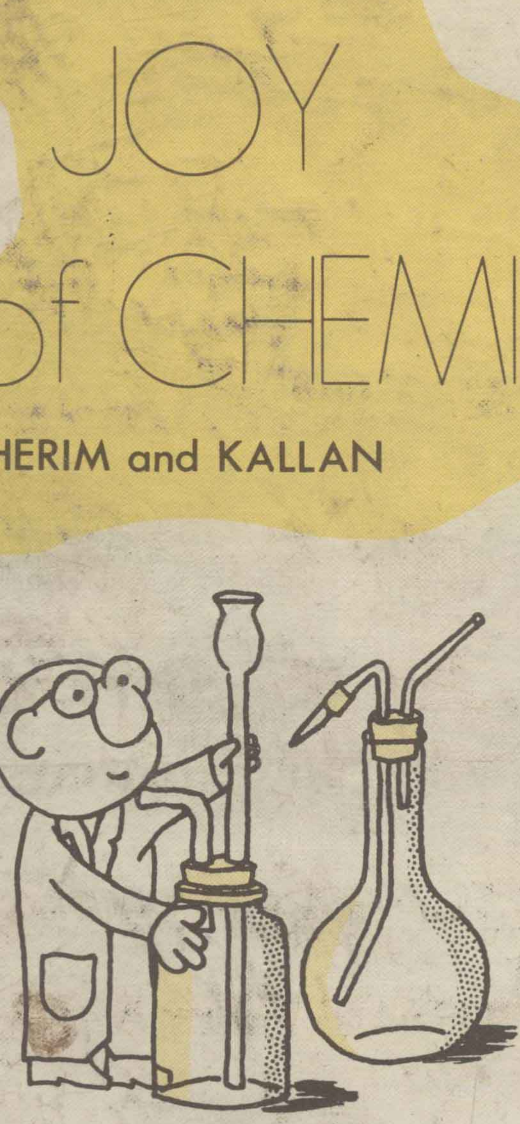
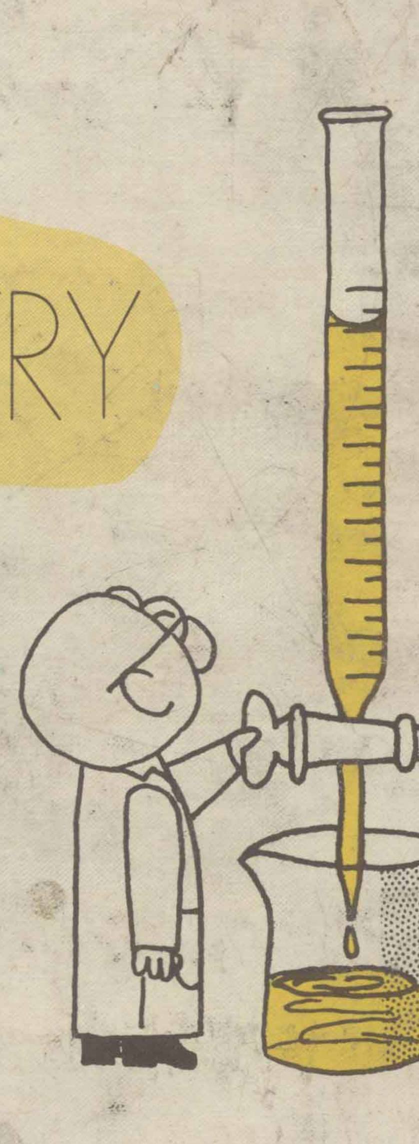
# The JOY of CHEMISTRY

**CHERIM and KALLAN**





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# PREFACE

Students who aspire to become chemists, physicists, biologists, engineers, physicians, or professionals in the health sciences are required to take comprehensive and rigorous chemistry courses. The first-year general chemistry course in colleges and universities presumes a certain amount of advance preparation, including recent exposure to a high-level high school course in chemistry. Qualified students have an understanding of the fundamentals of writing formulas, balancing equations, using the metric system, and solving simple stoichiometry problems.

