When x is less than 1 the second method is more suitable.

Ex.—$0{\cdot}23^{-1{\cdot}77}=\left(\frac{1}{0{\cdot}23}\right)^{1{\cdot}77}=4{\cdot}35^{1{\cdot}77}=13{\cdot}5$.

Set 1 on B to 0·23 on A, and under index of A read $\frac{1}{0{\cdot}23}=4{\cdot}35$ on B.

Set 1 on C to 4·35 on E, and under 1·77 on C read 13·5 on E.

As with the Davis rule, the exponent scale C will be read as $\frac{1}{10}$th its face value if its R.H. index (10) is used in place of 1.

THE LOG-LOG DUPLEX SLIDE RULE.—In this rule the log-log scale is in three sections placed one above the other, and in the position usually occupied by the D scale. The graduations range from 1·01 to 22,000, and are read in conjunction with the C scale (1 to 10) on the lower edges of the slide. Above the A scale is a log-log scale of decimal quantities ranging from 0·97 to 0·05. It is referred to the A and B scales. The log-log scale is so divided as to enable hyperbolic logarithms to be read without setting the slide. Numerous logarithmic scales are given on the two faces of the rule, graduations on the one side being referred to those on the other by a cursor which extends around the whole. The rule is produced by the Keuffel and Esser Company.

LONG-SCALE SLIDE RULES

IT has been shown that the degree of accuracy attainable in slide-rule calculations depends upon the length of scale employed. Considerations of general convenience, however, render simple straight-scale rules of more than 20in. in length inadmissible, so that inventors of long-scale slide rules, in order to obtain a high degree of precision, combined with convenience in operation, have been compelled to modify the arrangement of scales usually employed. The principal methods adopted may be classed under three varieties: (1) The use of a long scale in sectional lengths, as in Hannyngton's Extended Slide Rule and Thacher's Calculating Instrument; (2) the employment of a long scale laid in spiral form upon a disc, as in Fearnley's Universal Calculator and Schuerman's Calculating Instrument; and (3) the adoption of a long scale wound helically upon a cylinder, of which Fuller's and the "R.H.S." Calculating Rules are examples.

FULLER'S CALCULATING RULE. — This instrument, which is shown in Fig. 18, consists of a cylinder d capable of being moved up and down and around the cylindrical stock *f*, which is held by the handle. The logarithmic scale-line is arranged in the form of a helix upon the surface of the cylinder *d*, and as it is equivalent to a straight scale of 500 inches, or 41ft. 8in., it is possible to obtain four, and frequently five, figures in a result.

Upon reference to the figure it will be seen that three indices are employed. Of these, that lettered *b* is fixed to the handle; while two others, *c* and *a* (whose distance apart is equal to the axial length of the complete helix), are fixed to the innermost cylinder *g*. This latter cylinder slides telescopically in the stock *f*, enabling the indices to be placed in any required position relatively to *d*. Two other scales are provided, one (*m*) at the upper end of the cylinder *d*, and the other (*n*) on the movable index.

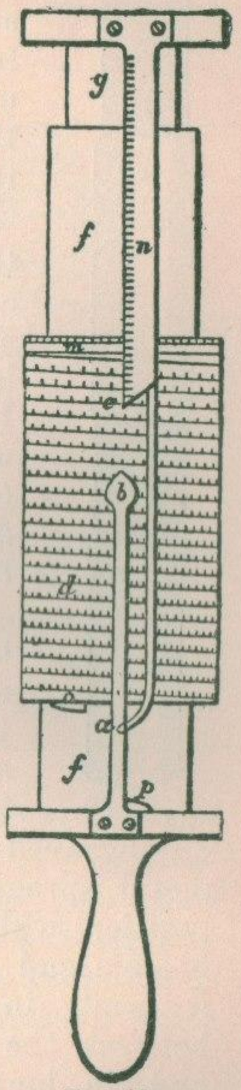


FIG. 18.

In using the instrument a given number on *d* is set to the fixed index *b*, and either *a* or *c* is brought to another number on the scale. This establishes a ratio, and if the cylinder is now moved so as to bring any number to *b*, the fourth term of the proportion will be found under *a* or *c*. Of course, in multiplication, one factor is brought to *b*, and *a* or *c* brought to 100. The other factor is then brought to *a* or *c*, and the result read off under *b*. Problems involving continuous multiplication, or combined multiplication and division, are very readily dealt with. Thus, calling the fixed index F, the upper movable index A, and the lower movable index B, we have for $a \times b \times c$:—Bring *a* to F; A to 100; *b* to A or B; A to 100; *c* to A or B and read the product at F.

The maximum number of figures in a product is the sum of the number of figures in the factors and this results when all the factors except the first have to be brought to B. Each time a factor is brought to A, 1 is to be deducted from that sum.

For division, as $\frac{a}{m \times n}$, bring a to F; A or B to m; 100 to A; A or B to a; 100 to A and read the quotient at F.

The maximum number of figures in the quotient is the difference between the sum of the number of figures in the numerator factors and those of the denominator factors, *plus* 1 for each factor of the denominator, and this results when A has to be set to all the factors of the denominator and all the factors of the numerator except the first brought to B. Each time B is set to a denominator factor or a numerator factor is brought to A, 1 is to be deducted.

FIG. 19.

Logarithms of numbers are obtained by using the scales m and n and hence powers and roots of any magnitude may be obtained by the procedure already fully explained. The instrument illustrated is made by Messrs. W. F. Stanley & Co., Limited, London, who also supply a No. 2 model identical with that described but having on the inner cylinder (a) a scale of logarithms giving logs of numbers to four decimal places; and (b) a scale of sines of angles from 5° 35′ to 88° correct to four places.

