CHEMISTRY IN FOCUS

SECOND EDITION

A Molecular View of Our World

NIVALDO J. TRO

Chemistry in Focus

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Nivaldo J. Tro
Westmont College

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Preface

To the Instructor

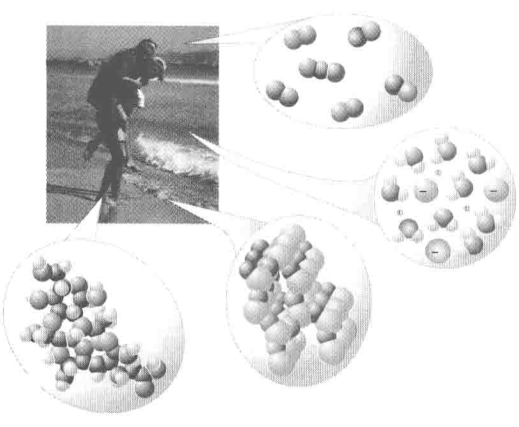
The two main goals of this book are for students to understand the molecular world and to understand the scientific issues that face society.

Chemistry in Focus is a text designed for a one-semester, introductory 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.

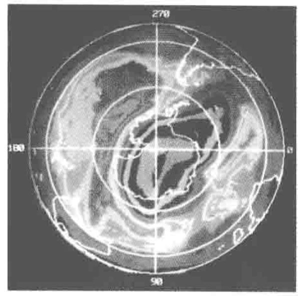
A Molecular Focus

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.

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 it. 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—since 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.


Chapter Summary 69

Chapter Summary

Molecular Concept	*Societal Impact*
We have seen that all things, including ourselves, are ultimately composed of atoms and that the macroscopic properties of things ultimately depend on the microscopic properties of the atoms that compose them. We completely specify an atom by indicating its atomic number (*Z*), the number of protons in its nucleus; its mass number (*A*), the sum of the number of protons and neutrons in its nucleus; and its charge (*C*). The mass number and charge can vary within a given element, but the atomic number defines the element and therefore cannot change. Atoms having 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, an anion.	Because all things are made of atoms, we can better understand those things if we understand atoms. The processes that occur around us at any time are caused by changes in the atoms that compose matter.
One characteristic of an element is its atomic weight, which is a weighted average of the masses of the isotopes that naturally compose that element. The atomic weight is also the weight of 1 mole, 6.022×10^{23} atoms, of that element in grams. It provides a conversion factor between grams and moles.	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.
The number of valence electrons, electrons in the outermost Bohr orbit, in an element's atoms is key in determining an element's properties. Elements with full outer orbits are chemically stable, whereas those with partially filled outer orbits are not. Elements with similar numbers of valence electrons form families or groups of elements and occur in vertical columns in the periodic table. Elements can also be classified with regard to their tendency to lose or gain electrons in chemical reactions: Those that tend to lose electrons are called metals, while those that gain electrons are called nonmetals. We will see in the next chapter how elements combine in chemical reactions to form compounds. The microscopic model developed in this chapter will be directly applicable in explaining why elements form the compounds that they do.	Reactive atoms, such as chlorine, can become environmental problems, especially when human activity moves them to places where they are usually not found. For example, chlorine atoms are transported into the upper atmosphere by synthetic compounds called chlorofluorocarbons. Once there, they react with the ozone layer and destroy it.

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.

