TAD

HANDBOOK OF ELECTRONIC CHARTS AND NOMOGRAPHS

by ALLAN LYTEL

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PREFACE

A nomograph is simply a chart which enables you, using only a straightedge, to solve numerical formulas and equations. It is faster and often more convenient to use than a slide rule. Properly planned, the accuracy of a nomograph is as good as or better than can be obtained from the average slide rule. You'll find this to be true of the nomographs in this book.

Included on the page opposite each nomograph is the related equation or formula, as well as instructions for using the nomograph to arrive at a solution. For example, Chart 7 has four vertical lines representing (from left to right) voltage, power, current, and resistance. The basic Ohm's-law formula is E = IR. Knowing I and R, you can easily find E by merely lining up a straightedge with the proper values for current and resistance. The flexibility of this nomograph is such that you can readily find the value for the unknown in any one of the twelve variations of the basic Ohm's-law equations given.

Maurice d'Ocagne is generally considered the father of nomography. Since he published his *Traite de nomographie (Treatise on Nomography)* in 1899, a few nomographs have been included in many texts and handbooks for engineers and technicians. To this author's knowledge, however, no one has ever developed a large selection for electronics personnel (this book has 58). Furthermore, there has been little or no effort to make printed nomographs practical insofar as usability and accuracy are concerned.

Notice the plastic overlay sheet bound into the back of the book. Heretofore, one of the problems associated with nomographs involving more than one step has been the necessity of remembering each step or making rules or marks on the nomograph itself. Now all you need do is rule a line or two directly on the overlay, and erase when you have your answer. (Complete instructions on using the overlay are included in "How To Use This Book" on page 6.) Two factors contribute to the accuracy of the nomographs in this book: (1) Every scale has been carefully calibrated and marked on an original drawing larger than the printed size. (2) The finished size is large and thus easy to interpolate.

Since all mathematical relationships do not conveniently lend themselves to nomographs, some charts have also been included. Each chart, if properly used, will give the same accuracy as the nomographs.

ALLAN LYTEL

June 1965

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Nomographs and Charts

HOW TO USE THIS BOOK

All charts and nomographs are numbered at the bottom of the page and also at the top of the facing page. In addition, they are listed by number in the Table of Contents.

The nomographs are arranged by usage. For example, formulas for transmission lines are numbered 41 through 50. To find the nomograph that applies to your particular problem, first look in the Table of Contents. If you are uncertain which nomograph is needed, look under the general subject desired, then look over the nomographs in that area until you find the one that applies to your problem.

Before using a specific chart or nomograph, be sure to read the explanatory material on the facing page. It explains the purpose of the nomograph, the formula to be solved, and at least one example of how to use the nomograph (or chart). Because many nomographs have more than one purpose, only the primary one is exemplified. However, it is important to keep the secondary uses in mind, too.

To use the plastic overlay sheet found at the back of the book, turn to the desired nomograph and fold the sheet over the page. Now you can use a straightedge and a soft, easy-to-erase lead pencil to draw lines directly on the overlay. When you're through, just erase them and re-use the overlay as often as you wish. The overlay is most useful where more than one operation is required.

INTRODUCTION TO NOMOGRAPHS

The word *nomograph* is derived from the Greek words *nomos,* which means "law," and *graph,* which means "to write." Literally, nomograph means "a written law." Nomographs stem from analytical geometry, which is essentially the technique of using drawings or graphical methods to solve an equation.

All nomographs are charts, but not all charts are nomographs. Undoubtedly you are familar with bar and pie charts. For example, how many times have you seen in your newspaper a bar chart, or graph, indicating the increase in population every decade since 1900? Or a pie chart sliced into portions to show what percentage of your paycheck goes for food, what percentage for clothing, and so on? Such charts have their limitations. They show only specific amounts—there are no intermediate values. Nomographs, on the other hand, do show such intermediate values.