THE OTIS KING CALCULATOR comprises two metal tubes, the smaller (the cylinder) being free to rotate and slide within the larger (the holder). On each of these tubes scale lines 66in. long are arranged in spiral form (Fig. 19). A third tube mounted on the holder forms a tubular cursor, carrying at each end an engraved arrow which can be set to any graduation. Three metal sprags on the top of the holder keep the cursor in position while preventing it from touching the scales. The bottom end of the cylinder is covered with velvet which holds it firmly in position and prevents chafing of the top scale between the two tubes. The instrument is $1\frac{1}{8}$in. in diameter, and 6in. long when closed; 10in. long when fully extended.

In using the instrument the arrow at the lower end of the cursor is set to the first factor and the second factor on the upper scale is set to the arrow at the top of the cursor. The latter is then moved until the third factor is in agreement with the lower arrow when the fourth term of the proportion will be found on the upper scale under the upper arrow. Models "K" and "L" are supplied by Messrs. Carbic Limited, London, Model "L" having a scale for logarithms.

THACHER'S CALCULATING INSTRUMENT, shown in Fig. 20, consists of a cylinder 4in. in diameter and 18in. long, which can be given both a rotary and a longitudinal movement within an open framework composed of twenty triangular bars. These bars are connected to rings at their ends, which can be rotated in standards fixed to the baseboard. The scale on the cylinder consists of forty sectional lengths, but of each scale line that

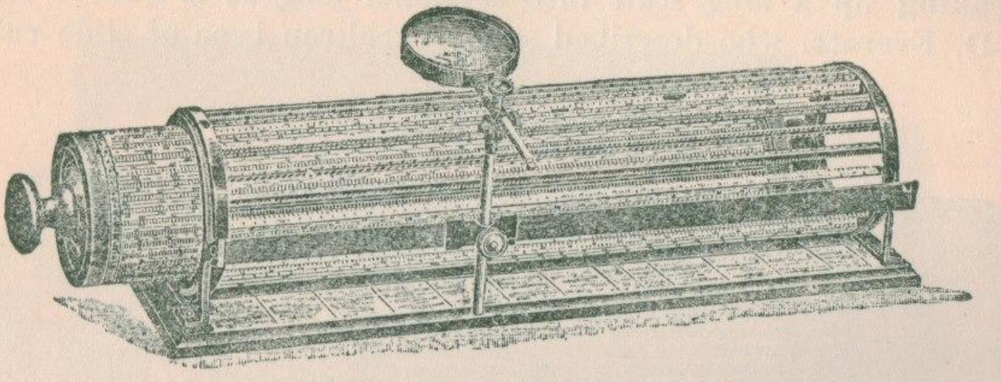


FIG. 20.

part which appears on the right-hand half of the cylinder is repeated on the left-hand half, one line in advance. Hence each half of the cylinder virtually contains two complete scales following round in regular order. On the lower lines of the triangular bars are scales exactly corresponding to those on the cylinder, while upon the upper lines of the bars and not in contact with the slide is a scale of square roots.

By rotating the slide any line on it may be brought opposite any line in the frame, and by a longitudinal movement any graduation on these lines may be brought into agreement. The whole can be rotated in the supporting standards in order to bring any reading into view. As shown in the illustration, a magnifier is provided, this being conveniently mounted on a bar, along which it can be moved as required.

THE NESTLER CYLINDRICAL CALCULATOR is on the same principle as the Thacher calculator, but arranged somewhat differently. As shown in Fig. 21, the cylinder is rotatable in fixed supports, while the slide takes the form of a cage of bars the ends of which are held in two rings slidable and rotatable upon the cylinder. The scales on the cylinder are repeated as in the Thacher instrument, enabling any value on the slide to be set to any value on the cylinder. Indicators in the form of clips are supplied which may be attached to the slide bars. These are convenient for locating values, especially in conversion calculations involving repetitive multiplication or division by a constant factor, combined multiplication and division, etc. The calculator is available in three sizes, of which the largest has a cylinder 21in. long and 6¼in. in diameter, the scale being equivalent to that of a slide rule 492in. in length.

SECTIONAL LENGTH OR GRIDIRON SLIDE RULES.—The idea of breaking up a long scale into sectional lengths is due to Dr. J. D. Everett, who described such a gridiron type of slide rule

