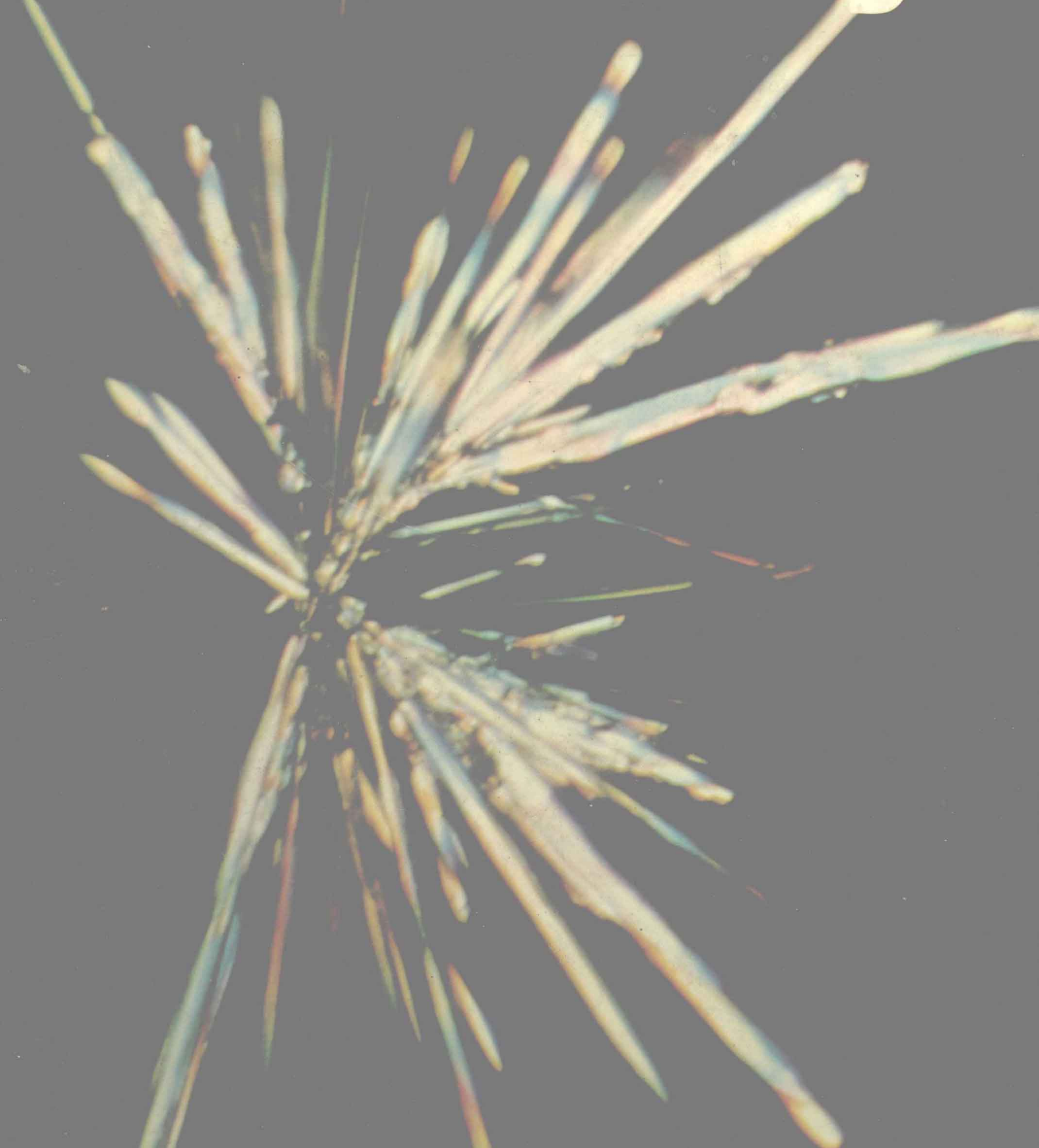
Chemistry



Masterton/Slowinski/Walford

CHEMISTRY

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Front cover photograph is a photomicrograph of a crystal of a cyclic monomer grown in a gaseous environment. This monomer is a building block for the production of a solid-state polymer. (Photo courtesy of National Bureau of Standards, and originally published in *Chemistry* magazine.)

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PREFACE

This book is designed for the mainstream course in high school chemistry. We believe it is suitable for students who will not pursue the subject further as well as those who will go on to take college chemistry. With this in mind, the principles covered are restricted to those which we feel are basic to a beginning course in chemistry. These principles are developed in considerable detail from a very elementary point of view. More advanced ideas are treated in optional sections set off from the rest of the text. These may be covered at the discretion of the instructor, but are not built upon in subsequent chapters.