But what about the capable and highly motivated student who has not taken high school chemistry? Or who took it years ago? Or who found his previous chemistry class a dismal encounter? We wrote *The Joy of Chemistry* for these students.

The format and content are designed to encourage a mastery of basic skills. Difficult concepts are described in simplified terms. Emphasis is placed on systematic methods of interpreting problems, organizing relevant data, and understanding the importance of dimensional analysis. The use of scientific notation and the handling of dimensional units are stressed in numerous examples and practice exercises.

We try to explain in clear and readable language such relatively difficult concepts as atomic structure, chemical bonding, acids and bases, and chemical equilibrium. We develop specific skills in dealing with chemical formulas, nomenclature, gases, types of reactions, solutions, and the techniques for balancing equations.

A rationale for the introduction of topics is included deliberately. Rather than imply, "Learn this because it is a traditional part of a chemistry course," we suggest valid reasons why it is to the student's advantage to study a topic.

Many devices are used to convince the student that the mole concept is indispensable in chemistry. We also explain that a minimum amount of physics is appropriate in a chemistry text, since many theories and concepts are fundamental to both disciplines.

Too often do otherwise educated people shudder at the mention of a chemistry course. We hope to show our readers that there is joy to be found in this exciting and dynamic field. The relevance of chemistry to modern concerns such as ecology, energy sources, pollution, and drugs elevates this subject above a mere intellectual exercise.

In view of our ambition to write a serious "nuts-and-bolts" text to serve the many needs of students with specific goals, you might wonder about the title, *The Joy of Chemistry.* The title is not meant to be tongue-in-cheek, sensational, or cute. Our conception of joy in the study of chemistry has nothing to do with the "la-de-dah tripping-through-the-daisies" vision of the romantic. We mean "joy" in a sense that has some curious parallels to Alex Comfort's objectives when he wrote *The Joy of Sex.* Admittedly, our parallels go just so far. But Comfort was dealing with a subject frought with fears, anxieties, "hang-ups," and misinformation. We, too, are dealing with a subject that historically has generated its share of similar unhappiness. Just as Comfort teaches the attitudes and techniques (blush) that can lead to joy in a human experience, we believe that the mastery of problem solving techniques, the understanding of basic physical concepts, and an appreciation for the rich historical aspects of chemistry can generate a joyful attitude. And the student who acquires these abilities will close the book at the end of the course not only with joy at its conclusion but also with much satisfaction and a feeling of personal accomplishment.

Some special features should aid the student. *The Joy of Chemistry* employs **boldface** type to call attention to technical terms, and *italics* are used for emphasis. Numerous sample problems are solved in annotated steps. Each chapter is prefaced with a list of learning objectives. The answers to problems and questions are provided in the Appendix.

We are indebted to a number of outstanding educators for their reviews of the text and for their many helpful suggestions, constructive criticism, and encouragement during the writing of the manuscript. Our gratitude specifically is extended to Sheldon I. Clare of the University of Pittsburgh, Alan Cunningham of Monterey Peninsula College, Richard B. Moreau of Alpena Community College, Fred Redmore of Highland Community College, Edwin L. DeYoung of The Loope College, Dorothy M. Goldish of California State University, and Ralph Burns of East Central Junior College.

We were fortunate to have been able to work closely with Joan Garbutt, Grant Lashbrook, John Hackmaster, Ivy Fleck Strickler, Amy Shapiro, and other staff members of W. B. Saunders Co.

We thank Chris Crowley for her excellent job of typing the entire manuscript. Finally, a note of thanks and love to our respective families, whose encouragement and patience were so important.

*Stanley M. Cherim*
*Leo E. Kallan*

# TO THE STUDENT

It seems to us that an important question a student should try to answer as he or she begins the study of chemistry is, "Why bother?" There must be some convincing rationale to make the sweat and toil of studying chemistry a worthwhile and enjoyable experience rather than an anticipation of dread. No one should cling to the illusion that a rigorous chemistry course is easy. We all know that insistence on quality demands a high price. What, then, can we offer to justify the effort?