Mentally visualize a thermometer with the common Fahrenheit scale running down the left side of the mercury column. Suppose we would also like to know the temperature in degrees centigrade? Ordinarily we would have to read the temperature on the Fahrenheit scale and then use the formula, $C = (°F - 32) \times 5/9$, to find the answer. (What a chore this would be if we wanted, say, an hourly temperature check!) A much simpler way—one which would give us the answer at a glance—is to place a centigrade scale down the right side of the mercury column. Now all we have to do is read the Fahrenheit scale on the left, then run our eye straight across and read the degrees centigrade.

Thus, nomographs are a pictorial method of "stating" an equation. We could put the equation $C = (°F - 32) \times 5/9$ in words: "The temperature in centigrade is equal to degrees Fahrenheit minus thirty-two, times the fraction five-ninths." Obviously this is too long and involved, besides being mathematically useless. Instead we express this mathematical law as an equation. Still, we must work it, as we said earlier. By putting the two values side by side on the thermometer, however, we have found a way to instantly solve all values of the equation by merely looking at a chart. In other words, we have made a nomograph.

The nomographs in this book represent most of those needed to solve problems in electronics. The equation is shown for each nomograph, and at least one problem is worked out so you can see how the nomograph is used.

SCALES

Fig. 1 shows some of the most common types of scales. Scale A is linear and is calibrated from 0 to 10. You can read values on this scale as closely as it is possible for you to make out the graduations. For example, at point V the reading is exactly 5.0. Scale values may differ, as shown by scale B. Here the point of interest lies between 30 and 80—we are not interested in values above 80 or below 30. Hence, they do not appear on the scale. The point marked W indicates a value of 67.5, which is halfway between 65 and 70. Sometimes a set of desired values is both positive and negative (temperature, for example). Thus, scale C goes from 0 to +60 as well as from 0 to −40 (point X indicates +10). Again, values outside this range are not of interest in this equation.

Many scales are not linear, but are logarithmic as shown at D. This is a single-cycle logarithmic scale giving values from 1 to 10. (Point Y indicates 7.)

To increase the range of logarithmic scales, it will be necessary to add cycles. Scale E has three logarithmic cycles. Notice that this scale is divided into three equal parts and that each part is subdivided like scale D. Hence, the first cycle is for values from 1 to 10, the second from 10 to 100, and the third from 100 to 1,000. (Point Z indicates 700.) This type of scale is highly useful when the range of values is wide. On logarithmic scales, pay particular attention to the major divisions. It is important to read them first, so that you will be able to estimate as closely as possible the exact reading of the answer.

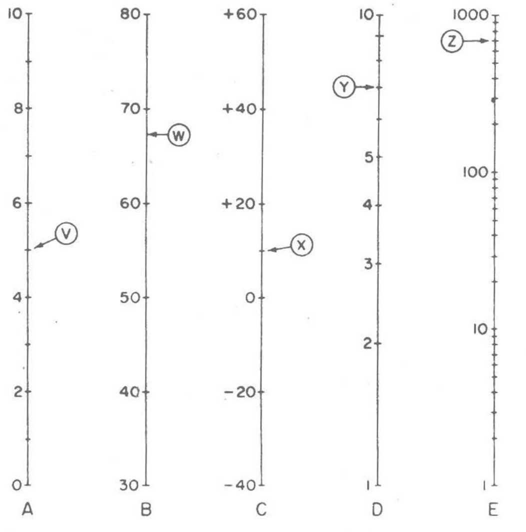


Fig. 1. Some of the scales used in nomographs.

TYPES OF NOMOGRAPHS

The simplest nomograph consists of a single scale with one side calibrated in one set of values and the other side in another set of values, like our thermometer. This type of nomograph is useful for converting from one unit of measurement directly to another. On this type of nomograph, we simply find the known value on the appropriate scale, then read the corresponding value, expressed in the other unit of measurement, on the other side of the scale.

Another type of nomograph, and the one this book is largely concerned with, is the alignment chart. In its simplest form, it consists of three vertical lines marked off in different values. By taking a straightedge and connecting a known value on one line with a known value on another, it is possible to read the unknown value on the third line.

