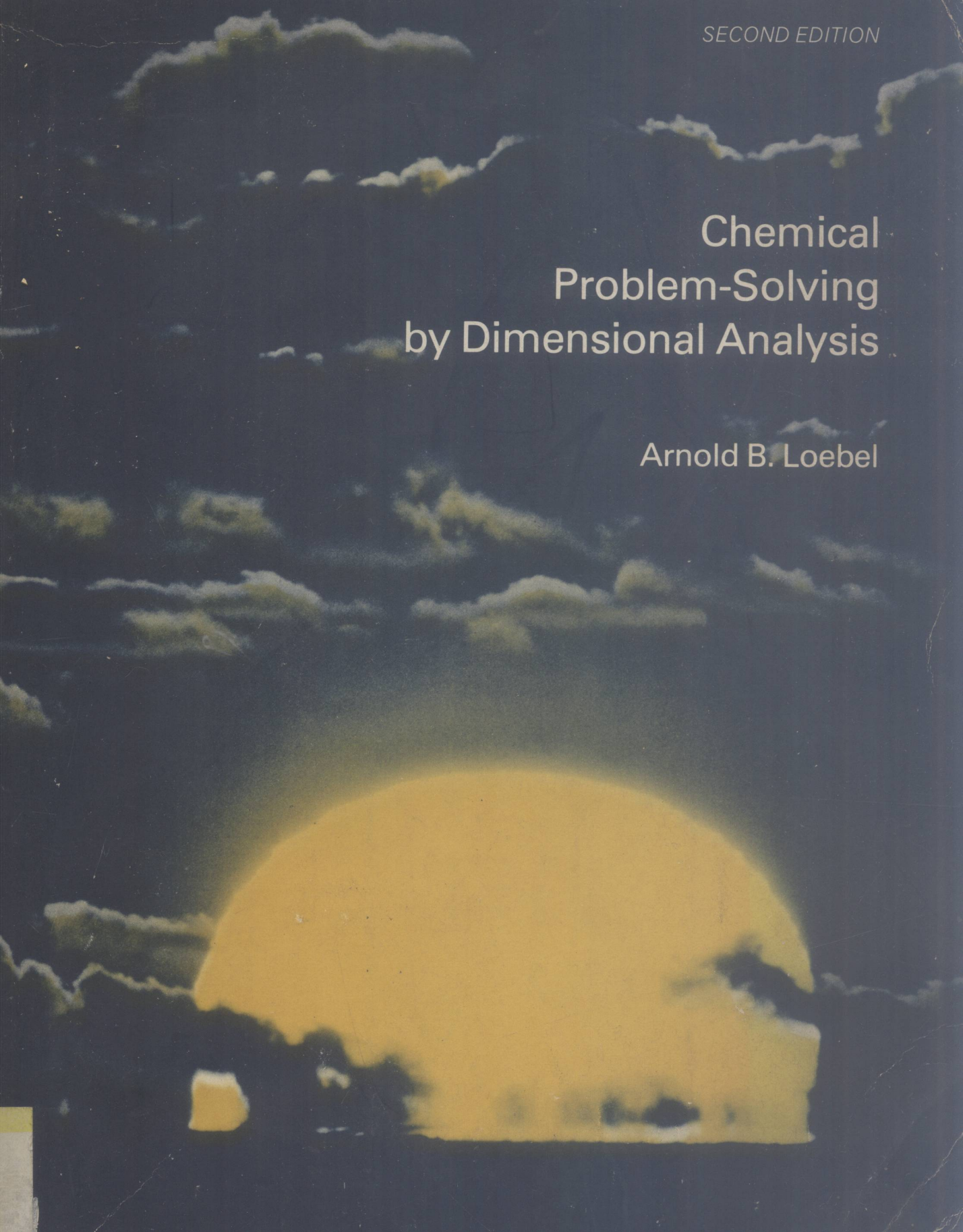
SECOND EDITION

Chemical Problem-Solving by Dimensional Analysis

Arnold B. Loebel



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Chemical Problem-Solving by Dimensional Analysis

A Self-Instructional Program

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Arnold B. Loebel

Merritt College, Oakland, California

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To Elizabeth L. Birns

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Chemical Problem-Solving by Dimensional Analysis

Preface to the Second Edition

The very widespread acceptance of the first edition of this totally programmed problem-solving book clearly showed the need for a text in this unique format which will serve the needs of a highly varied audience. The book has been used in situations which were never considered when it was first published. It has been used as the sole text in remedial courses for students with some previous chemistry background. It has been used as the sole text in courses preparatory to General Chemistry or given concurrently with General Chemistry, pre-General Chemistry or terminal chemistry courses for allied health students. It also has been used as a supplementary text for all the above courses. It has even found its way into college bookstores, where it is available on recommendation from instructors to students with problem-solving difficulties.