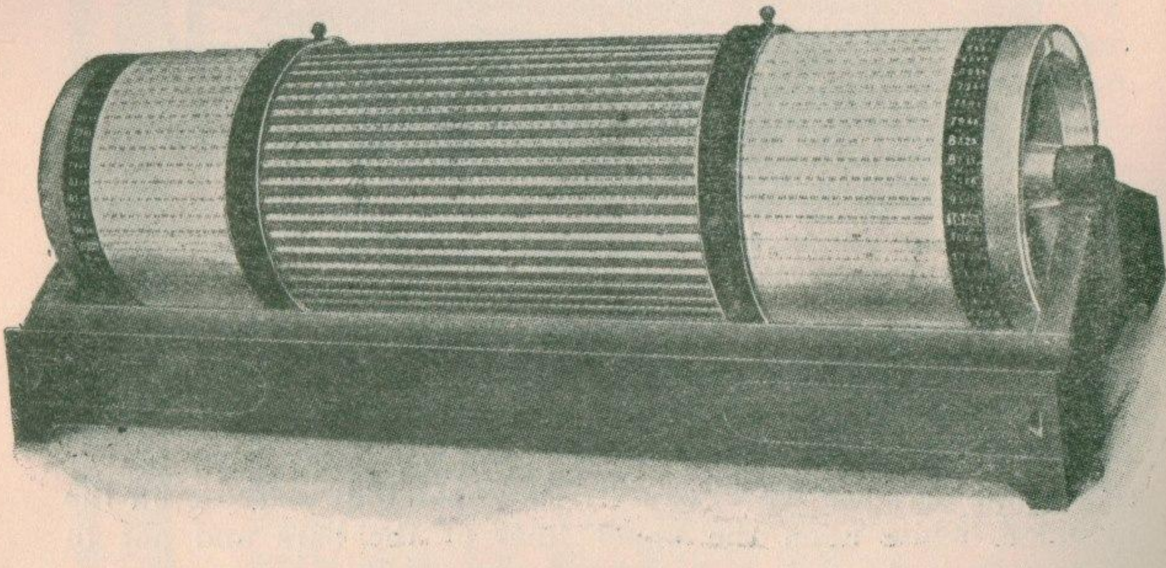


FIG. 21.

in 1866. Hannyngton's Extended Slide Rule is on the same principle. Both instruments have the lower scale repeated. H. Cherry (1880) appears to have been the first to show that such duplication could be avoided by providing two fixed index points in addition to the natural indices of the scale. The upper member of Cherry's calculator consists of a transparent sheet ruled with parallel lines, which coincide with the lines of the lower scale when the indices of both are placed in agreement. To multiply one number by another, one of the indices on the upper sheet is placed to one of the factors, and the position of whichever index falls under the transparent sheet is noted on the latter. Bringing the latter point to the other factor, the result is found under whichever index lies on the card.

THE COOPER SLIDE RULE.—In this instrument, based upon the principle just described, the logarithmic scale 100in. long is arranged in 20 parallel lines as shown in Fig. 21A. This scale is engraved on a sheet of white celluloid mounted on a base board about 8in. by 7in. On the base board is an outer frame capable of movement in a vertical direction. This carries an inner frame, movable in a transverse direction and having fixed to its underside a sheet of transparent celluloid covering the whole

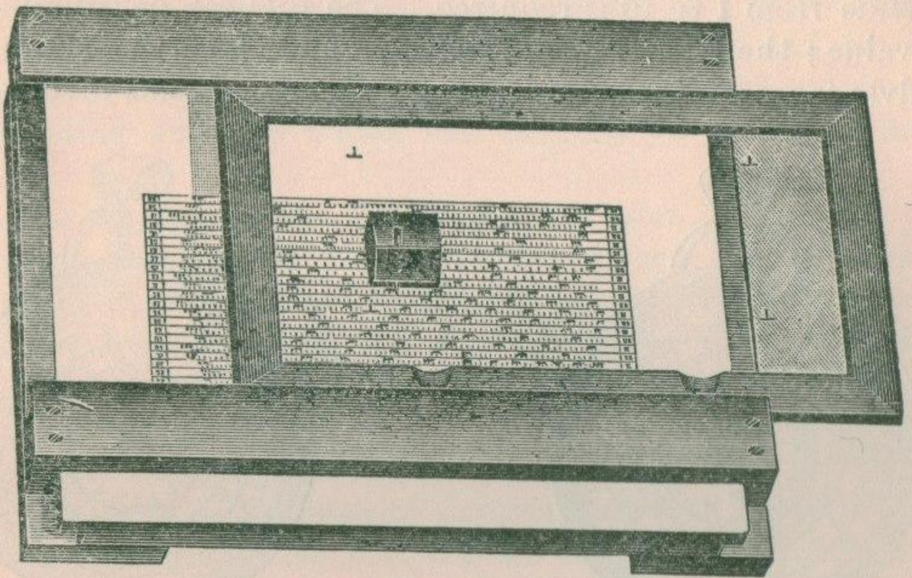


FIG. 21A.

of the opening. This sheet has four index lines (⊥) marked upon it, one near each corner, and any one of these can be made to coincide with any graduation on the scale by suitably adjusting the positions of the two frames.

The movable index necessary in calculators of this type takes the form of a large-headed steel pin, clipped to the inclined surface of a metal block, as indicated in the illustration. The under surface of the block is covered with rubber having a stipple-like surface, which effectually retains the block in position on the transparent sheet. The calculator is particularly convenient for percentage calculations of all kinds; while, of course, all problems in multiplication, division, proportion, etc., can be readily solved by its aid. A scale is given by means of which the logarithm of any given number can be readily determined, thus affording a means of calculating powers, roots, etc. Messrs. W. F. Stanley and Co. Limited, London, are the distributors of this calculator.

CIRCULAR CALCULATORS.

ALTHOUGH the 10in. slide rule is probably the most serviceable form of calculating instrument for general purposes, many prefer the more portable circular calculator, of which many varieties have been introduced during recent years. The advantages of this type are: It is more compact and conveniently carried in the waistcoat pocket. The scales are continuous, so that no traversing of the slide from 1 to 10 is required. The dial can be set quickly to any value; there is no trouble with tight or ill-fitting slides. The disadvantages of most forms are: Many problems involve more

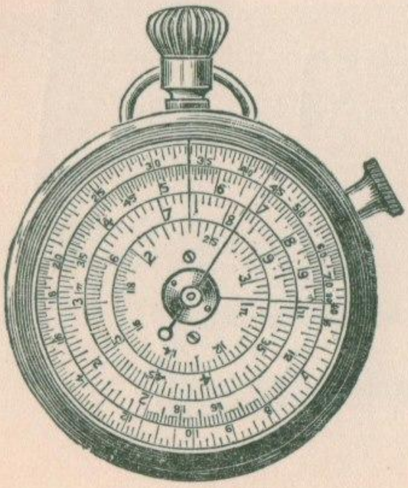


FIG. 22.

