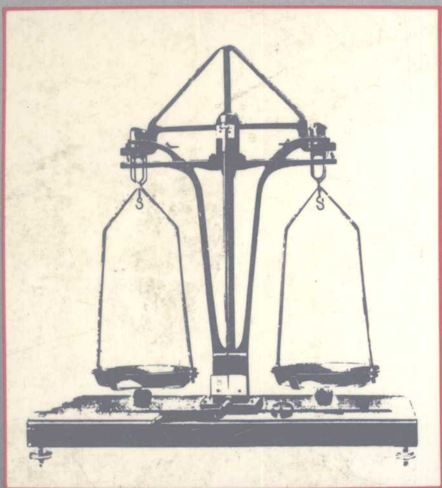
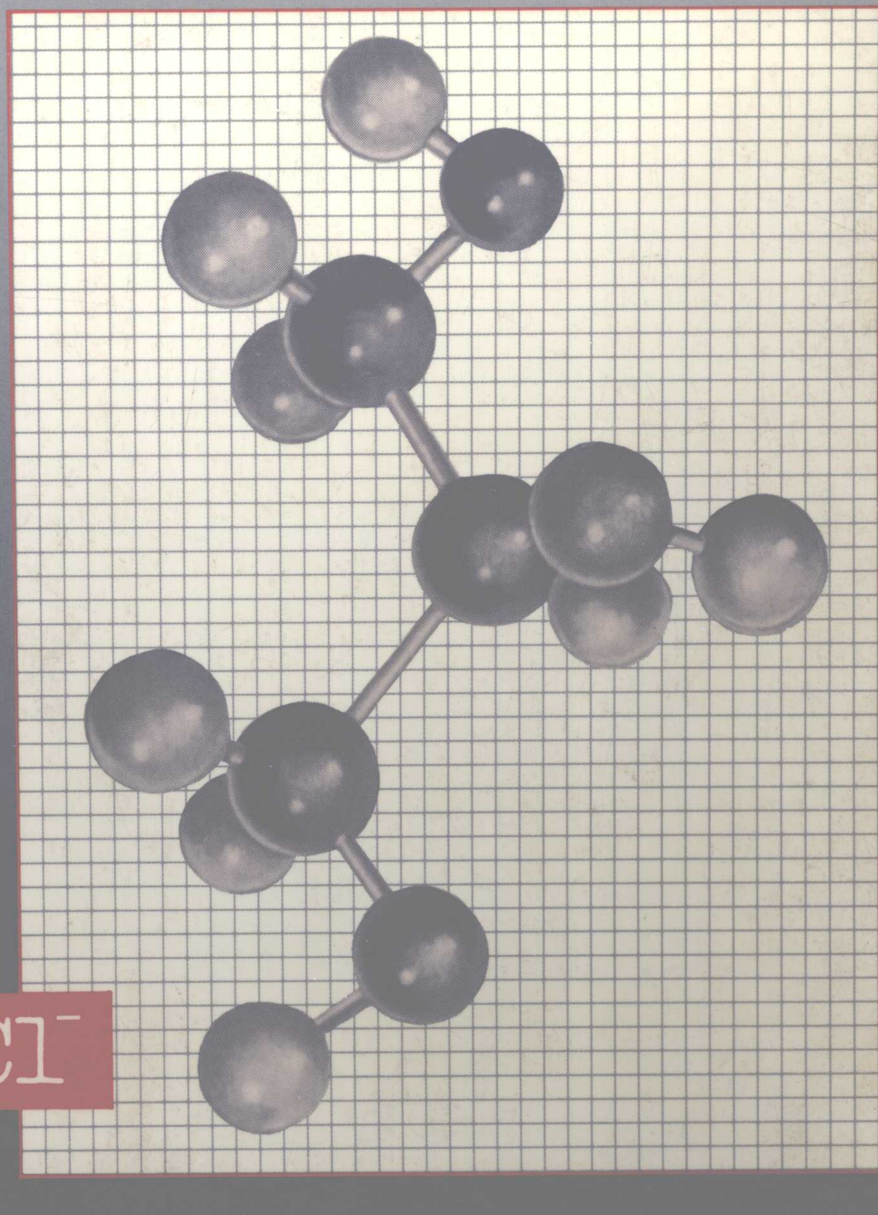
CHEMICAL SKILLS

THIRD EDITION

EDWARD I. PETERS
WILLIAM SCROGGINS





5
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10.81

$HCl \rightarrow H^+ + Cl^-$

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THIRD EDITION

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PREFACE

The purpose of Chemical Skills is to be to students a "tutor" that is always available, at any time and at any place, during the early stages of learning chemistry. The course's reputation as a "difficult" course is well known. We who teach it know that the "difficulty" often lies not in chemistry, but in weak mathematical skills or not knowing how to translate a problem into a workable calculation setup. A thousand-page textbook does not have space to develop basic skills for its readers. Nor does it have room to guide students gradually through the problem-solving methods that arise in the course. This book is designed to overcome both of these obstacles to starting out successfully in chemistry.

