General Chemistry Workbook

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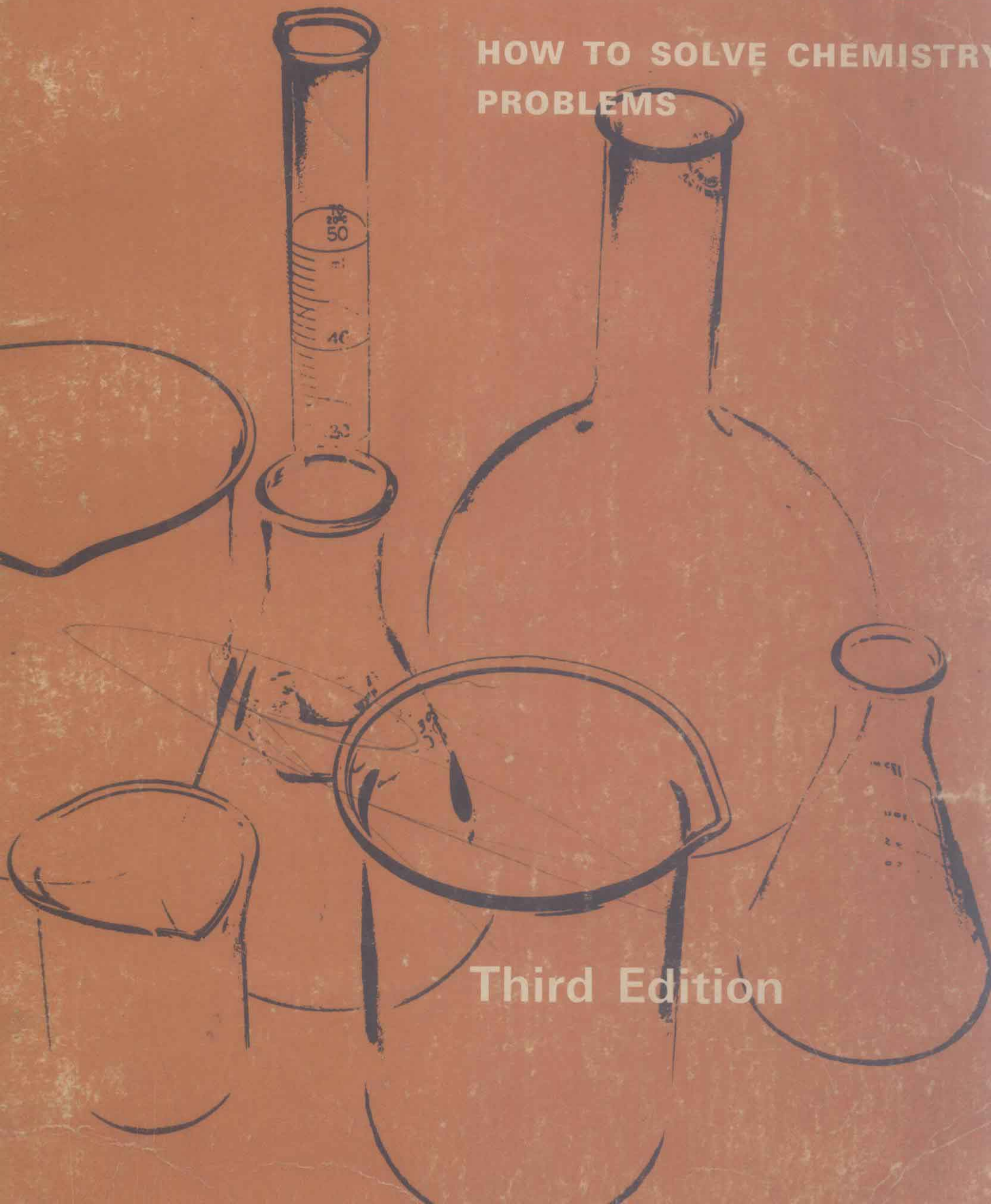

HOW TO SOLVE CHEMISTRY PROBLEMS

Third Edition

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Preface

Experience has shown that a large proportion of students in general chemistry courses need more drill exercises and solved problems than the authors of textbooks have space to include. Customarily much of this additional material is supplied by the teacher in the form of mimeographed sheets. This workbook is a compilation of the supplementary material we have developed over a period of years for use in our own classes. It is written solely as a supplement to the text and the lectures. What there is of repetition is intentional, for we have found that in some areas students need additional explanations and even alternative methods of looking at problems.