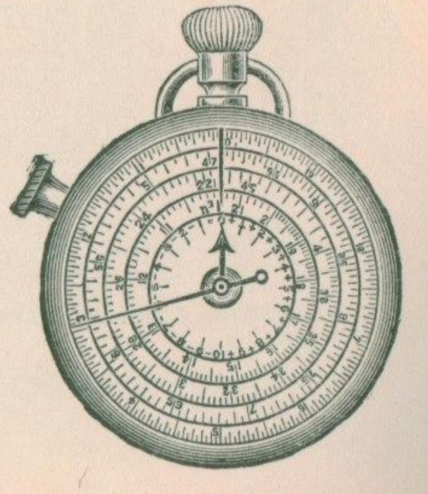


FIG. 23.

operations than a straight rule. The results being read under fingers or pointers, an error due to parallax is introduced, so that the results generally are not so accurate as with a straight rule. The inner scales are short, and therefore are read with less accuracy. Special scale circles are needed for cubes and cube roots. The slide cannot be reversed or inverted.

THE BOUCHER CALCULATOR.—This circular calculator resembles a stem-winding watch, being about 2in. in diameter and $\frac{9}{16}$in. in thickness. The instrument has two dials, the back one being fixed, while the front one, Fig. 22 (showing the form made by Messrs. W. F. Stanley, London), turns upon the large centre arbor shown. This movement is effected by turning the milled head of the stem-winder. The small centre axis, which is turned by rotating the milled head at the side of the case, carries two fine needle pointers, one moving over each dial, and so fixed on the axis that one pointer always lies evenly over the other. A fine index or pointer fixed to the case in line with the axis of the winding stem, extends over the four scales of the movable dial as shown. Of these scales, the second from the outer is the ordinary logarithmic scale, which in this instrument corresponds to a straight scale of about $4\frac{3}{4}$in. in length. The two inner circles give the square roots of the numbers on the primary logarithmic scale, the smaller circle containing the square roots of values between 1 and 3·162 ($=\sqrt{10}$), while the other section corresponds to values between 3·162 and 10. The outer circle is a scale of logarithms of sines of angles, the corresponding sines of which can be read off on the ordinary scale.

On the fixed or back dial there are also four scales, these being arranged as in Fig. 23. The outer of these is a scale of equal parts, while the three inner scales are separate sections of a scale giving the cube roots of the numbers taken on the ordinary logarithmic scale and referred thereto by means of the pointers. In dividing this cube-root scale into sections, the same method is adopted as in the case of the square-root scale. Thus, the smallest circle contains the cube roots of numbers between 1 and 10, and is therefore graduated from 1 to 2·154; the second circle contains the cube roots of numbers between 10 and 100, being graduated from 2·154 to 4·657; while the third section, in which are found the cube roots of numbers between 100 and 1000, carries the graduations from 4·657 to 10.

What has been said in an earlier section regarding the notation of the slide rule may in general be taken to apply to the scales of the Boucher calculator. The manner of using the instrument is, however, not quite so evident, although from what follows it will be seen that the operative principle—that of variously combining lengths of a logarithmic scale—is essentially similar. In this case, however, it is seen that in place of the straight scale-lengths shown in Fig. 4, we require to add or subtract arc-lengths of the circular scales, while, further, it is evident that in the absence of a fixed scale (corresponding to the stock of the slide rule) these operations cannot be directly performed as in the ordinary form of instrument. However, by the aid of the fixed index and the movable pointer, we can effect the desired combination of the scale-lengths in the following manner. Assuming it is desired to multiply 2 by 3, the dial is turned in a backward direction until 2 on the ordinary scale lies under the fixed index, after which the movable pointer is set to 1 on the scale. As now set, it is clear that the arc-length 1 – 2 is spaced-off between the fixed index and the movable pointer, and it now only remains to add to this definite arc-length a further length of 1 – 3. To do this we turn the dial still further backward until the arc 1 – 3 has passed under the movable pointer, when the result, 6, is read under the fixed index. A little consideration will show that any other scale-length may be added to that included between the fixed and movable pointers, or, in other words, any number on the scale may be multiplied by 2 by bringing the number to the movable pointer and reading the result under the fixed index. The rule for multiplication is now evident.

Rule for Multiplication.—Set one factor to the fixed index and bring the pointer to 1 *on the scale; set the other factor to the pointer and read the result under the fixed index.*

With the explanation just given, the process of division needs little explanation. It is clear that to divide 6 by 3, an arc-length 1 – 3 is to be taken from a length 1 – 6. To this end we set 6 to the index (corresponding in effect to passing a length 1 – 6 to the left of that reference point) and set the pointer to the divisor 3. As now set, the arc 1 – 6 is included between 1 on the scale and the index, while the arc 1 – 3 is included between 1 on the scale and the pointer. Obviously if the dial is now turned forward until 1 on the scale agrees with the pointer, an arc 1 – 3 will have been deducted from the larger arc 1 – 6, and the remainder, representing the result of this operation, will be read under the index as 2.