Chemical Skills addresses first poor mathematical skills. The first six chapters range from a review of basic arithmetic and algebra to graphing and logarithms. These chapters will be used selectively, depending on the level of the math background, whether or not graphing skills are needed in the laboratory, and whether or not the course reaches a need for logarithms.

Chapters 3 and 4 cover mathematics and its application to measurement. Chapter 3 introduces an approach to solving chemistry problems that is used throughout the book. It includes the usual advice found in most textbooks, but we formalize that approach by "analyzing" each problem. It also "explains" quickly and in a minimum of space how example problems are solved. More about that in a moment.

Chapters 7 through 11 tackle chemical formula and equations skills. These barriers to successful problem solving arise within the chemistry course itself. Our purpose is to remove them as barriers to quantitative work. The remaining ten chapters guide the student to skill in solving the problems that commonly appear when beginning to learn chemistry. In all of the above areas, Chemical Skills offers a more gradual, learning-oriented development than is possible in a textbook. Nearly all students benefit from such an approach, and for many it means survival itself.

In Chemical Skills, principles that underlie a particular skill are presented in the usual textbook format, but example problems are programmed. Rarely, when a student wants help in learning how to "do" something—solve a problem, write an equation, or perform any other act that employs what we have called a "chemical skill"—do we simply "show" him or her how to do it. More often we ask questions that will guide the student into doing it himself or herself, trusting that the act of doing will produce learning. That is what we have done in writing the programmed examples in this book. The success of this method is attested to by the large number comments received from users of earlier editions of this book and of other books that use programmed examples.

We referred above to a "formalized" problem solving approach. Most textbooks offer brief suggestions on how to solve problems. Writing down what is given and what is wanted is usually the first step. Many books do not complete that first step in their worked out examples. (We do it constantly.) Procedures vary after the given and wanted quantities are identified. In this book we recommend next a determination of which of two problem solving strategies are required by a specific example:

1. **Dimensional analysis** is used whenever the given and wanted quantities are related by one or more proportionalities. The necessary conversion factors are identified and a unit path is plotted.
2. **Algebra** is used if the relationship is fixed by a mathematical equation. Almost always, the equation is solved for the wanted quantity, the given quantities—*including units*—are substituted, and the result calculated.

We are not so naive as to believe a student will write down the given and wanted quantities, followed by an equation or a list of conversion factors and a unit path for each problem. Nor do we want them all to be written, *unless the student is unable to get started on a particular problem.* (We sometimes ask that they be written when a new topic is introduced.) But we do want the student *always to think of these steps*, not necessarily as sequential "steps," but rather as a means of analyzing the problem. To encourage this, we show the analysis of nearly every problem example. Usually, when the steps are written, the pattern for solving the problem is obvious and no further explanation is needed.

Perhaps you would like to see how this approach is developed. It first appears in Section 3.3, on page 38. Note particularly the last paragraph in the section. In Section 3.4 we introduce two other abbreviations that are used throughout the book. For problems solved by dimensional analysis, CF identifies conversion factors and UP refers to a unit path. A reminder of the dimensional analysis procedure appears in the middle of page 54, and again near the top of pages 212 and 213 after a long break from quantitative topics. The symbol EQ is first used on an equation-type problem on page 46. A reminder appears at the bottom of page 61, just before the next application for temperature conversions.

We have placed our description of the structure of Chemical Skills in a special "To the student" section entitled HOW TO LEARN CHEMISTRY FROM THIS BOOK. It follows this preface. Note particularly the instructions on how to solve programmed examples on page iv.

You might find it interesting to see the programmed format as a student sees it by a few minutes of role playing. If so, tear out one of the periodic tables to be used as a shield and reference source for atomic masses. A glance at the text just above Example 12.7 (page 215) will show you the form in which molar mass calculations have been developed. Then try the example, looking up the atomic mass on the periodic table and writing the needed information in the book. Example 12.10 (page 218) gives you a chance to apply molar mass to a mol → g conversion just as a student will do it for the first time. Continuing through several examples, here or elsewhere in the book, shows how the student is guided into learning by doing.

