MECHANICAL ENGINEERS' HANDBOOK

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MARKS' HANDBOOK

EXAMPLE 2. Find $x = (0.0291)^{1.41}$
Answer: $x = 6.825 \times 10^{-3}$
$= 0.006825$

$\log 0.0291 = 0.4639 - 2 = -1.5361$

$$\begin{array}{r} 1.5361 \\ \times 1.41 \\ \hline 15361 \\ 61444 \\ 15361 \\ \hline \log x = -2.1659 \\ = 0.8341 - 3 \end{array}$$

To Find the nth Root of a Number by Logarithms. Find from the table the log. of the number, and divide it by n; the result will be the log. of the nth root of that number. Then find the root itself from the table.

EXAMPLE. Find $x = \sqrt[3]{4.098}$ $\log 4.098 = 0.6126$
Answer: $x = 1.600$ $\log x = 0.2042$

In order **to avoid fractional characteristics,** if the characteristic is not divisible by n, make it so divisible by adding and subtracting a suitable number before dividing.

EXAMPLE. Find $x = \sqrt[3]{0.0004590}$. $\log 0.0004590 = 0.6618 - 4$
Answer: $x = 7.714 \times 10^{-2}$ $3)2.6618 - 6$
$= 0.07714$ $\log x = 0.8873 - 2$

But if the characteristic is positive, it is simpler to write it in front of the mantissa, and then divide directly.

THE SLIDE RULE

The slide rule is an indispensable aid in all problems in multiplication, division, proportion, squares, square roots, etc., in which a limited degree of accuracy is sufficient. The ordinary 10-in. Mannheim rule (see below) costs $3 to $4.50 and gives three significant figures correctly; the 20-in. rule ($12.50) gives from three to four figures; the Fuller spiral rule ($30) or the Thacher cylindrical rule ($35) gives from four to five figures. For many problems the slide rule gives results more rapidly than a table of logarithms; it requires, however, more care in placing the decimal point in the answer. In all work with the slide rule, the position of the decimal point should be determined by inspection (see p. 89), only the sequence of digits being obtained from the instrument itself. Rapidity in the use of the instrument depends mainly on the skill with which the eye can estimate the values of the various divisions on the scale; expertness in this respect comes only with practice. The following explanations should be sufficient to permit the use of the ordinary slide rule successfully without previous experience and without knowledge of logarithms.

Multiplication and Division with a (Theoretical) Complete Logarithmic Scale. Consider a *complete* logarithmic scale (D, Fig. 1), assumed to extend indefinitely in both directions, only the main section, from 1 to 10, however, being usually available. Note that the divisions within the several sections are indentical, except that the numeral attached to each division of any one section is ten times the numeral attached to the corresponding division in the preceding section. [The distances laid off from 1 are proportional to the logarithms of the corresponding numbers, the distance from 1 to 10 being taken as unity.] Consider also a duplicate scale, C, numbered from 1 to 10, and arranged to slide along the fixed scale D as in the figures. By means of such a scale D, and slide C, any two numbers between 1 and 10 (and hence any two numbers whatever, with proper attention to the decimal point) can be multiplied or divided, as in the following examples.

TO MULTIPLY 4 BY 6. In Fig. 1, starting with point 1 of the fixed scale, run the eye along from 1 to 4; then set the 1 of the slide opposite this point 4, and *run the eye forward along the slide from* 1 *to* 6; the point thus reached on the fixed scale is 24, which is equal to 4×6. This process gives the distance from 1 to 4 *plus* the distance from 1 to 6, and is, in fact, a mechanical method of adding the logarithms of these numbers; hence the result is the product of the numbers. Conversely,

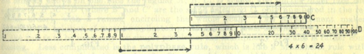

FIG. 1.

TO DIVIDE 4 BY 6. In Fig. 2, starting with the point 1 of the fixed scale, run the eye along from 1 to 4; then set the 6 of the slide opposite the point 4, and *run the eye backward along the slide from* 6 *to* 1; the point thus reached on the fixed scale is 0.667, which is equal to $4 \div 6$. This process gives the distance from 1 to 4 *minus* the distance from 1 to 6; and is, in fact, a mechanical method of subtracting the logarithms of these numbers; hence the result is their quotient.