Rule for Division.—Set the dividend to the fixed index, and the pointer to the divisor; turn the dial until 1 *on the scale agrees with the pointer, and read the result under the fixed index.*

The foregoing method being an inversion of the rule for multiplication, is easily remembered and is generally advised. Another plan is, however, preferable when a series of divisions are to be effected with a constant divisor—*i.e.*, when b in $\frac{a}{b}=x$ is constant. In this case 1 on the scale is set to the index and the pointer set to b; then if any value of a is brought to the pointer, the quotient x will be found under the index.

Combined Multiplication and Division, as $\frac{a \times b \times c}{m \times n} = x$, can be readily performed, while cases of continued multiplication evidently come under the same category, since $a \times b \times c = \frac{a \times b \times c}{1 \times 1} = x$. Such cases as $\frac{a}{m \times n \times r} = x$ are regarded as $\frac{a \times 1 \times 1 \times 1}{m \times n \times r} = x$; while $\frac{a \times b \times c}{m} = x$ is similarly modified, taking the form $\frac{a \times b \times c}{m \times 1} = x$. In all cases the expression must be arranged so that there is *one more factor in the numerator* than *in the denominator, 1's being introduced as often as required.* The simple operations of multiplication and division involve a similar disposition of factors, since from the rules given it is evident that $m \times n$ is actually regarded as $\frac{m \times n}{1}$, while $\frac{m}{n}$ becomes in effect $\frac{m \times 1}{n}$. It is important to note the general applicability of this arrangement-rule, as it will be found of great assistance in solving more complicated expressions.

As with the ordinary form of slide rule, the factors in such an expression as $\frac{a \times b \times c}{m \times n} = x$ are taken in the order:—1st factor of numerator; 1st factor of denominator; 2nd factor of numerator; 2nd factor of denominator, and so on; the 1st factor as a being set to the index, and the result x being finally read at the same point of reference.

Ex.—$\frac{39 \times 14{\cdot}2 \times 6{\cdot}3}{1{\cdot}37 \times 19} = 134$.

Commence by setting 39 to the index, and the pointer to 1·37; bring 14·2 to the pointer; pointer to 19; 6·3 to the pointer, and read the result 134 at the index.

It should be noted that after the first factor is set to the fixed index, the *pointer* is set to each of the *dividing* factors as they enter into the calculation, while the *dial* is moved for each of the *multiplying* factors. Thus the dial is first moved (setting the first factor to the index), then the pointer, then the dial, and so on.

Number of Digits in the Result.—If rules are preferred to the plan of roughly estimating the result, the general rules given on pages 21 and 25 should be employed for simple cases of multiplication and division. For combined multiplication and division, modify the expression, if necessary, by introducing 1's, as already explained, and subtract the sum of the denominator digits from the sum of numerator digits. Then proceed by the author's rule, as follows :—

Always turn dial to the LEFT ; *i.e., against the hands of a watch.*

Note dial movements only ; ignore those of the pointer.

Each time 1 *on dial agrees with or passes fixed index,* ADD 1 *to the above difference of digits.*

Each time 1 *on dial agrees with or passes pointer,* DEDUCT 1 *from the above difference of digits.*

Treat continued multiplication in the same way, counting the 1's used as denominator digits as one less than the number of multiplied factors.

Ex.—$\frac{8{\cdot}6 \times 0{\cdot}73 \times 1{\cdot}02}{3{\cdot}5 \times 0{\cdot}23} = 7{\cdot}95$ [7·95473+].

Set 8·6 to index and pointer to 3·5. Bring 0·73 to pointer (noting that 1 on the scale passes the index) and set pointer to 0·23. Set 1·02 to pointer (noting that 1 on the scale passes the pointer) and read under index 7·95. There are $1+0+1=2$ numerator digits and $1+0=1$ denominator digit ; while 1 is to be added and 1 deducted as per rule. But as the latter cancel, the digits in the result will be $2-1=1$.

When moving the dial to the left will cause 1 on the dial to pass *both* index and pointer (thus cancelling), the dial may be turned back to make the setting.

It will be understood that when 1 is the *first* numerator, and 1 on the dial is therefore set to the index, no digit addition will be made for this, as the actual operation of calculating has not been commenced.

In the Stanley-Boucher calculator (Fig. 23) a small centre scale is added, on which a finger indicates automatically the number of digits to be added or deducted ; the method of calculating, however, differs from the foregoing. To avoid turning back to 0 at the commencement of each calculation, a circle is ground on the glass face, so that a pencil mark can be made thereon to show the position of the finger when commencing a calculation.

To Find the Square of a Number.—Set the number, on one or other of the square root scales, to the index, and read the required square on the ordinary scale.

To Find the Square Root of a Number.—Set the number to the index, and if there is an *odd* number of digits in the number, read the root on the inner circle; if an even number, on the second circle.

To Find the Cube of a Number.—Set 1 on the ordinary scale to the index, and the pointer (on the back dial) to the number on one of the three cube-root scales. Then under the pointer read the cube on the ordinary scale.

To Find the Cube Root of a Number.—Set 1 to index, and pointer to number. Then read the cube root under the pointer on one of the three inner circles on the back dial. If the number has

1, 4, 7, 10 or −2, −5, etc., digits, use the inner circle.
2, 5, 8, 11 or −1, −4, etc., " " second circle.
3, 6, 9, 12 or −0, −3, etc., " " third circle.

For Powers or Roots of Higher Denomination.—Set 1 to index, the pointer to the number on the ordinary scale, and read on the outer circle on the back dial the mantissa of the logarithm. Add the characteristic (see p. 46), multiply by the power or divide by the root, and set the pointer to the mantissa of the result on this outer circle. Under the pointer on the ordinary scale read the number, obtaining the number of figures from the characteristic.