Alignment charts are extremely useful when many alike problems are to be solved. As an example, if you were interested in finding the characteristics of a given vacuum-tube amplifier, you could draw a series of load lines which would predict the tube's action for different load resistances and plate voltages. Similarly, if you were interested in solving a given equation several times over for different values, a nomograph would save you an enormous amount of time—compared with using a pencil or even a slide rule.

Like other graphical methods, a nomograph does not give you the accuracy of a calculator. However, a nomograph can be as accurate as a slide rule, the degree depending on the scale divisions and on the care with which you read the scale.

ADDITION AND SUBTRACTION

Fig. 2 is an elementary alignment nomograph of a simple equation showing addition, $C = A + B$. For instance, to add 2 and 4 (the values of A and B), you find 2 on the A scale and 4 on the B scale; by laying a straightedge across these two points you can find 6 on the C scale. In the same manner you can add 8 and 4, by finding 8 on the A scale and 4 on the B scale.

Notice that the A and B scales are linear from 1 to 10 and that the C scale is linear from 2 to 20. Thus, the sum of any values can be found, as long as they are between 1 and 10 inclusive. Actually this simple nomograph is more useful than it appears at first glance. Scale B reads more than from 1 to 10 as shown; it can also be read as 10 to 100, or 100 to a 1,000. Thus, point X can be read as 6, 60, or 600; point Y as 7.5, 75, or 750. In the same manner point Z is 9, 90, or 900.

By the same token, the line which is 8 + 4 = 12 is also 80 + 40 = 120, 800 + 400 = 1,200, or 8,000 + 4,000 = 12,000—depending on the values assigned to the scale calibrations.

It is also possible to use this scale for subtraction; since C = A + B, then A = C − B. In this way one nomograph can show both addition and subtraction. Again, 6 − 4 = 2 can also be read 60 − 40 = 20, or 600 − 400 = 200. From the above it also follows that B = C − A, so that 4 = 12 − 8 (or 40 = 120 − 80 or 400 = 1,200 − 800).

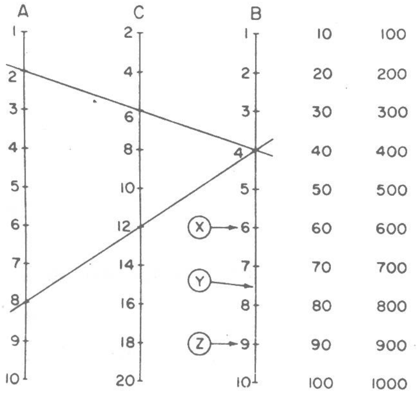


Fig. 2. A simple alignment-chart-type nomograph for addition or subtraction.

MULTIPLICATION AND DIVISION

A second form of nomograph is used for multiplying two numbers together. In Fig. 3, C is the product of A and B. Notice that the A and B scales are both logarithmic in three cycles. Each goes from 1 to 1,000 in three steps—1 to 10, 10 to 100, and 100 to 1,000. Scale C is also logarithmic, but has six cycles. Drawing a line from 100 on the A scale to 10 on the B scale will give 1,000 (100 × 10) on the C scale. It is usually unnecessary to multiply logarithmic scales by a factor of 10 or 100, although they can be if desired. Notice, however, that if the A and B scales are multiplied by 100, the C scale must be multiplied by 100^2, or 10,000.

The three scales shown in Fig. 3 can also be used for division. Here, A = C ÷ B and B = C ÷ A. Drawing a line from 100 on the A scale to 1,000 on the C scale, and then extending the line so it intersects the B scales, gives us 1,000 ÷ 100, or 10. The same line will give us C ÷ B on the A scale (1,000 ÷ 10 = 100). The range of the scales can be extended if the dividend and divisor scales are multiplied by 10 or 100. For example, to divide

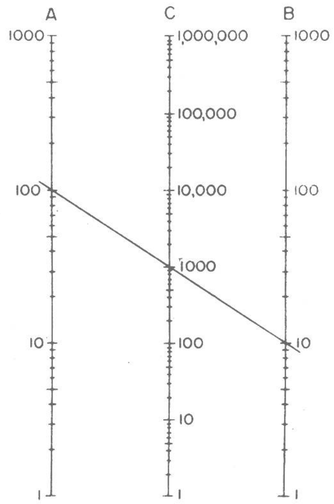


Fig. 3. A nomograph for multiplication or division.