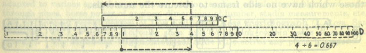

FIG. 2.

Multiplication and Division, Using Only a Single Section of the Scale. If only the main section of scale D is available (as is usually the case in practice), the result of multiplication may fall beyond the scale, as it does in Fig. 1. In such cases *divide the first factor by* 10 *before beginning to multiply;* this will bring the result within the scale, without affecting the sequence of digits.

For example, to multiply 4 by 6. Having found that the setting shown in Fig. 1 is not successful, *reset the slide as in Fig.* 3, *with* 10 *instead of* 1 *opposite* 4; run the eye backward along the slide from 10 to 1, thus reaching the (unrecorded) point corresponding to $4 \div 10$; then, continuing from this point, run the eye forward along the slide from 1 to 6, as before; the point finally reached on the main scale is 2.4, which has the same sequence of digits as the required value 24. After a little practice, this preliminary step of dividing by 10 will be performed almost intuitively. Whether or not this step is necessary in any given case, can be determined only by trial.

The **general rule for multiplication** may be stated as follows, if preferred: To find the product of two factors, find one factor on the fixed scale; opposite this, set (tentatively) point 1 of the slide; on the slide find the second factor, and opposite this read the product on the main scale, if possible. If the product falls beyond the scale, begin over again, using point 10 of the slide instead of point 1.

In division also, the result may fall beyond the main section of the scale, as it does in Fig. 2. In such cases, it suffices merely to *multiply the result by* 10 in order to bring it within the scale; this will not affect the sequence of digits.

For example, to divide 4 by 6, set the slide as in Fig. 4, and follow out mentally the steps indicated by the arrows. It will be noticed that the supplementary step of multiplying by 10 is performed by simply running the eye along the slide from 1 to 10 without resetting the slide; for this reason, division on the slide rule is slightly easier than multiplication.

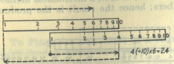

FIG. 3.

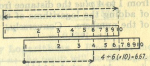

FIG. 4.

The Ordinary Mannheim Slide Rule has four scales, A, B, C, D, as shown in Fig. 5. Scales C and D are essentially the same as the C and D scales described above, and the principle just explained shows how they are used in multiplication and division. The fact that the D scale covers only the main section from 1 to 10 (all decimal points being omitted) is practically no restriction on the scope of the scale, as is seen in the preceding examples. A runner is provided, so that intermediate positions reached in the course of an extended computation may be indicated temporarily on the scale without the necessity of reading off their numerical values. The best runners are those which have no side frame to obscure the numerals.

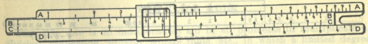

FIG. 5.

In problems involving successive multiplications and divisions, arrange the work so that multiplication and division are performed alternately.

For example, to calculate $\frac{a \times b \times c}{d \times e}$, divide the product $a \times b$ by d; multiply this quotient by c; and divide this product by e. Each operation will require only one shifting either of the slide (for multiplication) or of the runner (for division).

To multiply a number of different quantities by a *constant multiplier*, x, set the point 1 of slide opposite x, and read, by aid of the runner, the products of x by all the quantities which do not fall beyond the scale; then reset the slide, setting 10 instead of 1 opposite x, and read the products of x by all the remaining quantities.

To divide a number of different quantities by a *constant divisor*, y, first find (by the slide rule) the quotient $1 \div y$, and then use this as a constant multiplier.

Scales A and B are exactly like scales C and D, except that they cover two sections of the complete logarithmic scale, the graduations being only half as fine. Either pair of scales may be used for multiplication and division; C and D give more accurate readings, but have the disadvantage that in the case of multiplication the slide must often be shifted to the other end in order to keep the result on the scale—an inconvenience which is not present when the less accurate scales A and B are employed.