A Tour of the Text

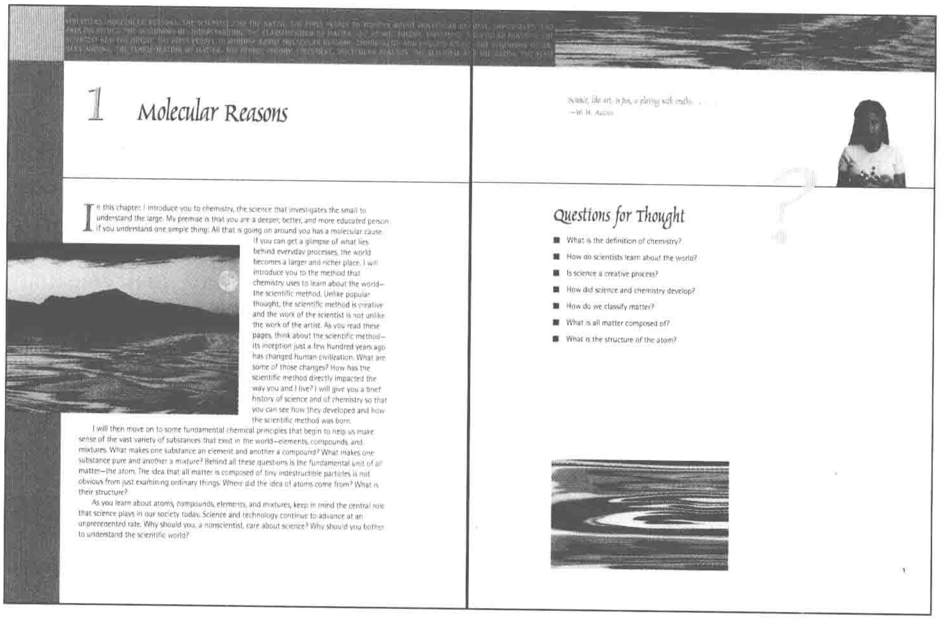
General Chapter Structure

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 paragraph to Chapter 1 states, "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?"

The opening paragraph of each chapter is 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.

Each chapter introduces the material with Questions for Thought.

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



1 Molecular Reasons

In this chapter I introduce you to chemistry, the science that investigates the small to understand the large. My premise is that you are a deeper, better, and more educated person if you understand one simple thing: All that is going on around you has a molecular cause. If you can get a glimpse of what lies behind everyday processes, the world becomes a larger and richer place. I will introduce you to the method that chemistry uses to learn about the world—the scientific method. Unlike 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 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? I will give you a brief history of science and of chemistry so that you can see how they developed and how the scientific method was born.

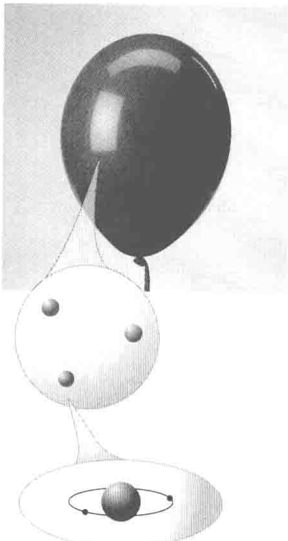
I will then move on to some fundamental chemical principles that begin to help us make sense of the vast variety of substances that exist in the world—elements, compounds, and mixtures. What makes one substance an element and another a compound? What makes one substance pure and another a mixture? Behind all these questions is the fundamental unit of all matter—the atom. The idea that all matter is composed of tiny indestructible particles is not obvious from just examining ordinary things. Where did the idea of atoms come from? What is their structure?

As you learn about atoms, compounds, elements, and mixtures, keep in mind the central role that science plays in our society today. Science and technology continue to advance at an unprecedented rate. Why should you, a nonscientist, care about science? Why should you bother to understand the scientific world?

Science, like art, is fun, a playing with truths. . . .
—W. H. Auden

Questions for Thought

- What is the definition of chemistry?
- How do scientists learn about the world?
- Is science a creative process?
- How did science and chemistry develop?
- How do we classify matter?
- What is all matter composed of?
- What is the structure of the atom?