10,000 by 100, draw a line from 10 (10 × 10 = 100) on the B scale to 1,000 (1,000 × 10 = 10,000) on the C scale. Extend the line to the A scale and read the answer—100.

As we said previously, the A and B scales in Fig. 3 are three-cycle logarithmic. If a smaller range is needed, one- or two-cycle logarithmic scales may be employed instead. Likewise, if a greater range is desired, each cycle may contain four or five cycles. Of course, the fewer the cycles, the greater the accuracy, because more subdivisions can be included on the scale.

OTHER OPERATIONS

Often the squares of two numbers must be multiplied. Both operations can be accomplished with the scales given in Fig. 4, where $C = A^2B^2$. Notice that the A and B scales are

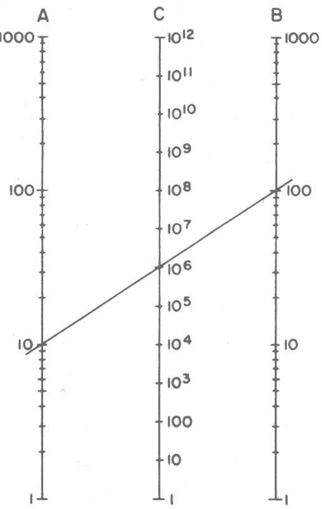


Fig. 4. A nomograph for multiplying the squares of two numbers.

the same as in Fig. 3, but that the C scale contains twice as many cycles. Scale C is calibrated so the square of the product can be read directly from it. Drawing a line from 10 on the A scale to 100 on the B scale will give us 10^6 (1,000,000) on the C scale ($10^2 = 100$, $100^2 = 10{,}000$; $100 \times 10{,}000 = 1{,}000{,}000$).

Another common operation is to extract the square root of the product of two numbers. This can be accomplished in a single operation with the scales in Fig. 5. Here, scale C equals the square root of A × B.

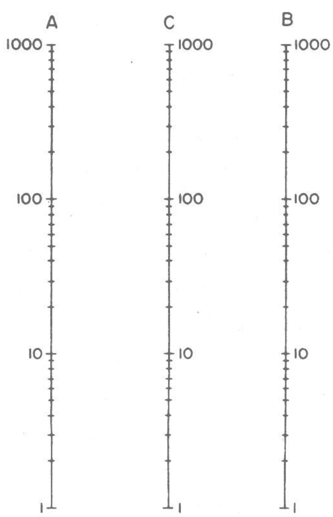


Fig. 5. A nomograph for multiplying two numbers and extracting the square root of the product.

Again, the only difference is in the calibration of the center scale.

Figs. 4 and 5 show two ways the basic multiplication-and-division nomograph in Fig. 3 can be altered. Many other variations, such as multiplying the product by a constant factor, taking the reciprocal, etc., may be employed. All that is required is for the scales to be properly plotted.

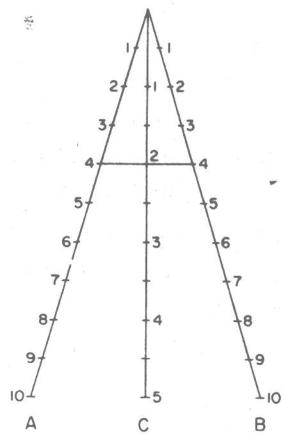


Fig. 6. A nomograph for taking the reciprocal of the sum of the reciprocals of two numbers.

Another form of nomograph you will encounter in this book is shown in Fig. 6. Here all three scales converge into a single point. This type of nomograph is useful for solving the general formulas:

$$C = \frac{1}{\frac{1}{A} + \frac{1}{B}}$$

$$C = \frac{AB}{A + B}$$

involving resistors or inductors in parallel or capacitors in series.