By the use of both pairs of scales, problems in squares and square roots may be readily solved; for every number on A, except for the decimal point is the square of the number directly below it on D (use the runner).

A scale of sines, tangents, and logarithms is often printed on the back of the slide. For further details concerning the use of the slide rule in various problems, see the instruction books furnished with each instrument: Wm. Cox, "Manual of the Mannheim Slide Rule;" F. A. Halsey, "Manual of the Slide Rule;" etc.

Other Types of Slide Rules. The **duplex slide rule** ($5 to $18 according to length) shows on one face the regular A, B, C, D scales, and on the other face the scales A, B', C', D (where B' and C' are the same as B and C, only numbered in the reverse order), with a runner encircling the whole scale. This arrangement makes possible the solution of more complicated problems with fewer settings of the slide, but if the rule is to be used only for simple problems, the multiplicity of scales is rather confusing. Less complicated is the **polyphase rule,** which is like a Mannheim rule with the addition of a single inverted scale, C', printed in the middle of the slide. The **log log duplex slide rule** (10 in., $8) is especially adapted for handling complex problems involving fractional powers or roots, hyperbolic logarithms, etc. A number of **circular slide rules** are on the market, the best of which are operated by a milled thumbnut, like the stem wind of a watch. The advantage of the circular rule, aside from its compact size (some models are scarcely larger than a watch), lies in the fact that the scale is endless, so that the slide never has to be reset in order to bring the result within the scale. A disadvantage is found in the necessity of reading the figures in oblique positions, or else continually turning the instrument as a whole in the band. The **Fuller and Thacher rules** already mentioned are invaluable for problems requiring greater accuracy than can be obtained with the ordinary rules. There are also many **special slide rules,** adapted to various special types of computation, such as calculating discharge of water through pipes, horse power of engines, dimensions of lumber, stadia measurements, etc. One of the most recent devices of this kind is the **Ross meridiograph** (L. Ross, San Francisco, Cal.), which is a circular slide rule for solving certain cases of spherical triangles. The **Eichhorn trigonometrical slide rule** solves any plane triangle.

COMPUTING MACHINES

For certain purposes computing machines have ceased to be luxuries and have become almost necessities; but they are expensive, and should be selected with reference to the special work which is to be done. The machines may be classified roughly into three groups, as follows:

Adding Machines, Non-listing. Of the machines of this kind, the most convenient in the hands of a careful operator is the well-known **Comptometer** (Felt & Tarrant Co., Chicago, Ill.; $300 to $400 according to size), or the recent **Burroughs non-listing** adding machine (Detroit, Mich., $175). To add a number, simply press a key in the proper column; the result appears on the dials in front of the keyboard. Multiplication as well as addition can be performed on this machine with great rapidity, and division also after a little practice. Weight, about 15 lb. Other key-operated machines are the **Barrett adding machine** (Philadelphia, Pa.) with multiplying attachment, and the **Mechanical Accountant** (Providence, R. I.). The **Gem** (Automatic Adding Machine Co., New York; $20), and the **Ray** (Richmond, Va.; $17.50) are small machines operated by the use of a stylus. The **Underwood typewriter** is now supplied with a complete electrically-driven adding machine attached, and the **Wahl adding attachment** is supplied on the Remington and other typewriters.

Adding and Listing Machines. The machines of this group not only add, but also print the items, totals and sub-totals. The **Burroughs** (Detroit, Mich.) and the **Wales** (Wilkes-Barre, Pa.), resemble each other in having an 81-key keyboard; the **Dalton** (Cincinnati, Ohio) and the **Sundstrand** (Rockford, Ill.) have a 10-key keyboard, admitting of operation by the touch method. On all these machines, in order to add a number, first depress the proper keys and then pull a handle (or, in the case of electrically driven machines, press a button) to record the item. The prices range from $125 to $1100, according to size and style, new models being constantly devised for special commercial purposes. Other machines are the **Barrett** (Lanston Monotype Machine Co., Philadelphia, Pa.; $200) and the new **American** (American Can Co.,