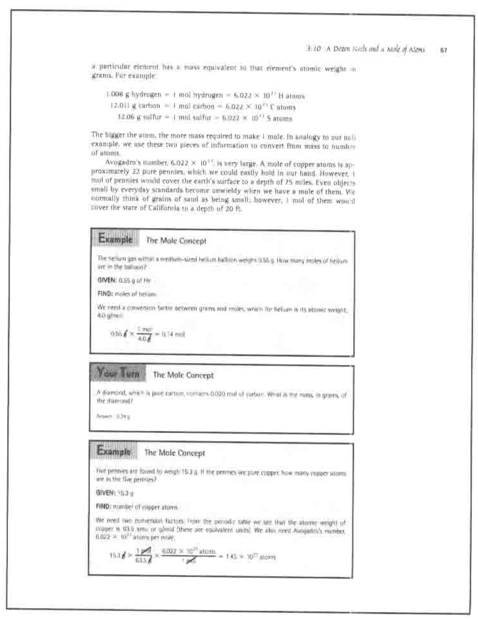
a greasy dish with soapy water. Why does plain water not dissolve the grease? The molecular reason is then given, enhanced by artwork that shows a picture of a soapy dish and a magnification showing what happens with the molecules.

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 make 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.

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. While 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 *Ex-*



3.10 A Dozen Nails and a Mole of Atoms 67

a particular element has a mass equivalent to that element's atomic weight in grams. For example:

1.008 g hydrogen = 1 mol hydrogen = 6.022×10^{23} H atoms
12.011 g carbon = 1 mol carbon = 6.022×10^{23} C atoms
32.06 g sulfur = 1 mol sulfur = 6.022×10^{23} S atoms

The bigger the atom, the more mass required to make 1 mole. In analogy to our nail example, we use these two pieces of information to convert from mass to number of atoms.

Avogadro's number, 6.022×10^{23}, is very large. A mole of copper atoms is approximately 22 pure pennies, which we could easily hold in our hand. However, 1 mol of pennies would cover the earth's surface to a depth of 75 miles. Even objects small by everyday standards become unwieldy when we have a mole of them. We normally think of grains of sand as being small; however, 1 mol of them would cover the state of California to a depth of 20 ft.

Example The Mole Concept

The helium gas within a medium-sized helium balloon weighs 0.56 g. How many moles of helium are in the balloon?

GIVEN: 0.55 g of He

FIND: moles of helium

We need a conversion factor between grams and moles, which for helium is its atomic weight, 4.0 g/mol:

$$0.56\ \text{g} \times \frac{1\ \text{mol}}{4.0\ \text{g}} = 0.14\ \text{mol}$$

Your Turn The Mole Concept

A diamond, which is pure carbon, contains 0.020 mol of carbon. What is the mass, in grams, of the diamond?

Answer: 0.24 g

Example The Mole Concept

Five pennies are found to weigh 15.3 g. If the pennies are pure copper, how many copper atoms are in the five pennies?

GIVEN: 15.3 g

FIND: number of copper atoms

We need two conversion factors. From the periodic table we see that the atomic weight of copper is 63.5 amu or g/mol (these are equivalent units). We also need Avogadro's number, 6.022×10^{23} atoms per mole.

$$15.3\ \text{g} \times \frac{1\ \text{mol}}{63.5\ \text{g}} \times \frac{6.022 \times 10^{23}\ \text{atoms}}{1\ \text{mol}} = 1.45 \times 10^{23}\ \text{atoms}$$

amples 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 wishing a more quantitative course should include these sections, while those wanting a more qualitative course can skip them.