As an example, if A is 4 and B is 4, C is 2. This can be expressed by saying that C is equal to the reciprocal of the sum of the reciprocals or, two 4-ohm resistors in parallel are equivalent to 2 ohms. All three scales are linear, but C is calibrated differently from A and B. To increase the range, multiply all scales by the same number. For example, multiplying by 10 gives us A = 40, B = 40, and C = 20.

The utility of nomographs may be seen from Fig. 7. The general equation here is $C = \sqrt{A^2 + B^2}$. There are many applications of a nomograph of this type in electronics. The same nomograph used to solve a right triangle in trigonometry is also used for finding the impedance in a series circuit. You will recognize that if A is the net reactance and B the circuit resistance, then the C scale will give the circuit impedance. By the same token, if A is one side of a triangle and B the other side, C will be the longest leg. Here the A scale is plotted according to the A^2 values and the B scale according to the B^2 values. Scale C is a plot of the square roots

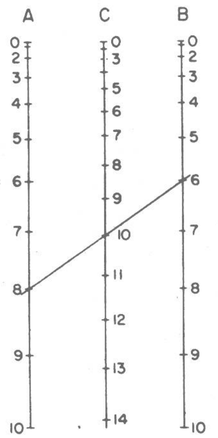


Fig. 7. A nomograph for extracting the square root of the sum of the squares of two numbers.

of the sums of the squares of the values on the A and B scales. To extend their range, all scales in Fig. 7 must be multiplied by an even-numbered power of 10 (10^2, 10^4, etc.).

Sometimes only the sum of the squares of two numbers is wanted. Scales A and B would then be the same as in Fig. 7, but scale C would be calibrated according to the sum of A^2 and B^2. For instance, the point marked *10* on scale C in Fig. 7 would be labeled *100*, since a line drawn from 8 on scale A to 6 on scale B intersects at this point on scale C($8^2 = 64$, $6^2 = 36$; $64 + 36 = 100$). To extend the range of this nomograph, multiply all scales by any power of 10.

SUMMARY

Before starting to work any problem, first take a good look at the nomograph. Notice how the scales are plotted. Some read from top to bottom, others from bottom to top. Some are linear, others are logarithmic, and some are plotted according to the square or square root of the values.

If you are doing a series of problems with more than one nomograph, study the example given first to familiarize yourself with the operation of the particular nomograph. It is advisable to work out a simple problem using powers of 10, so you will have a rough idea of what the answer should be.

These nomographs are carefully constructed and are as accurate as possible using graphical methods. It is important that you do not create any gross errors in the use of the nomographs by using them improperly or by mistaking a 1 for a 10, for example. Approximating the answer before you go too far will forestall such errors, especially when multiplying or dividing the scales by powers of 10 to extend their range.

ADDITION AND SUBTRACTION

Purpose: To add or subtract any two numbers.