To make sure that students become thoroughly familiar with basic principles, we have referred to them repeatedly throughout the text. Chemical formulas, equations, and stoichiometric calculations are introduced early and reviewed frequently. Most students do not grasp all the implications of a quantitative concept the first time it is presented. Only by frequent review does an idea such as the mole become a useful tool to the student.

Descriptive chemistry, both inorganic and organic, is emphasized throughout the book. Of the 27 chapters, 12 are primarily descriptive. These are distributed throughout the book and are designed to apply and illustrate chemical principles. We believe that this approach is necessary if the student is to get an accurate picture of what chemistry is all about. Too often, he or she emerges from a first course in the subject convinced that chemistry is a sterile, intellectual exercise with little application to the real world.

One unusual feature of the book is the large number of solved examples, about 200 in all. In the solutions, we have emphasized the reasoning involved rather than which number goes where. There are also a large number of questions (500) and problems (600) at the ends of chapters. The problems are graded in difficulty. The first several problems in a set are keyed directly to the solved examples and are answered in an appendix. These are followed by similar, unanswered problems which cover all the basic ideas presented in the chapter. Finally, there are a few more advanced problems, marked with asterisks, for which answers are provided.

Most students, upon their first exposure to chemistry, have difficulties with the vocabulary. Realizing this, we have listed at the end of each chapter the new terms introduced. All of these are defined in a glossary at the back of the book. We have also tried to make sure that the reading level is appropriate for the average high school student.

There is a laboratory manual available for use with this text. The sequence of experiments follows the chapter order. We have also prepared a teacher's guide. This contains answers to the questions in the text and detailed solutions to all the problems. It also includes learning goals (basic skills) for each chapter, suggestions as to coverage of material, and appropriate demonstrations.

A great many people have contributed, directly or indirectly, to this book. It is always a pleasure to acknowledge the assistance of our editor, John Vondeling. He and Kay Dowgun have made our writing task enjoyable, insofar as that is possible. We would also like to acknowledge the copy-editorial skills of David Milley. Amy Shapiro went to a great deal of trouble to obtain appropriate photographs, many of which we used. The art work was in the capable hands of George Kelvin. Our colleagues, Ray Boyington and Ruven Smith provided us with slides for the color plates in the center of the book.

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One of the few elements discovered by the alchemists was phosphorus. Hennig Brand, searching for the philosopher's stone in urine, a most unlikely source, isolated phosphorus instead. Bettman Archive.

1

AN INTRODUCTION TO CHEMISTRY

You are just beginning to read this book and probably just beginning a course in high school chemistry. You are in a position similar to that of a person beginning to climb a mountain. Both you and the climber should be asking yourself two questions: (1) Why am I here? and (2) What is the nature of this course over which I intend to spend considerable time and effort traveling?

In this chapter you will be introduced to some basic ideas of chemistry. This way, you will know better what to expect in your journey. You will also learn of some of the skills that will be required. With these skills, your experience in chemistry can be both enjoyable and rewarding.

1.1 THE NATURE OF CHEMISTRY

At the root of chemistry (and all other sciences) is curiosity, the desire to know. Ancient peoples were curious for practical reasons. They wanted to find answers to their needs for food, water, and shelter. Later, as civilization developed, men and women became curious for the sake of knowledge itself. We can only guess some of their first questions. What is everything made of? Why do things change? What happens when wood burns? when water freezes? when iron rusts?

For centuries, chemists have sought answers to questions such as these. They have used many different approaches, some more rewarding than others. In this section, we will trace briefly the evolution of modern chemistry. It began as abstract theory in ancient Greece. Later, during the Middle Ages, chemistry became an art, fascinating but obscure. Only within the past 200 years has chemistry become the useful science that we know today.

Chemistry as an Exercise in Logic: the Greeks

Early Greek philosophers developed curiosity into a system of reasoning. Answers to questions about the nature of things were stated on the basis of abstract logic. No attempt was made to do experiments. Apparently, Greek intellectuals felt it was demeaning to work with their hands. Aristotle (384–322 B.C.) was the most famous of this group. He had an answer to the question: what are things made of? According to Aristotle, there were four "elements" of matter: fire, air, water, and earth. All matter was made up of these elements in varying amounts. An object that was "hot and dry" was mostly fire. "Hot and moist" was associated with air, "cold and moist" with water, "cold and dry" with earth.

Aristotle was actually a better philosopher than he was a scientist.