The totally programmed format has made it possible for the text to be used in both an auto-tutorial situation—in which the student is rewarded with pass-fail credit for completing a certain number of modules—and in a normal lecture course. The ability of the book to work under all these varied situations has been gratifying indeed.

Even more gratifying have been the letters I have received from students using the text, saying what a help it has been to them in their studies. These letters often included a reticent mention of some error which appeared in the text. I hope that, in this second edition, all errata have been removed.

The section in Chapter 1 on the slide rule has been removed from this second edition. The emergence of very inexpensive pocket calculators has made the slide rule as antiquated as the horse and buggy. However, the alacrity with which these calculators produce eight-digit answers has necessitated a reinforcement of the section in Chapter 1 on significant figures. Much of this section has been completely rewritten, with strong warnings to the students on the dangers of the calculators.

The first edition was written to cover the types of calculations generally found in the first semester of a General Chemistry course. Usually pH is not covered until the second semester. However, the book has been used in such a wide variety of situations that it became apparent that pH should be included. Since pH does not fall into a dimensional-analysis form, it has been added as an appendix. To help the student, the appendix is totally programmed, as is the body of the text. If the instructor is concerned only with whole-number pH values, he or she may stop the student midway through the appendix.

Putting in a section on pH made it necessary to include logarithms. These have been placed in Chapter 1, Mathematics Review. The coverage is quite complete, but the use of logarithms for multiplication and division has been disregarded. The students' pocket calculators serve this function. However, the use of logarithms for

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determining powers and roots is included, as well as natural logarithms, for students' future reference. If the instructor wishes to eliminate any of these parts, no problems will result.

Many teachers have commented that they would like this text to go further into chemical calculations. Consequently, I added a lengthy chapter on thermodynamic calculations, and included in it those topics for which dimensional analysis is a viable tool: specific heats, latent heats, thermochemical reactions, and calorimetry. Hess' Law is brought out in a rather unique way. This chapter—Chapter 17—is quite independent of all material after stoichiometry, and can be dealt with at any point after Chapter 8.

In the first edition, calculations involving solutions (Chapters 10 through 14) preceded calculations involving gas laws (Chapters 15 and 16). Most beginning chemistry textbooks have the reverse order. Therefore, in this second edition, I have rearranged the chapters to conform to this customary sequence. Gas laws now appear in Chapters 10 and 11, and solutions are in Chapters 12 through 16.

I want to thank Professor Larry Krannich, of the University of Alabama, whose careful reading of the first edition was an immense help in uncovering the errata about which "grateful students" shyly write. Professor Krannich's interest in the book since its first publication in 1974 has been truly appreciated. I also want to thank Professor Curtis Sears, of Georgia State University, for our conversations, which have been very helpful in crystallizing my ideas as to the direction that the revisions should take. I am also grateful to Professor Bernard Coyle, City College of San Francisco; Professor John H. Nelson, University of Nevada; and Professor David W. Brooks, University of Nebraska. Their assistance in reviewing the manuscript for the Second Edition has proved helpful.

Preface to the First Edition

This programmed book covers the types of chemical problems common to the first semester of freshman chemistry or a full-year college chemistry survey course. It should add an extra dimension to a beginning course, but it does not stray into the provinces of a good chemistry textbook. Students who have completed high school chemistry but who have been unable to pass a qualifying examination into general college chemistry have found this particularly useful in preparatory course work in chemical mathematics.

The book offers pretests and achievement tests for each module. Thus it is ideal for self-paced individual study since it allows the student to check his progress as he or she goes. As an extra aid, Appendices I and II cover chemical nomenclature. As it was being written, the manuscript was thoroughly class tested, and these appendices developed from a series of nomenclature quizzes.

