscopic view of soap action.

Exercises

In addition to the many examples and practice exercises in the body of each chapter, we have three kinds of end-of-chapter exercises.

- Review Questions are intended to provide a qualitative measure of your understanding of the chapter.
- The Problems are arranged by topic; they test your mastery of the material and—where pertinent—of problem-solving techniques introduced in the chapter. These problems are arranged in matched pairs.
- The Additional Problems are not grouped by type. Some are intended to be a bit more challenging; they often require a synthesis of ideas from more than one chapter. Others, however, are not any more difficult than those arranged by topic. Rather, they pursue an idea further than is done in the text, or they introduce new ideas.

Many of the worked out examples have been revised to improve the pedagogy.

Supplements

For the Student

- **Student Study Guide with Solutions,** by Marvin L. Hackert of the University of Texas at Austin and Roger K. Sandwick of the State University of New York at Plattsburgh. This student-friendly manual contains chapter summaries, additional examples and problems, and numerous self-tests (with answers). Solutions correspond to the odd-numbered problems in the text. (0-13-574666-3; 57466-5)
- **Chemistry and Life in the Laboratory: Experiments in General, Organic, and Biological Chemistry,** by Victor L. Heasley and Val. J. Christensen of Point Loma Nazarene College and Gene E. Heasley of Southern Nazarene University. This manual contains 36 experiments that cover the same general topics as the text. Laboratory instructions are clear and thorough and the experiments are well written and imaginative. This revision includes more information on issues of safety and disposal. All experiments have been thoroughly class tested. (0-13-597725-8; 59772-4)
- **Allied Health Chemistry: A Companion,** by Tim Smith and Diane Vukovich, both of the University of Akron. This student companion teaches the basic mathematics inherent in the course by methods that are friendly and hands-on. (0-13-470460-6; 47046-8)
- **Prentice Hall/The New York Times Themes of Times.** Through this unique program, adopters of the *Chemistry and Life* are eligible to receive our *New York Times* supplement for their students. This newspaper-format resource uses current chemistry-related articles to emphasize the importance and relevance of chemistry in everyday life. (Free in quantity to qualified adopters through your local representative.)

For the Instructor

- **Instructor's Manual to the Laboratory Manual,** by Heasley et al. (0-13-597741-X; 59774-0)
- **Instructor's Manual,** by Roger K. Sandwick of the State University of New York at Plattsburgh, and **Test Bank,** prepared by Aninna Carter of Adirondack Community College. This instructor's resource contains solutions to the problems that are not answered in the text. The test bank has been revised extensively and now contains over 1100 multiple-choice questions. (0-13-594096-7; 57409-5)

- **PH Custom Test WIN** (0-13-574633-7; 57463-2) **PH Custom Test MAC** (0-13-574641-8; 57464-0). Electronic versions of the *Chemistry and Life* test bank which contains over 1100 multiple-choice questions.
- **Transparencies:** 125 full-color transparency acetates selected by the text authors.

Acknowledgments

JWH would like to thank his colleagues at the University of Wisconsin–River Falls for so many ideas that made their way into his other texts—some of which appear in this one—and to Kathy Sumter, Program Aide in the Department of Chemistry. He is especially indebted to Ina Hill and Cynthia Hill for library research, typing, and unfailing support throughout this project, and to Mike Davis for his encouragement and for sharing his love of learning.

We greatly appreciate the substantial support and guidance from the editorial staffs at Prentice Hall and Thompson Steele. Ben Roberts, Irene Nunes, Andrea Fincke, and Craig Kirkpatrick all played significant roles in converting the manuscript into a book of which we are all proud.

Both of us would like to thank our students, who have challenged us to be better teachers, and the reviewers of this and our other books, who have challenged us to be better writers.

Hugh A. Akers
Lamar University

Dave Becker
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No book—or other educational device—can replace a good teacher; thus we have designed this book as an aid to the classroom teacher. The only valid test of this or any text is in a classroom. We would greatly appreciate receiving comments and suggestions based on your experience with this book.

J. W. H.
S. J. B.
D. M. F.

To the Student

What is chemistry?

Chemistry is such a broad, all-encompassing area of study that people almost despair in trying to define it. Indeed, some have taken a cop-out approach by defining chemistry as "what chemists do." But that won't do; it's much too narrow a view.