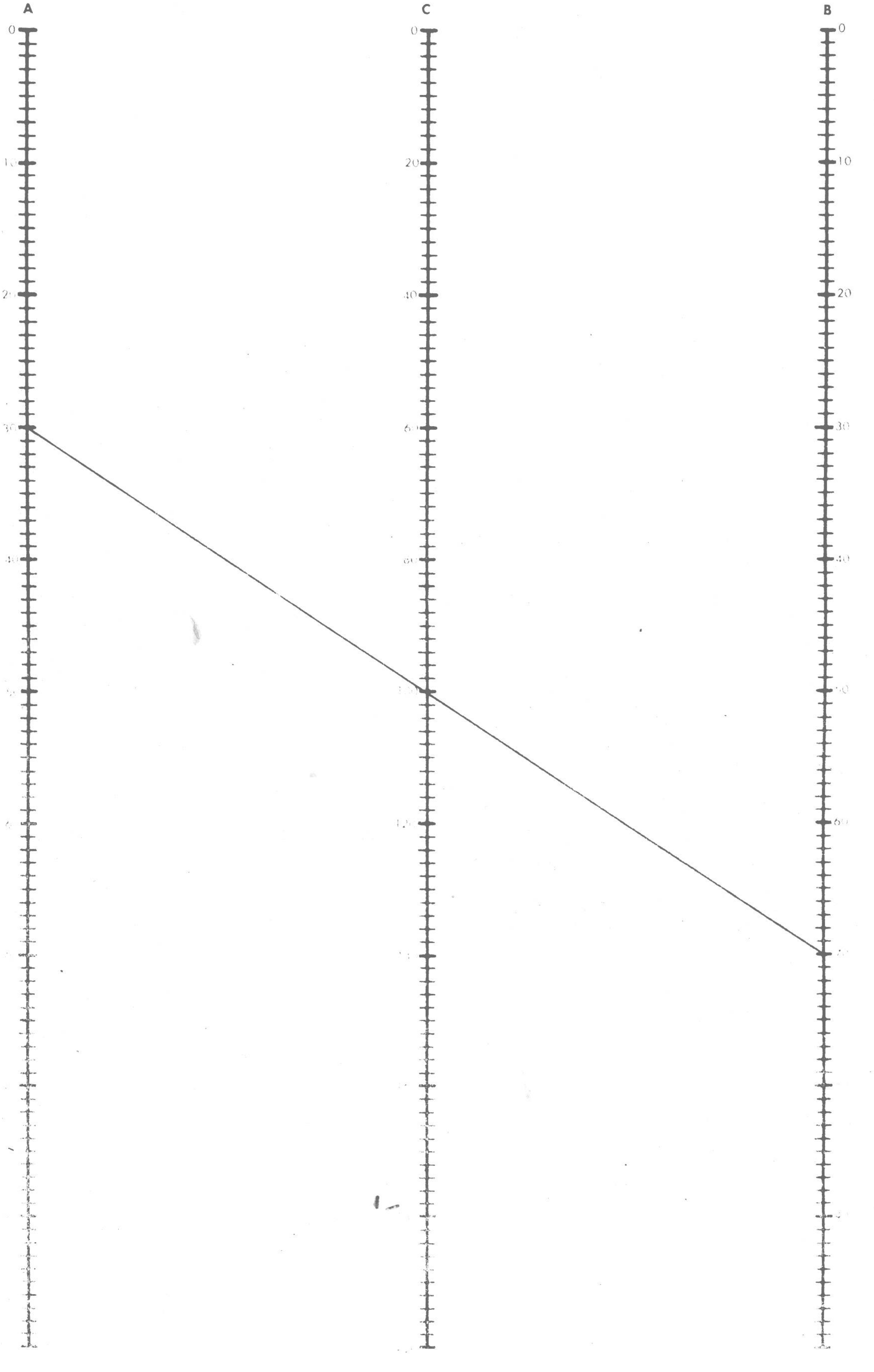
Formulas: $C = A + B$, $A = C - B$, $B = C - A$

Examples: (1) If A equals 30 and B equals 70, A + B equals 100 (read on C scale).

(2) If C equals 100 and A equals 30, C − A equals 70 (read on B scale).

All scales can be multiplied or divided by the same number and still be valid. Thus, if each scale is multiplied by 10, values from 1 to 1000 can be added or subtracted. Dividing all scales by 10 reduces the range to 1 to 10, but greatly increases the accuracy.

To add three numbers, first solve for two numbers as above. Then set the sum of the first two numbers on the A or B scale, set the remaining number on the other scale, and read the sum of the three numbers on the C scale.