Besides the obvious and rather prosaic reason that chemistry is a requirement in the curriculum or, perhaps, an essential for admission to a professional or graduate school, we believe that the study of chemistry can improve our scientific literacy and gratify our intellectual curiosity about the nature of the physical world.

### Getting the Most out of the Course

Your successful mastery of the content of a chemistry course will probably depend on more than sheer talent and desire. If those sparks of interest, curiosity, or even enthusiasm are to be fanned into a fire, a disciplined approach to your study is essential. To this end we have some suggestions regarding study habits for chemistry:

1. Study the learning objectives that precede each chapter. These will tell you something of what you should be able to understand, define, and do when you have mastered the content. We believe that it is helpful to know what is expected of you before you begin.

2. Don't hesitate to make marginal notes and underline those sections where you have questions to be raised or where your instructor has clearly indicated emphasis.

3. Keep complete and legible notes during the class lecture. It is very likely that your instructor will supplement the text with useful analogies, additional information, and sample problems.

4. Do the exercises that appear throughout the chapters and the additional questions and problems at the end of the chapters *even if they aren't assigned as homework.* There is often a large gap to be bridged between the understanding of how a problem is solved systematically and the actual solving of problems with pencil in hand. You will find the answers to problems in Appendix I so that you can keep a constant check on your progress.

5. Get into the habit of studying with paper and pencil. First read and then list key terms, outlining briefly those concepts having a sequential character, and attacking mathematical problems systematically.

6. Now let's deal with the mathematical problems—especially for those among you who feel overwhelmed in your lifelong battle with numerical problems. We suggest that the observance of the following steps may inspire you to confront "word problems" with a renewed determination to establish just who is the boss. The steps are as follows:

a) Read the entire problem and determine exactly what it is that you are looking for.

b) Organize the data in tabular form. Make sure that the units, or dimensions, are compatible.

c) When the problem is of the type that permits you to visualize actual quantities, to make simple sketches, or to construct mental models—do it! You can justify almost any device that helps you to move from the abstract to the tangible.

d) Most importantly, use dimensional analyses. Make sure that all units factor-out except for those required in the answer. Rarely will the answer to a problem be a unitless number. For example, the number 2.34 can mean anything or nothing, but 2.34 *grams* very clearly states a definite mass.

e) Check your calculations in an effort to catch careless mistakes in computation. Estimate your answers roughly as a preliminary check before you use a slide rule or calculator. Ask yourself whether the answer seems reasonable. If it seems good, allow yourself a few moments' warm glow of satisfaction or a thoughtfully modulated shout of triumph.

7. Make it a habit to come to class prepared to ask questions. Studying the homework assignment will help you to understand the lecture and to get the most out of it.

8. Finally, use the student guide that we have prepared to accompany the text. We have written this supplement with the hope and expectation that it will be a distinct aid in helping you to find the joy of chemistry.

*Stanley M. Cherim*
*Leo E. Kallan*

# CONTENTS

# The JOY of CHEMISTRY

# CHAPTER ONE

## LEARNING OBJECTIVES

At the completion of this chapter, you should be able to:

1. Distinguish among the metric units of length, volume, and mass.
2. Explain the difference between mass and weight.
3. List and define the metric system prefixes.
4. Convert measurement units within the metric system.
5. Apply dimensional analysis in problem solving.
6. Choose appropriate conversion factors from available tables.
7. Develop conversion factors when data are available.
8. Write numbers in the form of scientific notation.
9. List four types of volumetric glassware.
10. Distinguish between temperature and heat.
11. Convert temperatures among Fahrenheit, Celsius, and Kelvin scales.
12. Define the terms *density* and *specific gravity.*
13. Calculate densities, volumes, and masses from measurement data.