Chemistry is what we all do. We bathe, clean, and cook. We put chemicals on our faces, hands, and hair. Collectively, we use tens of thousands of consumer chemical products in our homes. Professionals in the health and life sciences use thousands of additional chemicals as drugs, antiseptics, or reagents for diagnostic tests.

Your body itself is a remarkable chemical factory. You eat and breathe, taking in raw materials for the factory. You convert these supplies into an unbelievable array of products, some incredibly complex. This chemical factory—your body—also generates its own energy. It detects its own malfunctions and can regenerate and repair some of its component parts. It senses changes in its environment and adapts to these changes. With the aid of a neighboring facility, this fabulous factory can create other factories much like itself.

Everything you do involves chemistry. Your read this sentence; light energy is converted to chemical energy. You think; protein molecules are synthesized and stored in your brain. All of us do chemistry.

Chemistry affects society as well as individuals. Chemistry is the language—and the principal tool—of the biological sciences, the health sciences, and the agricultural and earth sciences.

Chemistry has illuminated all of the natural world, from the tiny atomic nucleus to the immense cosmos. We believe that a knowledge of chemistry can help you. We have written this book in the firm belief that beginning chemistry can be related immediately to problems and opportunities in the life and health sciences. And we believe that this can make the study of chemistry interesting and exciting, especially to nonchemists.

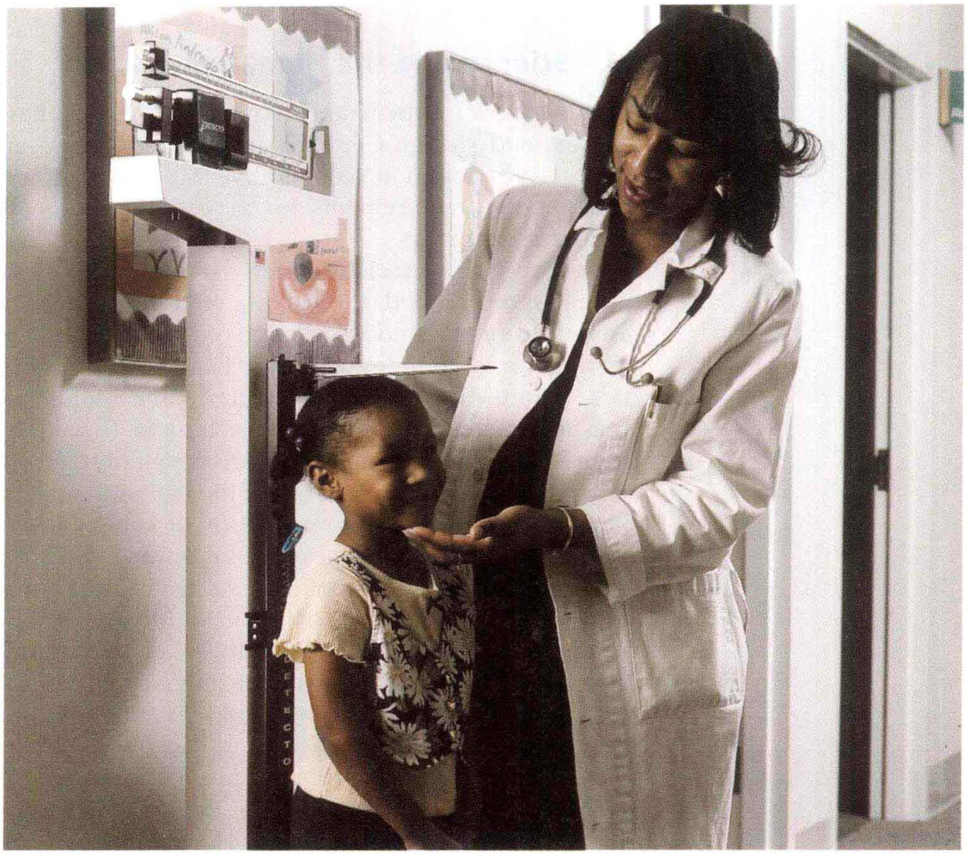
For example, an "ion" is more than a chemical abstraction. Enough mercury ions in the wrong place can kill you, but the right number of calcium ions in the right place can keep you from bleeding to death. "$PV = nRT$" is an equation, but it is also the basis for the respiratory therapy that has saved untold lives in hospitals. "Hydrogen bonding" is a chemical phenomenon, but it also helps to account for the fact that a dog has puppies while a cat has kittens and a human has human babies. There are hundreds of similar fundamental and interesting applications of chemistry to life.