Among the nicer things about writing a chemistry book are the comments and suggestions that come from instructors who review the manuscript. It is reassuring when a review praises what has been written; it is, perhaps, even more valuable when it does not. We are challenged to compare our time-honored ways with something someone else thinks is better. Sometimes we adopt the new method, and sometimes we stay with the old. Either way, we benefit from the challenge and the reevaluation. We want to express our sincere appreciation to the following who have contributed to this edition in this way:

Gordon Ewing	New Mexice State University
John Gelder	Oklahoma State University
Barry Gilbert	Rhode Island College
Reilly Jensen	San Diego State University
David F. Koster	Southern Illinois University
Evan Williams	Brooklyn College

Our appreciation goes also to Tom Serface, who guided us through the thorny paths of converting a manuscript prepared initially on one computer/word processor/printer combination to a second combination of all three so the final camera-ready copy could be printed on a laser printer.

Edward I. Peters   William T. Scroggins

To the student:

HOW TO LEARN CHEMISTRY FROM THIS BOOK

[1]**tutor** *n*: . . . a private teacher . . .

[2]**tutor** *vt*: . . . to teach or guide usu. individually in a special subject for a specific purpose . . .

Webster

Meet your tutor: this book that you hold in your hands. This is not as impersonal as it seems. This book expresses in print what we, the authors, have given to students like you when they have been stuck on some problem or skill as they are beginning to learn chemistry. Even though we cannot meet you personally, we hope you will let us help you as we have helped others in one-to-one tutoring sessions.

A tutor can help you to learn, but it is you who must do the learning. All the studying that you do and all the assignments you complete are wasted if you do not *learn* the material. Demand of yourself that you *learn* how to do what is required.

This book has been designed to help you learn. It does this by guiding you into putting into practice what you are learning while you are learning. If you use the book as it is intended—if you work the examples as suggested on the next page—you will learn more chemistry in less time. Your reward will be better test scores and more time for fun and games. Enjoy both; you will have earned them. Here are some of the features of this book that will help you to learn:

Prerequisites Most chapters open with a list of things you are expected to know or be able to do before you study the present chapter. These are things which we expect that you learned in an earlier chapter. Section references are given so you can check back if you need a refresher in a particular skill. And do check back when necessary. You will not learn something new if you have not already mastered what you need for the new learning.

Chemical Skills This is a list of things you will learn how to do when you study this chapter. Use this list as a preview of the chapter so you will know where to focus your attention as you reach different topics in your study. When you finish that topic, return to the particular chemical skill and ask yourself, "Can I do that?" If the answer is truly yes, go on. If not, go back to the section and study it some more. Solve more end-of-chapter problems. Do whatever else is necessary for you to be able to look again at that chemical skill and say with confidence, "I can do that." Then, and only then, have you *learned* that topic.

Text and Examples Here's where the actual learning takes place. We'll look at this item more closely in a moment.

End-of-Chapter Questions and Problems The only way you can be sure you have learned how to do something is to do it. The end-of-chapter questions and problems give you that opportunity. About two-thirds of the questions are answered in the back of the book. Answers to problems include complete calculation setups. Your instructor has answers to the remaining questions. The answered questions appear first, and they are separated from the unanswered questions by a bar:

┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼

Chapter Test This is a list of questions such as those which might appear on a test based on the chapter. We recommend that you answer these questions under test conditions. That is, use only a pencil, paper, calculator, and periodic table. Do not look back to the text or examples for help. Answers are in the back of the book.

Now let's look more closely at the **Text and Example** section of each chapter, the place where the real learning occurs. To save you time, or to learn more in less time, we strongly urge you to use this section in the following way. To do this you will need four things: a pencil, a calculator, an opaque shield, and a periodic table for references. If you must buy a calculator, you will be interested in the discussion of calculators in Chapter 1. We have combined the shield and the periodic table as a tear-out card elsewhere in this book. On the side opposite the periodic table is a summary of the instructions you are about to read.

After being given the theory or technique behind a particular skill, you will practice that skill immediately in blank spaces in the book itself. These practice spaces are identified as **Examples**, which are set apart like this:

When you reach such a point, you should glance down the page until you find a pair of T-bars on each side:

This is where the opaque shield is placed—just below the T-bars so it covers the printing beneath that point. Read the question or example. Usually, it is followed by some comment or suggestion about how to proceed. Follow that suggestion, writing the answer or solving the problem in the space provided.