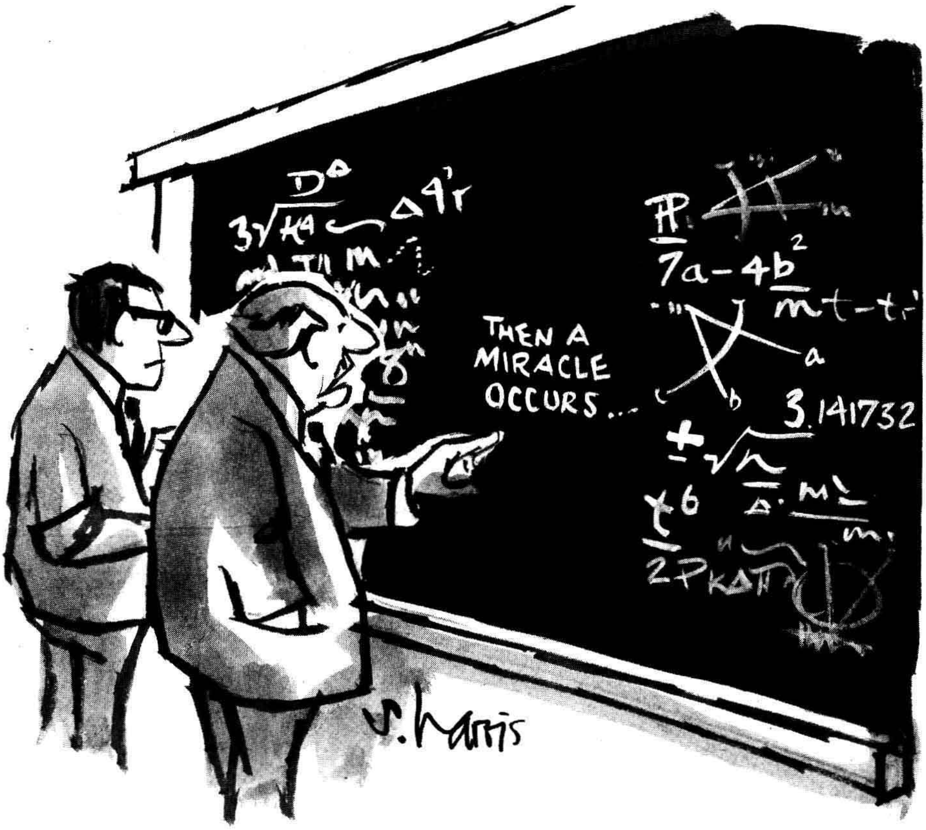
# MEASUREMENT

## 1.1 INTRODUCTION

When the great English scientist James Clerk Maxwell was a small child he began to demonstrate the powerful driving force of human curiosity. For Maxwell, life in its most meaningful and exuberant sense meant asking questions about the mysteries of our environment. As young Maxwell examined a mechanical device and asked his father, "What is the 'go' of that," he was raising the kind of question that characterizes the scientific mentality regardless of age. What is it made of? How does it work? What is it used for?

Maxwell typified the scientific approach by going first to the wellspring of recorded human experience. In other words, by learning something about the laws of nature as they were understood in the nineteenth century, he was better able to distinguish between the physical principles that might provide a sound basis for progress and those that needed to be questioned. It takes a trained mind to see clearly and objectively the cause-and-effect relationships present in natural phenomena, and it requires that peculiarly scientific mind to evaluate subjectively the significance of the observations. To make an orderly fabric (scientific discipline) out of a chaotic tangle of threads (isolated facts) can be a beautiful and creative human endeavor. We should be glad that the aesthetic aspects of science persist. It is true that we have moved through the centuries from the art and magic of the alchemists to the very different objectives and methods of modern chemistry, but there is a debt to be acknowledged. Despite the fact that the energies of our ancestors were fruitlessly devoted to the creation of the "philosopher's stone" with which common metals might be changed into gold and to the discovery of the "elixir of life" that would assure eternal youth, science had its raw beginnings in their arcane laboratories.

When the age of charlatans passed and with them their magical incantations and occult symbols, some light began to creep into the darkness of the Dark Ages. Soon men dared to question "sacred" authority, and they suffered for it. (Was something really true because Aristotle said so?) Nevertheless, it was during these ages of antiscience that glassblowers first produced retorts, beakers, funnels, and crude volumetric glassware. The




"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

potters fashioned earthenware crocks, crucibles, mortars, pestles, and ovens. And the blacksmiths gave us support stands, forceps, tongs, and spatulas. And so we moved from authoritarianism and the black arts to the modern arts, and from there to science—from magic and absolutes to tentative assumptions and systematic experimental testing. This is the scientific method. To paraphrase an old anonymous saying: in science we have moved from cocksure ignorance to thoughtful uncertainty.