A knowledge of chemistry has already had a profound effect on the quality of life. Its impact on the future will be even more dramatic. At present we can control diabetes, cure some forms of cancer, and prevent some forms of mental retardation because of our understanding of the chemistry of the body. We can't *cure* diabetes or cure *all* forms of cancer or *all* mental retardation, because our knowledge is still limited. So learn as much as you can. Your work will be enhanced and your life enriched by your greater understanding.

Be prepared. Something good might happen to you—and to others because of you.

Contents

1 Matter and Measurement



Accurate measurements are important in science and in medicine. Measurement of height and weight are meaningful first steps in any physical examination. Other measurements, often more sophisticated than these, are also essential in many medical procedures.

This book is called *Chemistry and Life*. What does chemistry have to do with life? What is chemistry? For that matter, what is life?

The last question is more than rhetorical. Progress in science, technology, and medicine has blurred the distinction between life and death. Is a person whose heart has stopped beating necessarily dead? Is a person whose vital functions are being maintained by machine truly alive? In this book we won't even attempt to supply a definitive answer to the question "What is life?" We'll simply note the critical significance of this question for our society.

How about the first question: "What does chemistry have to do with life?" A chemist would answer, "Just about everything." The human body, for example, is the most extraordinarily complicated, most elegantly designed, and most efficiently operated chemical laboratory there is. Our attempts to answer this first question will fill most of this text.

That leaves us with the middle question, "What is chemistry?"—which is the subject of this first chapter. We shall see how science in general and chemistry in particular have developed from earlier human endeavors. Our study will include a consideration of the methods of science and the manner of its progress. Finally, we shall develop some basic concepts necessary to our study of chemistry and its relationship to life.

1.1 Science and the Human Condition

We are taught in elementary school that people have three basic needs: food, clothing, and shelter. Certainly those three things—if adequate in quantity and quality—are enough to keep us alive. Most of us, however, would agree that there are two more requirements for a *good* life: reasonably good health and some chance for happiness.

In early human societies, nearly all human effort was dedicated to the hunting and gathering of food, the making of clothing, and the provision of shelter. Our early ancestors had no knowledge of the biological and chemical basis of illness, and they could do little about their health except pray and make sacrifices to their gods. With the coming of civilization, some people began to have enough leisure time to turn their thoughts to the human condition and to the natural world around them. Over the centuries, what we now call science grew out of their speculations. As this scientific study of the material universe progressed, the responsibility for adding to the growing body of knowledge was divided among various disciplines, and one of these disciplines was chemistry.

Modern chemistry's roots are planted in alchemy, a kind of mystical chemistry that flourished in Europe during the Middle Ages (about 500 to 1500 C.E.). Modern chemists inherited from the alchemists an abiding interest in human health and the quality of life. Alchemists not only searched for a philosopher's 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.

It was a Swiss physician, Theophrastus Bombastus von Hohenheim (1493–1541), who urged all chemists to turn away from their attempts to make gold and to seek instead medicines with which to treat disease. Possessed of a monstrous ego, von Hohenheim (who preferred the self-chosen name Paracelsus) alienated many of his contemporaries. His followers, however, were numerous enough to ally forever the science of chemistry with the art of medicine.

By the seventeenth century, a changed attitude, characterized by a reliance on experimentation, had been adopted by astronomers, physicists, physiologists, and philosophers. It was this change in orientation that signaled the emergence of chemistry from alchemy. The English philosopher Francis Bacon (1561–1626) had visions of these new scientific methods endowing human life with new inventions and wealth.

By the middle of the twentieth century, it appeared that science and its application in technology had made the dreams of Bacon and von Hohenheim a reality. Many diseases—such as smallpox, polio, and plague—had been virtually eliminated. Fertilizers, pesticides, and scientific animal breeding had increased and enriched our food supply. Transportation was swift, and communication was nearly instantaneous. Nuclear energy seemed to promise an unlimited source of power for our every need. New materials—plastics, fibers, metals, and ceramics—were developed to improve our clothing and shelter.

The Alchemist, a painting done by the Dutch artist Cornelis Bega around 1660, depicts a laboratory of the seventeenth century.