When this is done, move the shield down to the next set of T-bars, or the end of the example if there are no more T-bars. The first thing you expose on moving your shield down is the correct response to the question you have just answered. Compare your answer with the one in the book. If they are the same, as they will be most of the time, proceed as the book directs. If your answer and the book answer are not the same, find out why. Usually the comments that accompany the answer will be the only explanation you will need. If not, restudy the text material preceding the problem, or any other earlier material you may not have understood that is responsible for your incorrect answer. When you have corrected whatever needs to be corrected, proceed to the rest of the example. If you have reached the end of the example, it will close like this:

The importance of your active participation in solving example problems this way cannot be stated strongly enough. It is the key to *learning* chemistry from this workbook. Remember to demand that you master each step in the book. Satisfying that demand is the difference between merely *doing* your homework and *learning* chemistry—and the only thing that counts is what you learn.

Edward I. Peters William T. Scroggins

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1. CALCULATORS

1.1 INTRODUCTION

Chemistry is a quantitative science. You, as a student, will use solutions prepared from chemicals measured in the storeroom, and you will measure out quantities of different chemicals in performing experiments. Part of studying chemistry is learning how to calculate the quantities that are needed and the quantities that will be produced. To do this, you must have a calculator.

If you are about to buy a calculator, you will find many from which to choose. A "scientific" calculator that is acceptable for lower division chemistry courses will be able to do all of the following:

	FUNCTION	KEY SYMBOLS
(a)	perform the basic functions of addition, subtraction, multiplication, and division;	+, -, ×, ÷
(b)	work in exponential notation;	EE or EXP
(c)	do base 10 logarithms and antilogs; and	log x, INV log x or 10^x
(d)	raise any base to any power.	y^x
(e)	find reciprocals;	1/x
(f)	find squares and square roots; and	x^2, $\sqrt{x}$
(g)	work with natural (base e) logarithms;	ln x, INV ln x or e^x

A calculator with the above capabilities will also have trigonometric functions that are used in physics courses. One or more memory storages are also desirable.

Two types of operating systems are in common use: the Algebraic Operating System (AOS), used on most brands of calculators, and the Reverse Polish Notation (RPN), used mainly on Hewlett-Packard calculators. Note that the order of operations (addition, multiplication, etc.) is the same in both operating systems, but there is a difference in the order in which numbers and operations are keyed. Calculators also differ in the form of the display, particularly in the number of digits displayed. In this chapter, displays will show up to eight digits.

This chapter is limited to the calculator techniques required to solve the problems in this book. These techniques should take you all the way through lower-division chemistry courses. It is suggested that you perform each operation as you read it. If any operation cannot be performed as described, consult the instruction manual that came with your calculator.

1.2 ENTERING A NUMBER

To introduce a number into your calculator, you simply press the number keys in their proper order. This includes the decimal. If the number is negative, press the +/- key (sometimes identified by CHS or some other symbol) after the last digit. The number will appear in the display window of the calculator as it is entered.

Some calculators permit you to "fix" the number of digits that will be displayed after the decimal point. Or you can allow the decimal to "float," that is, to show only the minimum digits needed to display the answer.

Most calculators can display eight or more digits. Very small numbers, with more than eight digits to the right of the decimal, such as 0.000000834, may have some of the digits lost in the display. This may cause the number to appear as 0.0000008, for example.

Numbers which are quite large or quite small should be entered in exponential notation, also known as scientific notation. This shows the number as the product of a coefficient, N, and an exponential, 10 raised to some integral (whole number) power, x, as $N \times 10^x$. In the standard form of exponential notation, N is equal to or more than 1, but less than 10. If you enter N outside of this range, the calculator adjusts the display to this form. Exponential notation is discussed in detail in Section 3.1 of this book.

The procedure for entering a number in exponential notation is:

1. Type the coefficient, N. If the number is negative, type +/-.
2. Type EE (or whatever key is used for entering exponents).
3. Type the exponent. If the exponent is negative, type +/-.

Note: Most calculators will DISPLAY an entered number in exponential notation only if (a) the calculator has been changed from "FIX" mode to "SCI" or "EXP" mode, or (b) if the entered number is too large or too small to fit the eight-digit display.