ADDITION AND SUBTRACTION

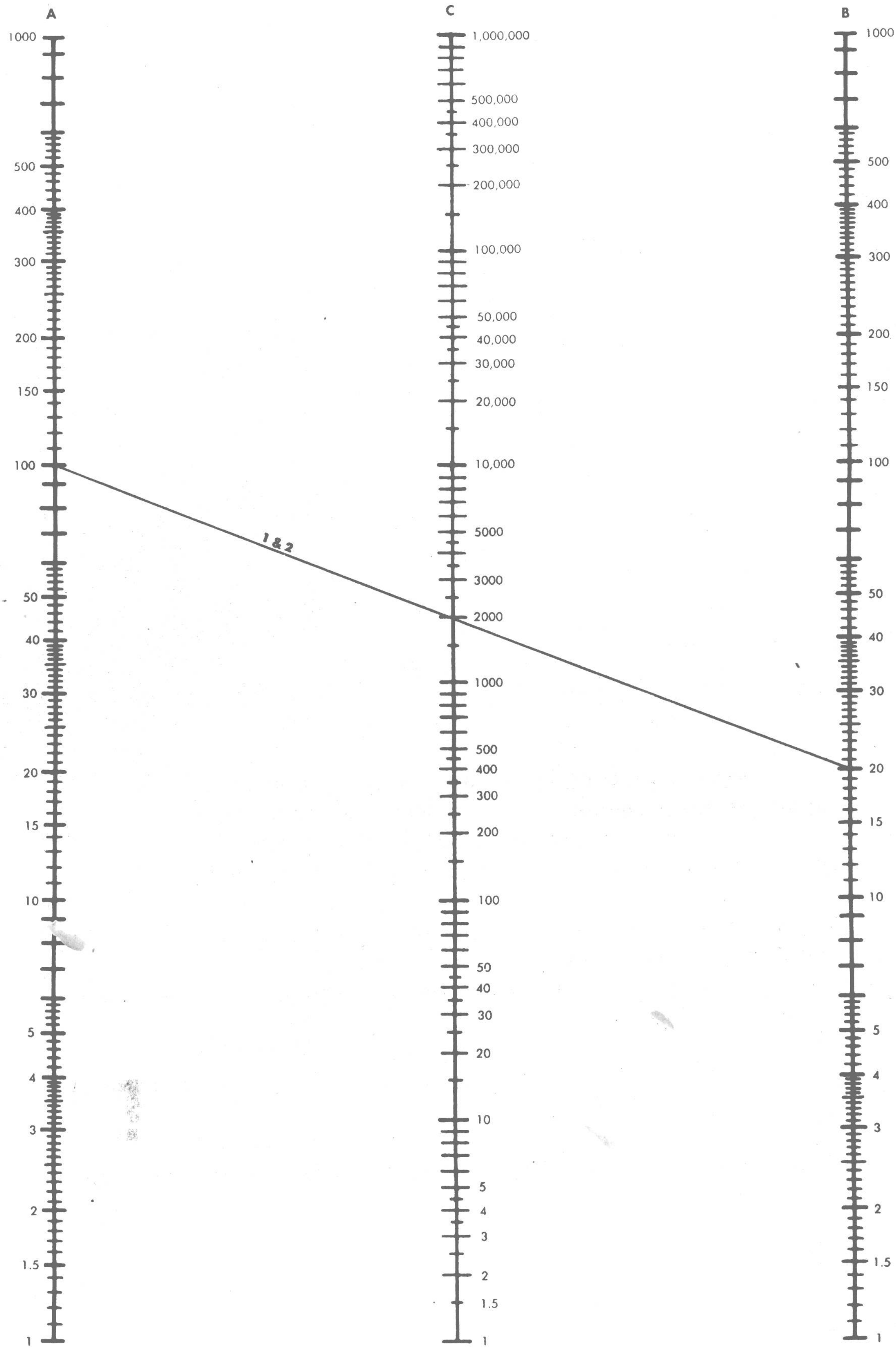
MULTIPLICATION AND DIVISION

Purpose: To multiply or divide any two numbers.

Formulas: $C = A \times B$, $A = C \div B$, $B = C \div A$

Examples: (1) If A equals 100 and B equals 20, then $A \times B$ equals 2,000 (read on C scale).
(2) If C equals 2,000 and A equals 100, then $C \div A$ equals 20 (read on B scale).

If three numbers are to be multiplied, first multiply the first two as explained above. Then place the product of the first two on the A or B scale and the third number on the remaining scale. Read the product of the three numbers on the C scale.



MULTIPLICATION AND DIVISION