Chapter 1 brings students up to the mathematical level required for the rest of the book. Readers are subsequently introduced to dimensional analysis, the only method used here for solving problems. (Gas law problems are an exception; they do not lend themselves to this procedure.) At first glance, this approach may seem nondidactic. It literally cajoles students away from the logical method of problem-solving in steps, traditionally conceived as the way of getting students to "think." However, sound motivation for "thinking" is also present in the dimensional-analysis method which has the added advantage of giving readers on-the-spot check points for testing how well they have learned a particular point. This is practical and remarkably successful.

Divisions are not included in the setup of problems. Instead, the invertibility of conversion factors, i.e., the use of their reciprocals, is brought out from the beginning. Students believe that they are always multiplying. This has eliminated many student errors. The chapters follow the order of most general chemistry courses, although the chapters related to solutions (10 through 14) precede the chapters on gases (15 and 16). The sequence can be reversed at the instructor's discretion since there is virtually no carry-over from one group to the other. There are also two chapters on stoichiometry (8 and 9). The first contains relatively simple material, while the second contains more complex problems with various involved conversions. If an instructor feels that the complicated stoichiometry chapter is unnecessary or overly burdensome, it can be eliminated.

Chapters 11 and 12 involve the concept of equivalency. The current trend is to downgrade the use of equivalency and normality, particularly in freshman chemistry. Consequently, these two chapters can be omitted, as the carry-over to Chapter 13 is minimal. Where the concept does occur, it is noted in the text so students will know that the problems are optional.

Numerical answers to pretests and a scoring procedure follow on

the next page. Students can grade themselves, and each student's score will reveal whether he or she is ready to go directly to the problem set at the end of the chapter, or whether he or she should work through certain, or all, sections of the chapter. Problems in the pretest are used as examples in the body of each chapter.

Following each chapter are problem sets, arranged in order of increasing complexity and sometimes divided into groups corresponding to various sections of the chapter. Answers and dimensional-analysis setups for all problems follow the problem set. Thus students can immediately see where they are correct and where they may have made mistakes. Relatively complex problems are marked with an asterisk to indicate they are optional. Better prepared and more motivated students thus have a challenge, and the text takes on broader flexibility for use by students with a range of background skills.

The appendix on nomenclature is programmed in the same manner as the text. The level is relatively low, but it covers most compounds encountered in the first semester of freshman chemistry. IUPAC notation has been used, although lip service is paid to the old names such as ferric chloride and cobaltous nitrate.

I would like to thank the many students who have used this text and whose feedback has helped to develop it into its present form. Also I would like to thank Professor Ethelreda Laughlin of Cuyahoga Community College whose careful scrutiny has helped eliminate many errors, and Professor Mildred Johnson of the City College of San Francisco whose hawk-like eye has uncovered innumerable impossibly concentrated solutions and unlikely chemical reactions.

A.B.L.

To the Student

This book has a very special design. It is a self-instructional program, and you must work with it in a very specific way. If you do, you will find that in a short time you will be able to solve chemical problems of dazzling complexity with so little effort that it will seem as though someone else were doing the work. It will be no more difficult to figure out the number of seconds in three hours than to figure out the number of milliliters of a 6.0 *N* solution of potassium permanganate required to completely react with 1.0 liter of a 3.7 weight percent solution of sodium oxalate whose density is 1.08 g/ml. (If this problem looks impossible, wait until you get to Chapter 13; it will be a snap!)

The book is divided into eighteen chapters, each of which covers only a single topic. Early in the chapter is a group of problems which cover the material in that chapter. This is called a pretest. If you think that you can handle the material in the chapter, take the pretest. On the next page you will find the answers to these problems and a guide to scoring yourself. Your score will tell you either that you can skip immediately to the problem set at the end of the chapter, or that you had better work through certain sections of the chapter first.

Each chapter is presented with the text on the inside and a separate column on the outside with occasional words or numbers. This is the special design of a self-instructional program. Even if you have worked with this type of a program before, you will still benefit by reading the next few words of instruction here.