Major changes have been made in both high school and college teaching of introductory chemistry in the ten year period since the book was first published. Today there is much more emphasis on physico-chemical principles, on the chemical bond, and on atomic and molecular structure than there was a decade ago. Today the high school graduate is often better trained than the college freshman was after completing the first-year course of yesterday.

The purpose of this revision of the *Workbook* is to incorporate the changes made in our teaching as a result of the changing pattern in preparation of the entering students. Many changes have been made in the presentation, and some material has been deleted. Stoichiometry is treated in separate chapters grouped according to the applications, with all computations based on the use of the mole. Equivalent weights and normality are presented separately. New material includes a more rigorous treatment of probability in relation to the reliability of measurements, a chapter dealing with the sizes and shapes of molecules that is useful in explaining chemical properties and reactions, a chapter on gaseous equilibria intended to precede the study of ionic equilibria, incorporation of thermodynamic relations in the study of electrochemistry and thermochemistry, and a complete revision of the final chapter, which deals with why reactions go and how to devise synthetic methods for the preparation of compounds. Sections on correction of weights for the buoyant effect of air, on calibration of volumetric glassware, and on standardization of solutions for titrimetric analyses are added for use when quantitative analysis is included in the laboratory work.

We wish to thank the many teachers and students who have given us criticisms and comments on the material of the preceding editions and hope that those who use this edition will be equally frank in calling to our attention any errors or omissions they may note.

CONWAY PIERCE
R. NELSON SMITH

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1. How to Study Problems

For many of you the first course in chemistry will be a new experience and perhaps a difficult one. To understand chemistry, you will need to work hundreds of problems; for many students the mathematical side of the course is just too much, and the casualties are high.

If you are serious about wanting to learn chemistry, a few suggestions now may help make the way much easier.

1. Learn each assignment before going on to a new one. Chemistry has a vertical structure; that is, each new concept depends on previous material. Don't pass over anything, expecting to make up later. And don't postpone study until exam time. Keep up to date.

2. Understand problems before you try to work them. Chemistry problems use terms that may be new to you, and too often students fail to understand what these terms mean.

When you read a problem, try to analyze it before solving it. Every problem can be broken down into two parts that can be thought of as questions: (a) What information is given in the data of the problem? (b) What are you asked to find in working the problem?

To illustrate (without using chemical terms), suppose we are given this problem: "A boy rows a boat at the rate of 4 miles per hour. He heads upstream in a current of 5 miles per hour. Where will he be in 1.5 hours?"

First, what do the data tell us? If the boat were in still water, it would go 6 miles in 1.5 hours. But, while the boat is moving against the current that current is carrying it downstream at the rate of 5 miles per hour; in 1.5 hours the boat, if it were not being rowed, would be carried 7.5 miles downstream.

Now, what is asked in the problem? We want to calculate the position of the boat after 1.5 hours. Using the information, we see that the boat drifts downstream 7.5 miles while being rowed upstream 6 miles. At the end of the given time interval the boat is $7.5-6 = 1.5$ miles below the starting point.

This looks, and really is, easy. So will be most of the chemistry problems you will encounter in this course if you really understand them before trying to solve them. Don't become frightened if a problem is stated in moles, liters, or other new terms. They are just as simple as miles and hours once you understand them.

3. Know how to perform the *mathematical* operations you need in solving problems. The mathematics used in general chemistry is most elementary, involving only arithmetic and very simple algebra. Nevertheless, if you don't understand it, you can expect troubles before long. So, before we start any chemistry, it is necessary that you learn the material in Chapters 2–4.

As you go through the solved problems of your text, the lectures, and this book, work through the mathematical operations. Then, if you run into anything you don't understand, clear it up before going ahead.

2. Exponents, Logarithms, and the Slide Rule

EXPONENTS AND DECIMAL POINTS

An exponent is a number that shows how many times another number (called the base) appears as a factor; exponents are written as superscripts. Thus 10^2 means $10 \times 10 = 100$. Here, the number 2 is the *exponent*; the number 10 is the *base*, and is said to be raised to the second *power*. Likewise, 2^5 means $2 \times 2 \times 2 \times 2 \times 2 = 32$; here 5 is the exponent and 2 is the base. The base is raised to the fifth power.