EXERCISE 1.1: Enter the following numbers into your calculator:

10^4; 5.6709 10^{-8}; -9.87 10^6; -5.43 10^{-2}.

10^4

Enter	Press	Display
1	EE	1.00
4		1.04

5.6709×10^{-8}

Enter	Press	Display
5.6709	EE	5.6709 00
8	+/-	5.6709-08

-9.87×10^6

Enter	Press	Display
9.87	+/-, EE	-9.87 00
6		-9.87 06

-5.43×10^{-2}

Enter	Press	Display
5.43	+/-, EE	-5.43 00
2	+/-	-5.43-02

Did you get 10,000 or 10^5 instead of 1000 or 10^4? Enter exponential numbers which don't have coefficients as "1×10^x" not as "10×10^x." Were your displays in decimal rather than exponential notation? Were digits missing? When some calculators run out of display space for a very small decimal number, they show only the zeros after the decimal, or perhaps the first one or two nonzero digits. The calculator carries the other digits, but hides them from view. Correctly calculated answers are displayed incorrectly. Be sure to change to exponential notation so that what you see is acceptable.

1.3 ONE-NUMBER FUNCTIONS

From the calculator standpoint, the easiest operations are those in which one number is keyed into the calculator, and then something is done with that number. These are called **one-number functions**. The common one-number functions are multiplying a number by itself (squaring the number); finding the square root of a number; finding the inverse, or reciprocal, of a number (dividing the number into 1); finding the logarithm of a number (finding the power to which 10 must be raised to produce the number); and finding the antilogarithm of a number (raising 10 to the power of the number given). Logarithms and antilogarithms are discussed in detail in Chapter 6.

A one-number function is calculated as follows:

1. Enter the number.
2. Press the desired function key.

EXERCISE 1.2: Calculate: 1/123; 123^2; $\sqrt{123}$; and log 123.

1/123

Enter	Press	Display
123	1/x	0.0081301

123^2

Enter	Press	Display
123	x^2	15129

$\sqrt{123}$

Enter	Press	Display
123	$\sqrt{\ }$	11.090537

log 123

Enter	Press	Display
123	log x	2.0899051

If $N = 10^x$, then

$$\log N = x \tag{1.1}$$

and

$$N = \text{antilogarithm } x = \log^{-1} x \tag{1.2}$$

If your calculator has a 10^x key, the antilogarithm is found simply by entering the logarithm and pressing that key. On other calculators the one-number sequence for antilogarithms requires two function keys. Finding an antilogarithm is the inverse of finding a logarithm. The INV key (sometimes labeled "2ND") is therefore used before the log key.

EXERCISE 1.3: Find the antilogarithm of 1.23.

Enter	Press	Display	OR	Enter	Press	Display
1.23	10^x; or	16.982437		10	y^x	10
	INV, log	16.982437		1.23	=	16.982437

1.4 EXPONENTIALS

An **exponential** is a number in which a base, y, is raised to a power, x, as in y^x. If your calculator has a "y^x" key, that key can be used to find the value of any base raised to any power. The general procedure is

1. Enter the base, y, the number that is to be raised to a power.
2. Press y^x.
3. Enter the exponent, x, the power to which the base is to be raised.
4. Press =.

Note that, in the answers to the exercises that follow, the display on your calculator may not be the same as that shown in the book. When working with exponentials, some calculators display all answers in exponential notation, while others use exponential notation only if the number of digits is more than the calculator can display. Also, the number of digits the calculator can show varies among different brands.

EXERCISE 1.4: Calculate (a) 1.23^4; (b) $5.67^{0.25}$; (c) $(8.91 \times 10^{-2})^{3.4}$

1.23^4

Enter	Press	Display
1.23	y^x	1.23
4	=	2.2888664

$5.67^{0.25}$

Enter	Press	Display
5.67	y^x	5.67
.25	=	1.543106

$(8.91 \times 10^{-2})^{3.4}$

Enter	Press	Display
8.91	EE	8.91 00
2	+/-, y^x	8.91-02
3.4	=	2.689-04

Equation 1.2 indicates that if $N = 10^x$, N is the antilogarithm of x. If x, the logarithm of N, is known, N can be found simply by raising 10 to the x power.