To Find the Sines of Angles.—Set 1 to index, pointer to the angle on the outer circle, and read under the pointer the *natural sine* on the ordinary scale; also under the pointer on the outer circle of the back dial read the *logarithmic sine.*

THE HALDEN CALCULEX.—After the introduction of the Boucher calculator in 1876, circular instruments, such as the Charpentier calculator, were introduced, in which a disc turned within a fixed ring, so that scales on the faces of both could be set together and ratios established as on the slide rule. Cultriss's Calculating Disc is another instrument on the same principle. The Halden Calculex, of which half-size illustrations are given in Figs. 24 and 25, represents a considerable improvement upon these early instruments. It consists of an outer metal ring carrying a fixed scale ring, within which is a dial. On each side of this dial are flat milled heads, so that by holding these between the thumb and forefinger the dial can be set quickly and conveniently. The protecting glass discs, which are not fixed in the metal ring but are arranged to turn therein, carry fine cursor lines, and as these are on the side next to the scales a very close setting can be made quite free from the effects of parallax. This construction not only avoids the use of mechanism, with its risk of derangement, but reduces the bulk of the instrument very considerably, the thickness being about $\frac{1}{4}$in.

On the front face, Fig. 24, the fixed ring carries an outer evenly-divided scale, giving logarithms, and an ordinary scale, 1—10, which works in conjunction with a similar scale on the edge of the dial. The two inner circles give the square roots of values on the main scales as in the Boucher calculator. On the back face, Fig. 25, the

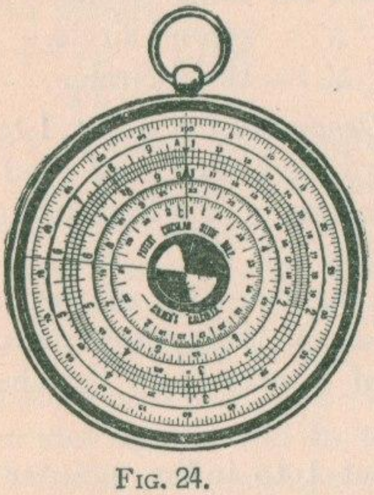


FIG. 24.

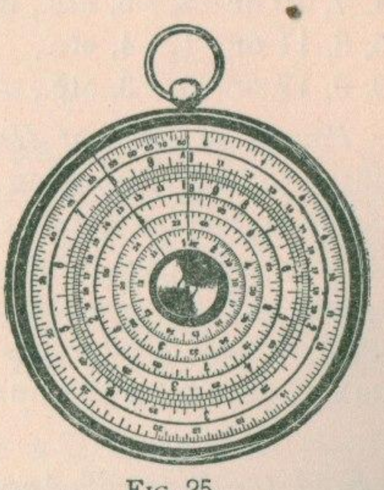
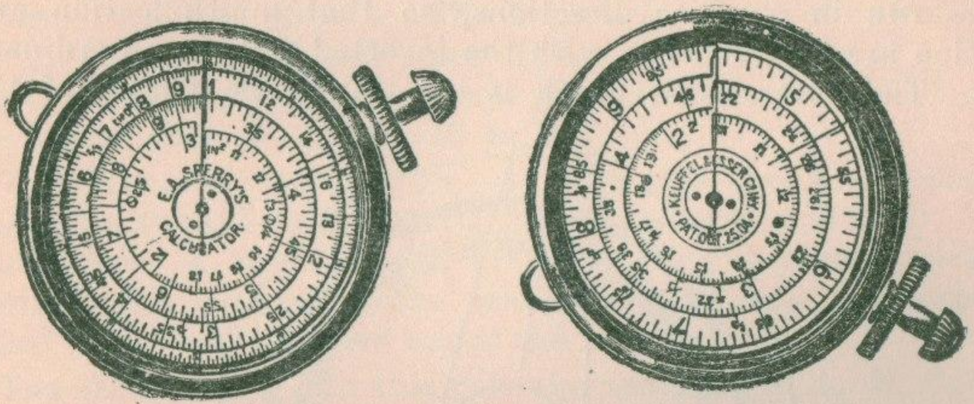


FIG. 25.

ring bears an outer scale, giving sines of angles from 6° to 90° and an ordinary scale, 1—10, as on the front face. The scales on the dial are all reversed in direction (running from right to left), the outer one consisting of an ordinary (but inverse) scale, 1—10, while the three inner circles give the cube roots of values on this inverse scale. As the fine cursor lines extend over all the scales, a variety of calculations can be effected very readily and accurately.

SPERRY'S POCKET CALCULATOR, made by the Keuffel and Esser Company, New York (Fig. 26), has two rotating dials, each with its own pointer and fixed index. The S dial has an outer scale of equal parts, an ordinary logarithmic scale, and a square-root scale. The L dial has a single logarithmic scale arranged spirally, in three sections, giving a scale length of $12\frac{1}{2}$in. The pointers are turned by the small milled head, which is concentric with the milled thumb-nut by which the two dials are rotated. The gearing is such that both the L dial and its pointer rotate three times as fast as the S dial and pointer. All the usual calculations can be made with the spiral scale, as with the Boucher calculator, and the result read off on one or other of the three scale-sections. Frequently the point at which to read the result is obvious, but otherwise a reference to the single scale on the S dial will show on which of the three spirals the result is to be found.