Unfortunately, science has not always been a pure and beautiful monument to man's nobler instincts. Chemistry, the science concerned with the structure and behavior of matter, has provided more than an adventure in living. It has been and still is the basic tool for death and destruction in war. Problems of environmental pollution provide us with unique and critical challenges and teach us about moral responsibility. The poisoning of our waters and air bring the relationship between science and life into a new and very special focus. The young Maxwells of our age are likely to ask, "What is the 'nice' of it?" in addition to the "go" of it. The old and rather meaningless adage, "science for science's sake" is hopefully giving way to "science for mankind's sake."

## 1.2 THE AREAS OF CHEMISTRY

The broad physical science of chemistry is commonly subdivided into specialty areas. *Inorganic* chemistry deals with all the known elements and combinations of elements in terms of their structures and changes. *Organic* chemistry is specially concerned with compounds of carbon, which are most familiar to us in forms of living things and in synthetic fabrics and plastics. *Analytical* chemistry is involved with finding out what a substance is composed of and how much is there. *Physical* chemistry is most directly concerned with the complexity and mechanism of chemical change and its relationship to energy. *Biochemistry* is tied in with the nature of the chemical changes that sustain life. It is difficult to find any aspect of life in which chemistry does not predominate. Think of ways in which the beauty of chemistry is apparent in economics, philosophy, politics, theology, business, and art.

## 1.3 MEASUREMENT

Any serious attempt to learn about the forces and energy effects that relate to the structure and behavior of matter requires an understanding of the concept of measurement. How else can the observations of "how much," "how many," "how far," and "how fast" be described? Measurement is a fundamental effort needed to increase the orderly expansion of our knowledge. Dimensional units must be used if sense is to be made out of linear distance, mass, time, and temperature. And an understanding of how these basic units are interrelated is necessary so that the more sophisticated phenomena of energy, density, force, and volume can be understood. The international standards for measurement today constitute what is known as the *metric system*. Throughout the book the fact that all measurements include both a *number* and a *dimension* will become obvious.

Now let us consider how a scientist handles numbers conveniently (scientific notation), sensibly (significant figures), and with an ability to discriminate between correctness and reproducibility (accuracy and precision). Then we can see how the dimensions (unit labels) are applied to the numbers in such a way that we can carefully reason out and check the problem solving process (dimensional analysis).

## 1.4 SCIENTIFIC NOTATION

Scientific notation is a method of increasing efficiency in calculations by expressing cumbersome, many-digit numbers in a compact form. It consists of writing with exponents. The exponent indicates the number of times a value is multiplied or divided (in the case of negative exponents) by itself. Some examples are as follows:

$$2^2 = 2 \cdot 2 = 4$$

$$2^3 = 2 \cdot 2 \cdot 2 = 8$$

$$2^{-2} = \frac{1}{2 \cdot 2} = \frac{1}{4}$$

$$2^{-3} = \frac{1}{2 \cdot 2 \cdot 2} = \frac{1}{8}$$

$$N^4 = N \cdot N \cdot N \cdot N$$

$$N^{-4} = \frac{1}{N \cdot N \cdot N \cdot N}$$

The last example provides a useful focal point, because the base number 10 is the heart of the international system (metric system) of weights and measures. Note the relationship between the exponent and the number of digits (zeros in this case):

$$10^{③} = 1000 \qquad 3 \text{ digits}$$

The following examples support the observation that the exponent of the base 10 is exactly the same as the number of places that the decimal point is moved in the coefficient.

$$1.0 \times 10^{②} = 100$$

$$2.0 \times 10^{⑤} = 200{,}000$$

$$1.0 \times 10^{⑥} = 1{,}000{,}000$$

$$2.5 \times 10^{③} = 2500$$

This direct relationship between the exponent and the number