Today we can smile at these ideas or dismiss them as utter nonsense. Yet they persisted for nearly 2000 years. In part, this was due to the remarkable success of the Greeks in certain areas of science, notably geometry. Perhaps more important, there was no way to test these ideas in the laboratory. Any attempt to combine fire with water is doomed to failure. Indeed, it would never have occurred to Aristotle to try such an experiment. The moral is clear:

1. *A theory or explanation which cannot be tested by experiment is worthless.* It may satisfy curiosity for a time, but it leads only to a dead end.

Chemistry as Fun and Games: the Alchemists

The pseudo-science of alchemy began around 300 A.D. It flourished in Europe as late as 1700 A.D. A major goal of the alchemists was to find the "philosopher's stone" which would convert base metals to gold. To achieve this they carried out a great many experiments. In this respect, the alchemists progressed beyond the Greek philosophers.

The laboratory work of the alchemists left a great deal to be desired. Their procedures and descriptions were, to say the least, obscure. Consider, for example, the following recipe for obtaining the philosopher's stone.

> "Take all the mineral salts there are, also all salts of animal and vegetable origin. Add all the metals and minerals, omitting none. Take two parts of the

salts and grate in one part of the metals and minerals. Melt this in a crucible, forming a mass that reflects the essence of the world in all its colors. Pulverize this and pour vinegar over it. Pour off the red liquid into English wine bottles, filling them half-full. Seal them with the bladder of an ox (*not* that of a pig). Punch a hole in the top with a coarse needle. Put the bottles in hot sand for three months. Vapor will escape through the hole in the top, leaving a red powder, . . ."

This experiment, as you can imagine, is not easy to duplicate. If you wanted to repeat it, you might be able to locate English wine bottles. Perhaps you could even find the bladder of an ox. However, you could spend a lifetime collecting *all* the salts, metals, and minerals in the world. From this story we conclude that:

A scientific experiment usually isn't done just once.

2. *An experiment which cannot be repeated is worthless.* It must be described in such a way that others can perform it, confirming or refuting the results.

To their credit, some of the later alchemists carried out rational experiments. Consider, for example, Jon Baptista van Helmont (1577–1644). He planted a young willow tree, weighing 5 lb, in a tub filled with 200 lb of dry earth (Figure 1.1). For five years, he added only water to the tub. At that point, the tree weighed 169 lb. Virtually all of the 200 lb of earth remained. Van Helmont concluded that:

"164 lb of wood, bark, and roots arose out of water only"

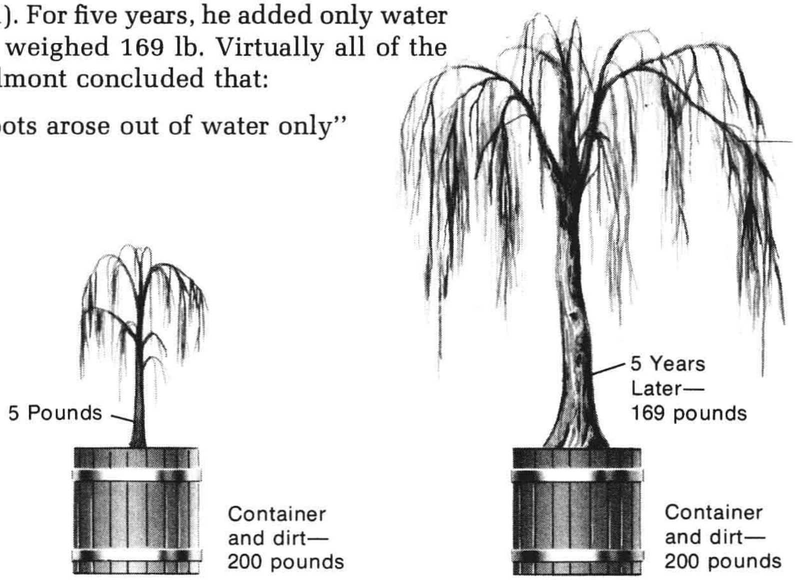

FIGURE 1.1

Van Helmont found that the mass of his tree went from 5 to 169 lbs in five years. Since he had added only water to the tub, he figured that the tree had gained its mass from the water added. He didn't realize that the added mass could have, and did, come from the air around the tree as well as from the water that was added.

This observation overlooked a possible source of the increase in mass of the willow tree. This is the air over the tree. Today we know that growing plants take in carbon dioxide from the air as well as water. In fact, more than half of the increase in mass came from the carbon dioxide. Without being too critical of van Helmont, we can say that:

3. *An experiment must be carried out under carefully controlled conditions.* Any factor which could affect the results must be taken into account.

The Dawn of Modern Chemistry: Lavoisier

One man more than any other transformed chemistry from an art to a science. Antoine Lavoisier was born in Paris in 1743. He died in