S. Dial. FIG. 26. L. Dial.

The K and E Calculator, also made by the Keuffel and Esser Company, is shown in Figs. 27 and 28. It has two dials, of which only one revolves. This, as shown in Fig. 27, has an ordinary

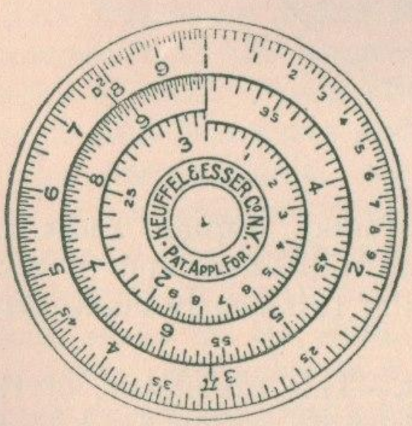


FIG. 27.

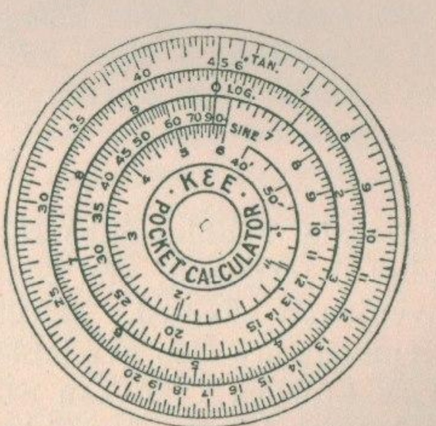


FIG. 28.

logarithmic scale and a scale of squares. There is an index line engraved on the glass of the instrument. The fixed dial has a scale of tangents, a scale of equal parts and a scale of sines, the latter being on a two-turn spiral. The pointers, which move together, are turned by a milled nut and the movable dial by a thumb-nut, as in Sperry's Calculator, Fig. 26.

THE PICOLET CIRCULAR SLIDE RULE.—A simple form of circular calculator, made by Mr. L. E. Picolet, of Philadelphia, is shown in Fig. 28A. It consists of a base disc of stout celluloid on which turns a smaller disc of thin celluloid. A cursor formed of transparent celluloid is folded over the discs, and is attached so that the friction between the cursor and the inner disc enables the latter to be turned by moving the former. By holding both discs the cursor can be adjusted as required. The adjacent scales run in opposite directions, so that multiplication and division are performed as with the inverted slide in an ordinary rule. The outer scale, which is two-thirds the length of the

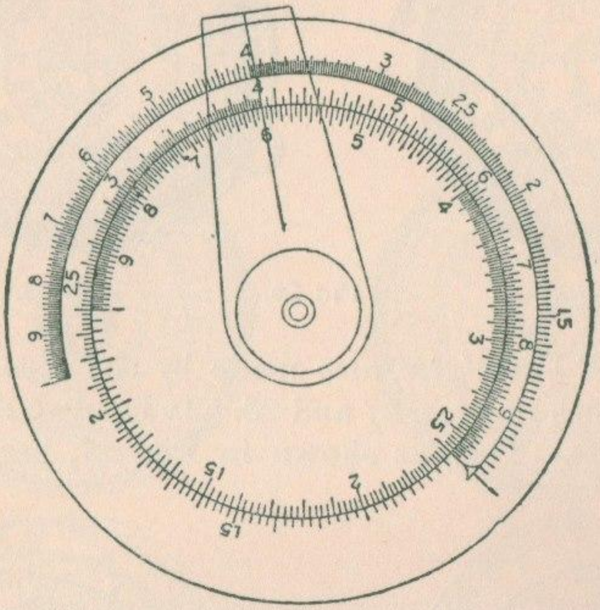


FIG. 28A.

main scale, enables cube roots to be found. Square roots are readily determined, and continuous multiplication and division conveniently effected. Modified forms of this neatly made little instrument are also available.

THE FOWLER CIRCULAR SLIDE RULE.—This calculator, of the watch type, has front and back dials turning within fixed rings. A radial cursor is also provided. In the long-scale type of calculator by the same makers there is no fixed annulus. In addition to the radial rotating cursor, however, there is a fixed radial datum line extending over all the scales. A long scale, arranged in six concentric circles, gives a total scale length of 30in. Both types have scales giving square roots, logarithms, sines and tangents of angles, etc.

SPECIAL TYPES OF SLIDE RULES.

The many special slide rules now available may be grouped roughly into (*a*) slide rules with scales arranged so as to facilitate the carrying out of calculations generally, and (*b*) slide rules designed for specific calculations. In the first group, consideration may first be given to several rules made by A. Nestler.

THE NESTLE SLIDE RULE.—The A and B scales of this rule are ordinary scales, 1 to 10. The C scale is similar but reversed in direction—*i.e.*, 10 to 1. The D scale is a scale of cubes, 1 to 1000; while above A and below D are the two parts of a 20in. scale. Thus the uppermost scale (E) runs from 1 to $\sqrt{10}$; and the lowest scale (F) from $\sqrt{10}$ to 10.

THE HANAUER SLIDE RULE.—In this case the A, B, and D scales are alike (1 to 10); the C scale is reversed (10 to 1). The scale above A runs from 1 to 100, giving squares; while a similar scale appears in the middle of the slide. A scale of cubes (1 to 1000) is placed under the D scale.

THE RIETZ RULE.—In this rule the usual scales A, B, C, and D are provided, while at the upper edge is a scale which, being three times the range of the D scale, enables cubes and cube roots to be directly evaluated and also $n^{\frac{3}{2}}$ and $n^{\frac{2}{3}}$.

A scale at the lower edge of the rule gives the mantissa of the logarithms of the numbers on D.