Boxed Features

MOLECULAR REASONING

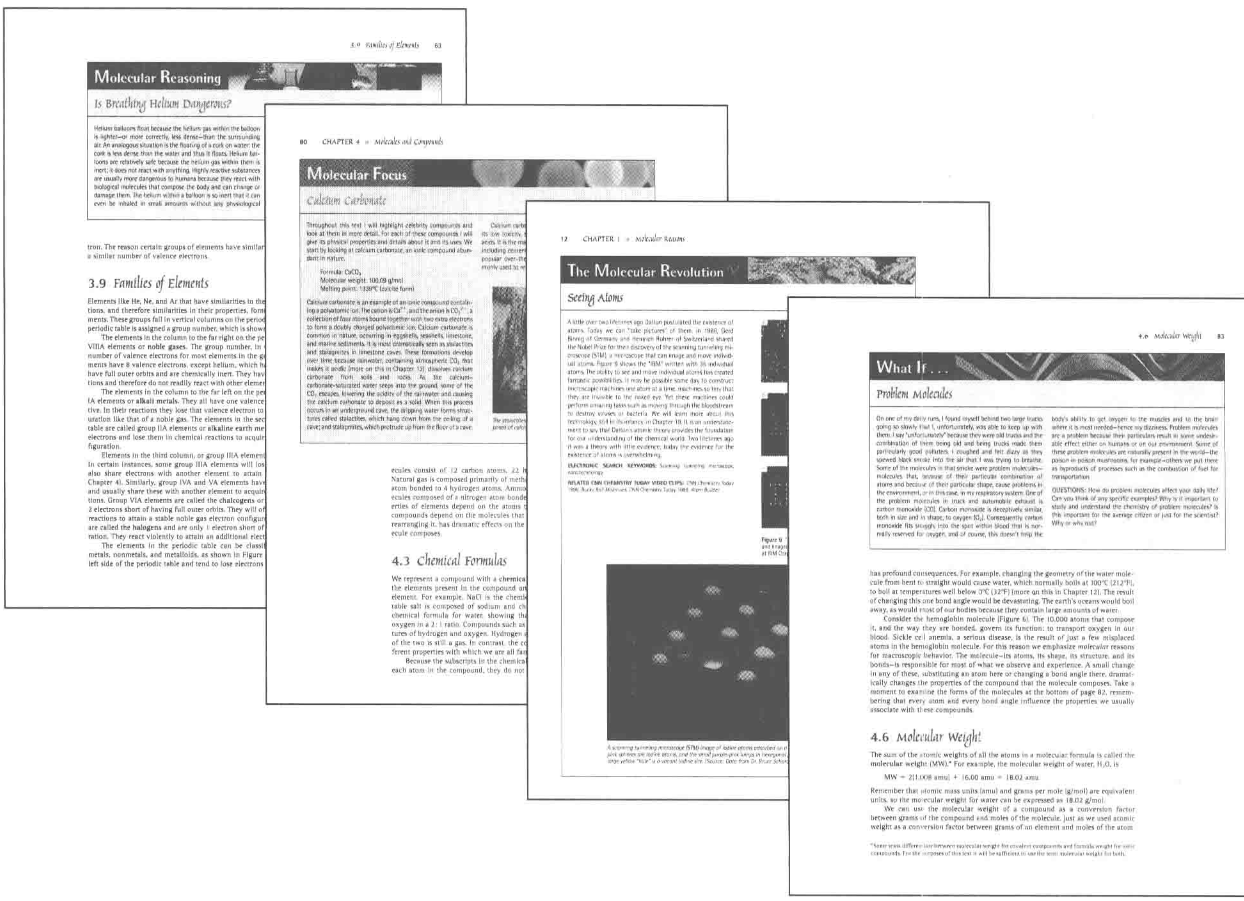
Molecular Reasoning boxes describe an everyday observation related to the chapter material. The student is then asked to explain the observation based on what the molecules are doing. For example, in Chapter 4, when discussing chemical equations and combustion, the *Molecular Reasoning* box describes 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.

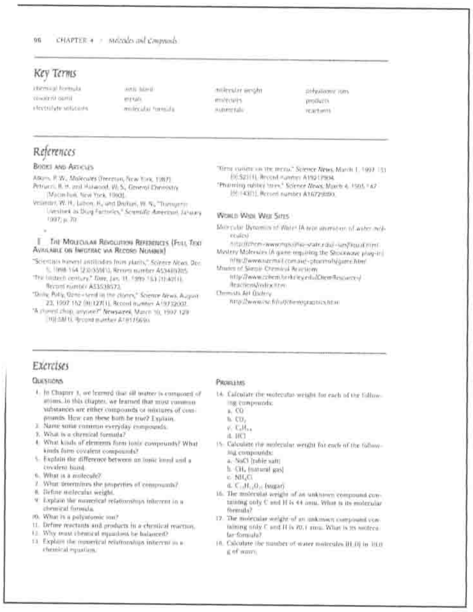
Boxed features show relevance and ask students to interact with the material.

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.