In the decimal system we use, it is a simple matter to represent a number in exponential form as the product of some other number and a power of 10. For integral (whole) powers of 10 we have $10 = 1 \times 10^1$, $100 = 1 \times 10^2$, $1{,}000 = 1 \times 10^3$, etc. If a number is not an integral power of 10, we can express it as the product of two numbers, one of which is an integral power of 10, then write the integral power of 10 in exponential form. For example, 2,000 can be written as $2 \times 1{,}000$ and this put into the exponential form 2×10^3. We have shifted the decimal point and have indicated the number of places through which the point has been shifted by the value of the exponent. Therefore:

To write a number in exponential form, set the decimal point at any desired position; to restore the decimal point to its original position, multiply by 10 raised to the proper power.

The exponent is the number that tells the number of places the decimal point must be moved from the selected position to restore it to the original position. A positive exponent means that the decimal point must be moved to the right; a negative exponent means that the point must be moved to the left.

PROBLEM: Write 3,500,000 in exponential form.

SOLUTION: The decimal point can be set at any convenient place. Suppose we select the position shown below by the small x, between the digits 3 and 5. This gives as the first step

$$3_x500{,}000$$

The true position of the decimal point is after the fifth zero. To restore the decimal point, we must move it six places to the right. In exponential form the number is

$$3.5 \times 10^6$$

The number might equally well be written as 35×10^5, 350×10^4, or 0.35×10^7, and so on. All of these are equivalent, and for each calculation we arbitrarily set the decimal point at the most convenient place. Generally it is most convenient to leave the numerical portion in the range between 1 and 10, that is, with a single digit before the decimal point.

PROBLEM: Write the number 0.0005 in exponential form.

SOLUTION: Arbitrarily set the decimal point after the 5, as indicated by the small x. This gives

$$0.0005_x$$

To restore the decimal point to the original position, it must be moved four places to the left. Therefore the exponential form is 5×10^{-4}. We might equally well use 50×10^{-5}, or 0.5×10^{-3}, and so on.

To use the exponential forms of numbers in mathematical operations, we need remember only a few simple rules (it is assumed that all numbers are expressed as the product of a number and some integral power of 10):

1. In multiplication, treat the numerical portion in the usual manner, and add the exponents of multiplier and multiplicand to obtain the exponent of the product.

PROBLEM: Multiply 3,000 by 400,000.

SOLUTION: Write each number in exponential form. This gives

$$3{,}000 = 3 \times 10^3$$
$$400{,}000 = 4 \times 10^5$$

Multiply:

$$3 \times 4 = 12$$
$$10^3 \times 10^5 = 10^{3+5} = 10^8$$

The answer is 12×10^8.

If some of the exponents are negative, there is no difference in the procedure; the exponents are added algebraically.

PROBLEM: Multiply 3,000 by 0.00004.

SOLUTION:

$$3{,}000 = 3 \times 10^{3}$$
$$0.00004 = 4 \times 10^{-5}$$

Multiply:

$$3 \times 4 = 12$$
$$10^{3} \times 10^{-5} = 10^{3-5} = 10^{-2}$$

The answer is 12×10^{-2} or 0.12.

2. In division, treat the numerical portion in the usual manner, and subtract the exponent of the divisor from the exponent of the dividend to obtain the exponent of the quotient.

PROBLEM: Divide 0.0008 by 0.016.

SOLUTION: Write in exponential form. This gives

$$0.0008 = 8 \times 10^{-4}$$
$$0.016 = 1.6 \times 10^{-2}$$

Divide:

$$\frac{8}{1.6} = 5$$
$$\frac{10^{-4}}{10^{-2}} = 10^{-4-(-2)} = 10^{-4+2} = 10^{-2}$$

The answer is 5×10^{-2}.

3. In addition or subtraction, first make all powers of 10 the same. Then add the numerical portions, but keep the exponents the same.

PROBLEM: Add 2×10^{3} to 3×10^{2}.

SOLUTION: Change one of the numbers to give its exponent the same value as the exponent of the other; then add the numerical portions.

$$2 \times 10^{3} = 20 \times 10^{2}$$
$$3 \times 10^{2} = \underline{\ \ 3 \times 10^{2}}$$
$$\text{Add:} \qquad 23 \times 10^{2}$$

4. When the exponent is zero, the number is 1. That is, $10^{0} = 1$ (or, more generally, $N^{0} = 1$).

PROBLEM: Multiply 0.003 by 3,000.

SOLUTION:

$$0.003 = 3 \times 10^{-3}$$
$$3{,}000 = 3 \times 10^{3}$$

Multiply:

$$3 \times 10^{-3} \times 3 \times 10^{3} = 9 \times 10^{3-3} = 9 \times 10^{0} = 9 \times 1 = 9$$

The use of these rules in problems involving both multiplication and division is illustrated in the following example.