EXERCISE 1.5: Find the antilogarithm of (a) 3.42; (b) -4.322.

antilog 3.42

Enter	Press	Display
3.42	INV, log; or 10^x	2630.268

antilog -4.322

Enter	Press	Display
4.322	+/-, INV, log; or 10^x	0.0000476 or 4.7643099-05

1.5 ADDITION, SUBTRACTION, MULTIPLICATION, AND DIVISION

The general procedure on an AOS calculator for the one-step addition, subtraction, multiplication, or division of two numbers, A and B, is

1. Enter A.
2. Press required function key.
3. Enter B.
4. Press =.

EXERCISE 1.6: Calculate (a) 12 + 345; (b) 12 - 345; (c) 12 × 345; (d) 12 ÷ 345.

12 + 345

Enter	Press	Display
12	+	12
345	=	357

12 - 345

Enter	Press	Display
12	-	12
345	=	-333

12 × 345

Enter	Press	Display
12	×	12
345	=	4140

12 ÷ 345

Enter	Press	Display
12	÷	12
345	=	0.0347826

1.6 CHAIN CALCULATIONS

A **chain calculation** is one in which two or more operations are performed, one after the other. The order in which the operations are done may be critical. Most AOS calculators perform simple calculations in the proper order when numbers and operations are entered exactly as they appear in the calculation setup, although the insertion of parentheses, ( ), and brackets, [ ], may be required. (This is not true with RPN calculators.) When a setup becomes complex, a bit more knowledge of the proper order in which the calculation is to be done is needed.

The expression "0.5054 × 78.92 + 0.4946 × 80.92" mixes addition and multiplication. When your calculator performs this computation, 0.5054 and 78.92 are multiplied, then 0.4946 and 80.92 are multiplied, and finally the products of these two multiplications are added together.

The order in which the calculations are done may be changed by the insertion of parentheses. The expression "0.5054 × (78.92 + 0.4946) × 80.92" means: add 0.5054 to the product of 78.92 and 0.4946 and then add 80.92. The sequence of operations for both calculations is shown below.

0.5054 × 78.92 + 0.4946 × 80.92

Enter	Press	Display
0.5054	×	0.5054
78.92	+	39.88617
0.4946	×	0.4946
80.92	=	79.9092

0.5054 × (78.92 + 0.4946) × 80.92

Enter	Press	Display
0.5054	×	0.5054
	(	0
78.92	+	78.92
0.4946	)	79.4146
	×	40.136139
80.92	=	3247.8164

The numerical results are, of course, very different!

For more complicated expressions with parentheses, the basic rule to follow is to work "from inside out"—that is, to do those calculations within parentheses first, then any operation on the value within the parentheses, and finally any other operation specified. The evaluation of $4(0.10 + 3.00)^2$ illustrates the steps.

	Enter	Press	Display
Start with 0.10 + 3.00	0.1	+	0.1
	3	=	3.1
Then square the result		x^2	9.61
Multiply by 4		×	9.61
	4	=	38.44

EXERCISE 1.7: Evaluate the expressions below.

(a) $\dfrac{84.0 - 80.0}{80.0} \times 100$

Enter	Press	Display
84	-	84
80	=	4
	÷	4
80	×	0.05
100	=	5

(b) $4.74 + \log \dfrac{0.10}{2.0}$

Enter	Press	Display
.1	÷	0.1
2	=	0.05
	log, +	-1.301030
4.74	=	3.438970

The most common chain calculation is the evaluation of an expression that has two or more factors in the numerator and two or more factors in the denominator. The factors may be entered in any order in such a problem. For example, the evaluation of ab/cd may be done in any of the following ways:

a × b ÷ c ÷ d	a ÷ c × b ÷ d	a ÷ d × b ÷ c
a × b ÷ d ÷ c	a ÷ c ÷ d × b	a ÷ d ÷ c × b
b × a ÷ c ÷ d	b ÷ c × a ÷ d	b ÷ d × a ÷ c
b × a ÷ d ÷ c	b ÷ c ÷ d × a	b ÷ d ÷ c × a

EXERCISE 1.8: Use three different sequences to evaluate $\dfrac{72 \times 96}{18 \times 16}$.

96 ÷ 16 ÷ 18 × 72

Enter	Press	Display
96	÷	96
16	÷	6
18	×	0.3333333
72		24

96 ÷ 18 × 72 ÷ 16

Enter	Press	Display
96	÷	96
18	×	5.3333333
72	÷	384
16	=	24

72 × 96 ÷ 16 ÷ 18

Enter	Press	Display
72	×	72
96	÷	6912
16	÷	432
18	=	24

1.7 SIX COMMON CALCULATOR ERRORS

This section is added to call attention to, and hopefully prevent, six errors that are common among beginning calculator users.