Key Terms

References

Exercises

The Molecular Revolution

Molecular Revolution boxes highlight topics of modern research and recent technology related to the chapter's material. Examples include the measuring of global temperatures, imaging atoms with scanning tunneling microscopy, and the development of electric and hybrid/electric cars. The *Molecular Revolution* boxes contain electronic search key terms to be used in searching for additional information with electronic databases such as Infotrac (http://www.infotrac-college.com/wadsworth/). Also included are references to relevant CNN/Chemistry Today video clips. The reference section of each chapter contains *Molecular Revolution References*, a list of relevant articles in publications such as *Time, Newsweek, U.S. News & World Report,* and *Science News*. All articles are text accessible through the Web by record number at the Infotrac Web site.

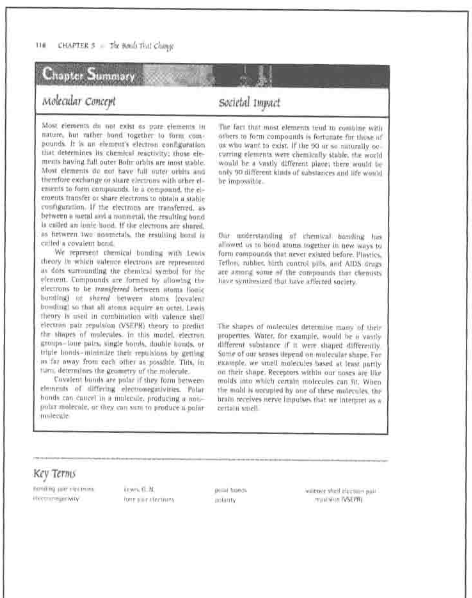
What If

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, genetic engineering, and others.

Chapter Summaries

Chapter summaries review main molecular concepts and their societal impacts.

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 Summary

Molecular Concept | Societal Impact

Key Terms

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 the student to recall many of the key concepts from the chapter. The *problems* ask the student 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.

Acknowledgments

Although the cover of this book bears only one name, it should rightly bear many. I am grateful to my colleagues at Westmont College, who have given me the space to write this book. I am especially grateful to Stan Gaede and Allan Nishimura for their support and to David Marten for answering my never-ending questions. Thanks also to Claire Pettiette-Hall for her excellent work in accuracy checking, to Terri Wright for her beautiful design and photographs, and to Trish Finley and Tessa Avila for their herculean efforts in production. I cannot begin to express my gratitude to Jennifer Huber, my editor, whose energy, ideas, and constant enthusiasm made writing this edition a joy.

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—Nivaldo J. Tro
Westmont College

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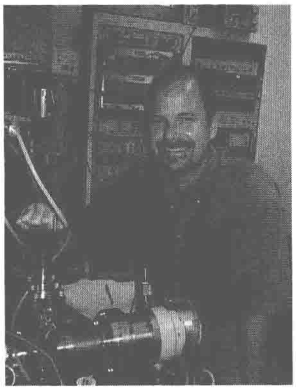
To Annie

About the Author



Nivaldo J. Tro received his BA degree from Westmont College and his PhD degree from Stanford University. He went on to a post-doctoral research position at the University of California at Berkeley, and in 1990, he joined the chemistry faculty at Westmont College in Santa Barbara, California. In addition to teaching and writing, Professor Tro investigates the reactions of surface-adsorbed molecules. He publishes the results of this research, usually co-authored with undergraduate students, in scientific journals such as *The Journal of Physical Chemistry.*

Professor Tro lives in the foothills of Santa Barbara with his wife, Ann, and their two children, Michael and Alicia. In his leisure time, Professor Tro likes to spend time with his family in the outdoors. He enjoys running, hiking, mountain-biking, and fishing.

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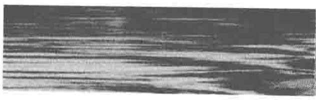


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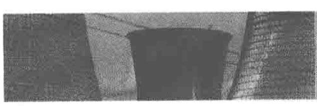

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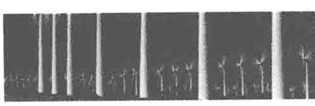

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