PROBLEM: Use exponents to solve

$$\frac{2{,}000{,}000 \times 0.00004 \times 500}{0.008 \times 20} = ?$$

SOLUTION: First, rewrite all numbers in exponential form. Preferably we set the decimal point so that each number is less than 10.

$$2{,}000{,}000 = 2 \times 10^{6}$$
$$0.00004 = 4 \times 10^{-5}$$
$$500 = 5 \times 10^{2}$$
$$0.008 = 8 \times 10^{-3}$$
$$20 = 2 \times 10^{1}$$

This gives

$$\frac{2 \times 10^{6} \times 4 \times 10^{-5} \times 5 \times 10^{2}}{8 \times 10^{-3} \times 2 \times 10^{1}}$$

Solution of the numerical portion gives

$$\frac{2 \times 4 \times 5}{8 \times 2} = \frac{5}{2} = 2.5$$

The exponent of the answer is

$$\frac{10^{6} \times 10^{-5} \times 10^{2}}{10^{-3} \times 10^{1}} = \frac{10^{6-5+2}}{10^{-3+1}} = \frac{10^{3}}{10^{-2}} = 10^{3-(-2)} = 10^{3+2} = 10^{5}$$

The complete answer is 2.5×10^{5} or 250,000.

APPROXIMATE CALCULATIONS

A trained scientist often makes mental estimates of numerical answers to quite complicated calculations, with an ease that to the uninitiated appears to border on the miraculous. Actually, all he does is round off numbers and use exponents to reduce the calculation to a very simple form. It is quite useful for you to learn these methods. By using them you can save a great deal of time in homework problems and on tests.

PROBLEM: We are told that the population of a city is 256,700 and that the assessed value of the property is $653,891,600. Find an approximate value of the assessed property per capita.

SOLUTION: We need to evaluate the division

$$\frac{\$653{,}891{,}600}{256{,}700} = ?$$

First write the numbers in exponential form, setting the decimal points so that each number is less than 10.

$$\frac{6.538916 \times 10^8}{2.56700 \times 10^5}$$

Round off to

$$\frac{6.5 \times 10^8}{2.6 \times 10^5}$$

Mental arithmetic gives

$$\frac{6.5}{2.6} = 2.5$$

$$\frac{10^8}{10^5} = 10^3$$

The answer is $2.5 × 10³ or $2,500. This happens to be a very close estimate; the value obtained with a calculator is $2,547.29.

PROBLEM: Find an approximate value for

$$\frac{2{,}783 \times 0.00894 \times 0.00532}{1{,}238 \times 6{,}342 \times 9.57}$$

SOLUTION: First rewrite in exact exponential form (set the decimal points to make each number as near 1 as you can):

$$\frac{2.783 \times 10^3 \times 0.894 \times 10^{-2} \times 5.32 \times 10^{-3}}{1.238 \times 10^3 \times 6.342 \times 10^3 \times 0.957 \times 10^1}$$

Rewrite the numbers, rounding off to integers.

$$\frac{3 \times 10^3 \times 1 \times 10^{-2} \times 5 \times 10^{-3}}{1 \times 10^3 \times 6 \times 10^3 \times 1 \times 10^1}$$

Multiplication now gives

$$\frac{3 \times 1 \times 5 \times 10^{-2}}{1 \times 6 \times 10^7} = \frac{15}{6} \times 10^{-9} = 2.5 \times 10^{-9}$$

LOGARITHMS

The logarithm (abbreviated log) of a number N is the power to which 10 (called the base) must be raised to give N. The logarithm is therefore an exponent. Thus log 1 = 0, log 10 = 1, log 100 = 2, and so on.

Since logarithms are exponents, we have the following relations:

$$\log AB = \log A + \log B$$

$$\log \frac{A}{B} = \log A - \log B$$

$$\log A^n = n \log A$$

$$\log \sqrt[n]{A} = \frac{\log A}{n}$$

The logarithm of a number N consists of two parts, called the characteristic and the mantissa. The characteristic is the number before the decimal point. It is determined by the position of the decimal point in N. The mantissa, read from a log table, is the number after the decimal point.

FINDING THE LOG OF A NUMBER. To find the log of a number:

1. Write the number in exponential form with *one* digit before the decimal point (that is, the number should be between 1 and 10).
2. Look up the mantissa in a log table. In finding the mantissa, pay no attention to the decimal point of the number.
3. The exponent is the characteristic of the log.