Indeed, it seemed that, despite its sometimes less than honorable intentions, science could do no wrong. For example, during World War I, when the German armies' supply of ammonia (which they needed to make nitrate explosives) was cut off, a process invented by Fritz Haber (1868–1934) provided them with an alternative supply. Haber's work probably lengthened the war, but it is far more significant for its influence on modern agriculture. Ammonia and nitrates are the stuff of which fertilizers are made, and fertilizers are essential to modern high-yield farming. In fact, most of the ammonia made by the Haber process today goes into fertilizers.

The explosive potential of ammonium nitrate in contact with organic materials was dramatically revealed in an enormous explosion aboard a cargo ship in Texas City, Texas in 1947. Nearly 600 people were killed and several thousand were injured. Explosive mixtures of ammonium nitrate fertilizer and fuel oil were used in the terrorist attacks on the World Trade Center in New York in 1993 and on the federal building in Oklahoma City in 1995.

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 cornerstone of what we mean by the "modern" world.

1.2 Problems in Paradise

If during the first half of the twentieth century science was viewed as humankind's savior, during the latter half it is sometimes viewed as quite the opposite. Those anesthetics that made surgery painless for the patient have caused female anesthesiologists, surgeons, and surgical nurses to suffer a high percentage of miscarriages compared with other health personnel. Fertilizer runoff from farms has polluted streams, and insecticides have had a devastating effect on some wildlife. On occasion, industrial workers making modern products for our use have died from diseases caused by the chemicals they worked with, and chemical waste dumps may threaten the health of us all.

One solution to these problems would be simply to throw out science. But do we really wish to return to surgery without anesthetics? Most of us don't. We need scientists, for it is they who will search for safer anesthetics, for approaches to increased agricultural production compatible with the natural environment, and for analytical techniques that will ensure healthful working conditions for industrial personnel.

The simple fact is that chemistry and its products, both good and bad, are so intimately involved in determining the quality of life that to ignore the subject is to court disaster. It will take an educated, informed society to ensure that science is used for the betterment of the human condition.

1.3 The Way Science Works—Sometimes

Textbooks often define science as a "body of knowledge," and it is frequently taught as a finished work rather than an ever-changing approach to learning. Science is organized into concepts. For example, even though we will often speak of the structure of an atom as if it were readily observable, atomic structure is merely a convenience that successfully describes many observable facts in a metaphorical way. It is not the "body of facts" that characterizes science but the *organization* given to those facts. To be useful, concepts must have predictive value. If the atomic theory is to be useful, it should enable scientists to predict how matter will behave.

The most distinguishing characteristic of science is its use of processes or methods. The making of observations and the cataloging of facts are bare, though necessary, beginnings to these intellectual processes. Scientists must be able to make careful measurements, but they must also be able to grasp the central theme of these observations. They must recognize the variables and be able to note the effect of changing one variable at a time. Scientists must be able to sort out the useful aspects of information and ignore the irrelevancies. Perhaps basic to these intellectual processes is the ability to formulate testable hypotheses. Even an educated guess is of little value to scientists unless an experiment can be devised to test its validity. In fact, if a hypothesis cannot be tested, the question is generally considered to lie outside the realm of science.

Science is not totally different from other disciplines. For example, creativity is central to both science and the humanities. Science does not involve cold logic to the exclusion of other human characteristics. Albert Einstein recognized that there was no *logical* path to some of the laws that he formulated. Even he relied on intuition based on experience and understanding.

It is important to realize that there is no single "scientific method" that, when followed, produces guaranteed results. Scientists observe, gather facts, and make hypotheses, but somewhere along the way they test their hunches and their organization of facts by experimentation. Scientists, like other human beings, use intuition and may generalize from a limited number of facts. Sometimes they are wrong. One of the strengths of science lies in the fact that results of experiments are published in scientific journals. These results are read—and often checked—by other scientists in all parts of the world. To become an accepted part of the "body of knowledge," the results must be reproducible. Scientists also extend each other's work, sometimes to the point that we see a "bandwagon" effect. One breakthrough sometimes results in the unleashing of vast quantities of new data and leads to the development of new concepts. For example, early in the nineteenth century it was thought that certain chemical substances, called *organic* compounds, could be produced only by living tissue, such as someone's liver or the leaf of a plant. These substances were in contrast to other materials, labeled *inorganic,* which could be prepared by a chemist in a laboratory. In 1828, Friedrich Wöhler (1800–1882), a German chemist, succeeded in making an organic compound from an inorganic one in the laboratory. The belief that such a compound could not be prepared in this manner was so strong that Wöhler did the same thing over and over again to assure himself that he had really done the