In the text, on the inside of the page, you will see blanks, _____, in the middle of sentences or after questions. In the column on the outside, on the same line as the _____, you will find the word or number which fills the _____. The one thing you must do—and without this it won't work at all—is to write the response for each and every _____ without looking at the response in the outside column. You can do this best by covering the column on the outside with the card located at the front of the book. Read the text material, and when you get to a _____, write down the appropriate word or number either in the _____ or on a piece of scratch paper. (You are going to need scratch paper anyway, since as you progress in the book the responses to the _____'s will involve building up the solution to the problems in the order of dimensional analysis, and you must keep a running solution in order to proceed to the next _____.) Then uncover the response for the _____ and check the answer you wrote down to see that it is the same. It will almost always be the same. If,

by some strange chance it isn't, just go back a few _____'s and try it over again until you are sure you understand.

The main thing to remember is that you cannot simply read through the program as you would a textbook. You must work through and write down the responses to every _____. You are not taking a test or simply filling in blanks when you are working with a program; you are learning by doing. The program works so that each response gives you sufficient understanding to make the next response, and on and on and on.

When you get to the end of the chapter you will be ready to do a real problem set. There are special instructions on some of these which will tell you that some problems need not be done. You can check your answers as soon as you have completed a problem set. All the answers are given on the following page, and the problems are worked out so that you can examine your solutions. You often will be told how many you should have done correctly and to which section of the chapter you should refer to find the method of solving a certain type of problem that you couldn't manage.

Remember that you are not just taking tests, you are learning by doing. You can work along at your own rate, and you can grade yourself as you go. In this way, you will be able to check your learning each step along the way. You will be surprised at how easy this is to do. So tear out the card, cover up the responses, and get to work.

Arnold

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Contents

Chapter 1
Mathematics Review

PRETEST

1. Express 56,000 in scientific notation (that is, as a number between 1 and 10 times 10 raised to a power).
2. Express 0.0031 in scientific notation.
3. Perform the operation $3.5 \times 10^{-6} \times 2.0 \times 10^{2}$.
4. Perform the operation $\dfrac{8.4 \times 10^{-4}}{2.0 \times 10^{2}}$.
5. Perform the operation $6.7 \times 10^{18} + 3.00 \times 10^{19}$.
6. Perform the operation $(3.0 \times 10^{-8})^{3}$.

Using the four-place table of logarithms in Appendix III, determine the following.

7. log 10^{3}
8. log 55.5
9. log 0.000558
10. antilog -9.2291
11. $e^{0.25}$
12. $\sqrt[5]{35}$
13. Express 2.4321640 to three significant figures.
14. Perform the operation

$$6.0 \times 4.3 \times \frac{4.3271}{3.}$$

15. Perform the operation $4.321 + 6.5$ and express your answer to the correct number of significant figures.

PRETEST ANSWERS

1. 5.6×10^{4}
2. 3.1×10^{-3}
3. 7.0×10^{-4}
4. 4.2×10^{-6}
5. 3.67×10^{19} or 36.7×10^{18}
6. 2.7×10^{-23} or 27×10^{-24}
7. 3
8. 1.7443
9. −3.2534
10. 5.90×10^{-10}
11. 1.284
12. 2.036
13. 2.43
14. $4. \times 10^{1}$
15. 10.8

If you had all of them right, you're a whiz. You can skip Chapter 1 and do the problem set at the end immediately.

If you had all but one right in numbers 1–6, you probably can skip Section A in Chapter 1. If you missed two or more out of questions 1–6, you should work through Section A. If you got all of numbers 7–12 correct, you can skip Section B in Chapter 1. If you just missed number 11, take a look at the part of this section on natural logarithms. If you missed only number 12, check the last part of Section B, Determination of Powers and Roots. If you did numbers 13, 14, and 15 all correctly, you can skip Section C.

The whole purpose of this chapter is to give you the tools you will need to get a number answer once you have set up chemical problems by "dimensional analysis." There is nothing very complicated in this chapter. It is divided into three sections which, though quite different, all have to do with handling numbers. Remember that the way to use this text is to cover the outside of the page with a piece of paper so that you cannot see the answers that go in the blanks. Then you read the inside, and when you get to a _____ you write down what goes in it. Then slide your piece of paper down the outside and check that you have written down the correct word or number. We are going to start with what is called "exponential notation."

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