PROBLEM: Find the log of 203.

SOLUTION:

1. Write the number as 2.03×10^2.
2. In the log table find 2.0 (or 20) in the left-hand column. Read across to the column under 3. This gives log 2.03 = 0.3075.
3. Since the exponent is 2, the characteristic is 2. Therefore, $\log 2.03 \times 10^2 = 2.3075$.

When a number is less than 1 the logarithm is negative, since log 1 = 0. We have a choice of two ways to express a negative log,

1. The mantissa is positive but the characteristic is negative, or
2. Both characteristic and mantissa are negative.

PROBLEM: Find the log of 0.000203.

SOLUTION: Write the number as 2.03×10^{-4}. $\text{Log } 2.03 \times 10^{-4} = 0.3075 - 4 = -3.6925$. If we wish to write the log as a positive mantissa we indicate the negative characteristic by a bar over the number, that is, $\bar{4}.3075$.

INTERPOLATION. The log tables of this book show only three digits for N. If the log of a four-digit number is desired, you must interpolate. An example will illustrate this process. To find the log of 2,032, proceed as follows:

log 2,032 = $\log 2.032 \times 10^3$
mantissa 204 = 3096 (to save time, the decimal point before the mantissa is left out while making the interpolation)
mantissa 203 = 3075
difference = 21
mantissa 2,032 = $3075 + (\frac{2}{10} \times 21) = 3075 + 4 = 3079$
log 2,032 = 3.3079

ANTILOGS. The number that corresponds to a given logarithm is known as the antilogarithm or antilog.

PROBLEM: Find the antilog of 1.5502.

SOLUTION: Locate 0.5502 (or the number nearest to it) in a log table, then find the value of N that has this log. We find N to be 3.55. Since the characteristic is 1, the number is $3.55 \times 10^1 = 35.5$.

MULTIPLICATION BY LOGS. To multiply numbers, find their logs, add these, and find the antilog of the sum. For example, to multiply 167 by 0.00518:

$$\begin{aligned} &\log 167 &&= \log 1.67 \times 10^2 &&= 2.2227 \\ &\log 0.00518 &&= \log 5.18 \times 10^{-3} &&= \bar{3}.7143 \\ &\text{Adding gives} && && \bar{1}.9370 \end{aligned}$$

$$\text{antilog } \bar{1}.9370 = 8.65 \times 10^{-1} = 0.865$$

DIVISION BY LOGS. To divide one number by another, subtract the log of the divisor from that of the dividend, and look up the antilog of the remainder to find the quotient. For example, to divide 167 by 0.00518:

$$\begin{aligned} &\log 167 &&= 2.2227 \\ &\log 0.00518 &&= \bar{3}.7143 \\ & && 4.5084 \end{aligned}$$

$$\text{antilog } 4.5084 = 3.224 \times 10^4$$

ROOTS OF A NUMBER. To obtain the root of a number, find the log of the number, divide by the value of the root desired, and look up the antilog. For example, to find $\sqrt[5]{225}$:

$$\log 225 = 2.3522$$

$$\text{Divide by 5:} \quad \frac{2.3522}{5} = 0.4704$$

$$\text{antilog } 0.4704 = 2.954 \times 10^0 = 2.954$$

SLIDE RULE

Every student of chemistry or physics should use a slide rule for arithmetical calculations. It is sheer waste of time and effort to carry out multiplications and divisions by longhand, when the slide rule will give satisfactory answers in a tenth of the time or less.

In general, a 10-inch rule is preferable to other sizes. A simple rule with A, B, C, D, K, and log scales is sufficient for the problems of the general chemistry course.

In learning to use a slide rule, it is helpful to realize that it is a graphic log table. The lengths of the scale divisions are proportional to the mantissas of the logarithms of the scale numbers. Therefore, to multiply two numbers, we add the scale lengths for multiplier and multiplicand; to divide two numbers, we subtract the scale length of the divisor from that of the dividend.

CONSTRUCTION OF THE SLIDE RULE. When operating a slide rule we add or subtract scale distances. For these operations the rule is constructed of three essential parts. There is a frame-like part that contains scales D, A, and K. A movable part known as the slide contains scale C and others with which we are not at present concerned. To mark scale readings, there is a glass or plastic cursor that carries an index line.

READING SCALES. Multiplications and divisions are carried out on the C and D scales. The two are identical, with D fixed and C on the slide. Before you start to use a rule, you must learn how to read the scales accurately. Take your own rule and locate the C and D scales. Set the slide so that 1 on C coincides with 1 on D. The two scales should now coincide throughout.

Marked readings for a portion of the rule are shown in Fig. 2-1. Use your own rule to locate the same readings. Set the index at 12 on the C and D scales, verify by checking with Fig. 2-1, then move to the next reading. If you can locate each of the readings of Fig. 2-1, you will have no further difficulty in reading the C and D scales.

The A and K scales are used for squares and cubes of numbers. Note that the A scale is a series of two scales, each half as long as the D scale and the K scale is a series of three, each one-third the length of the D scale.

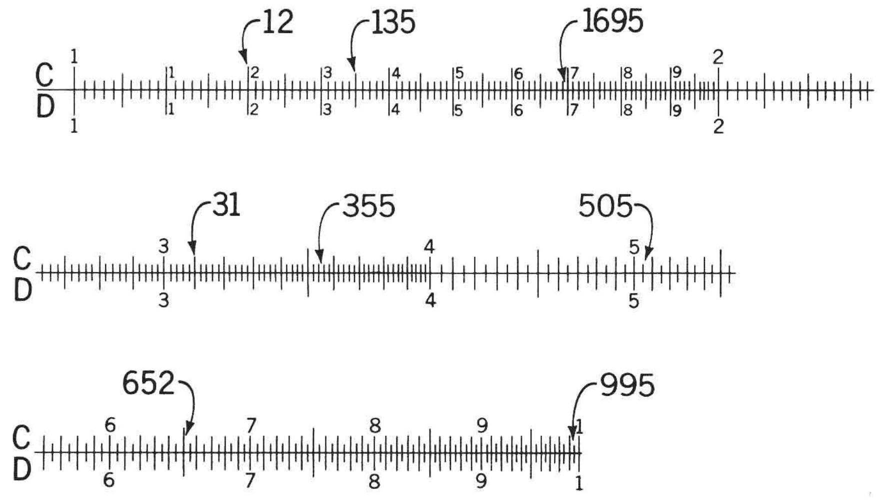

Figure 2-1. *Portion of a slide rule, showing C and D scales.*

Since the scale lengths of a slide rule are proportional to the mantissas of the logarithms of the scale numbers, the reading for a number is not influenced by the location of the decimal point. Thus the reading for 2, 20, 200, 0.02, and so on is the same. The user must supply his decimal point for the answer; the slide rule gives only the digits of the answer.

MULTIPLICATION. Take your own rule, and perform each step as directed. First, we will multiply 2 by 3.

1. Set 1 on C at 2 on D.
2. Move the hair-line index to 3 on C.
3. Read the answer 6 on D (beneath the hair line).

You will note that we have added the two scale distances; since these are proportional to the logs of the numbers, we are multiplying the numbers.

Without moving the slide, which is still set with 1 on C at 2 on D, move the index to 4 on C. Now read the index on D. The answer is 8. We have multiplied 2 by 4.

Move the index to 45 on C. It now reads 9 on D, which is the product of 2×45. Note that, although the answer is 90, the slide-rule reading is 9.

Suppose now that we wish to multiply 2 by 6. You find that 6 on C is beyond the end of the D scale. Whenever this occurs, reverse the slide by moving it to the left until the right-hand 1 on C lies at 2 on D. In this position move the index to 6 on C. The answer 12 can now be read on D.

SUCCESSIVE MULTIPLICATIONS. Suppose we wish to multiply $2 \times 3 \times 4$. Carry out the following operations.

1. Set 1 on C at 2 on D.
2. Move the index to 3 on C. Do not read on D.
3. Move the slide to bring the right-hand 1 on C to the position of the index.
4. Move the index to 4 on C.
5. Read the answer 24 on D.

DIVISION. To illustrate division, we will divide 24 by 6. Go through the following steps.

1. Set the index at 24 on D.
2. Move the slide to bring 6 on C to the index.
3. Move the index to 1 on C.
4. Read the answer 4 on D.

SUCCESSIVE OPERATIONS. In a series of multiplications and divisions we save moves by alternating the processes. To illustrate, we will solve the following problem:

$$475 \times \frac{720}{760} \times \frac{273}{298}$$

We could first multiply $475 \times 720 \times 273$, then divide the answer by 760 and divide that answer by 298. However, it is faster to carry out the operations in the following order.