THE PRECISION SLIDE RULE.—In this rule the scales are so arranged that the accuracy of a 20in. rule is obtainable in a length of 10in. This is effected by dividing a 20in. (50cm.) scale length into two parts and placing these on the working edges of the rule and slide. On the upper and lower margins of the face of the rule are the two parts of what corresponds to the A scale in the ordinary rule; while in the centre of the slide is the scale of logarithms which, used in conjunction with the 50cm. scales on the slide, is virtually twice the length of that ordinarily obtainable in a 10in. rule. The same remark applies to the trigonometrical scales on the under face of the slide. Both the sine and tangent scales are in two adjacent lengths, while on the edge of the stock of the rule, below the cursor groove, is a scale of sines of small angles from 1° 49′ to 5° 44′. This is referred to the 50cm. scales by an index projection on the cursor.

If C and C′ are the two parts of the scale on the slide and D and D′ the corresponding scales on the rule, it is clear that in multiplying two factors 1 on C can only be set directly to the upper scale D ; while 10 on C′ can only be set directly to the lower scale D′. Hence if the first factor is greater than about 3·2, the cursor must be used to bring 1 on C to the first factor on D′. Similarly, in division, numerators and denominators which occur on C and D′ or on C′ and D cannot be placed in direct coincidence but must be set by the aid of the cursor.

Any uncertainty in reading the result can be avoided by observing the following rule : *If in setting the index* (1 *or* 10) *in multiplication, or in setting the numerator to the denominator in division, it is necessary to cross the slide, then it will also be necessary to cross the slide to read the product or quotient.*

THE UNIVERSAL SLIDE RULE.—In this instrument the stock carries two similar scales running from 1 to 10, to which the slide can be set. Above the upper one is the logarithm scale and under the lower one the scale of squares 1 to 100. On the edge of the stock of the rule, under the cursor groove, is a scale running from 1 to 1000. An index projecting from the cursor enables this scale to be used with the scales on the face of the rule, giving cubes, cube roots, etc.

On the slide, the lower scale is an ordinary scale, 1 to 10. The centre scale is the first part of a scale giving the values of sin n cos n, this scale being continued along the upper edge of the slide (marked "sin-cos") up to the graduation 50. On the remainder of this line is a scale running from right to left (0 to 50) and giving the value of $\cos^2 n$. In surveying, these scales greatly facilitate the calculations for the horizontal distance between the observer's station and any point, and the difference in height of these two points.

On the back of the slide are scales for the sines and tangents of angles. The values of the sines and tangents of angles from 34′ to 5° 44′ differ little from one another, and the one centre scale suffices for both functions of these small angles.

THE FIX SLIDE RULE.—This is a standard rule in all respects, except that the A scale is displaced by a distance $\frac{\pi}{4}$ so that over 1 on D is found 0·7854 on A. This enables calculations relating to the area and cubic contents of cylinders to be determined very readily.

THE "PLUTOCRAT" SLIDE RULE.—In addition to the usual scales, this rule is provided with a scale of cubes (F) placed above the A scale, while under the D scale is an evenly divided scale (E) giving the logarithms of numbers on D.

THE "MONOCRAT" SLIDE RULE.—Seven scales appear on the face of this rule. These comprise the usual A, B, C, and D scales; a scale of sines above the A scale; a scale of tangents running along the middle of the slide; and an evenly divided or logarithm scale under the D scale.

THE "DAFIELD" SLIDE RULE is identical with the "Monocrat" with the addition of a split unit scale contiguous to the evenly divided logarithm scale. This enables the latter scale to be used as a decimal equivalent scale for subdivisions of any desired standard unit. In this rule the split-unit scale is divided into 20 equal parts representing shillings, each main division being subdivided into pence and halfpence. Hence above any value in shillings and pence is found the equivalent decimal of a pound. The reverse process is equally simple. Further, by using the shilling and threepenny graduations, cwts. and qrs. can be converted into decimals of a ton.

THE COMMERCE RULE.—In this rule the split-unit scale and its adjacent logarithm or decimal scale are placed in the middle of the slide, which in this case is rather wider than usual. There are some advantages in this arrangement when, as in this case, the rule is specially intended for commercial calculations. The remaining scales are the usual A, B, C, and D scales.

These four rules are made by Messrs. John Davis and Son Ltd.

THE POLYPHASE SLIDE RULE, made by the Keuffel and Esser Company, has, in addition to the usual scales, a scale of cubes on the face of the rule below the D scale, while in the centre of the slide is a reversed C scale (10 to 1).

THE POLYPHASE DUPLEX RULE, by the same makers, has a greatly extended range. It will be understood that a duplex rule comprises two side strips securely clamped at the ends to form the body of the rule, the slide moving within the space between the side strips. Both the front and back faces of the rule and slide are therefore available, graduations on one side being referred to those on the other by the cursor which extends around the whole. On the front face the C and D are normal. The upper pair of scales are similar, but are so displaced or "folded" that π is in alignment with the indexes of

C and D. A folded scale of the same kind, but reversed in direction, runs along the centre of the slide. On the back of the rule scales A, B, and D are normal, while C is reversed in direction. Above A is a scale of cubes, and below D an evenly divided logarithm scale. The sine and tangent scales are placed in the middle of the slide. The LOG-LOG DUPLEX rule is referred to on page 92.

THE BAUR SLIDE RULE.—In this rule the usual 25cm. measuring scale on the bevelled edge of the stock is utilised for determining powers and roots. Three sets of numerals appear on this scale: 0 to 25; 25 to 50; and 50 to 75, these representing, in effect, repetitions of the original scale. A tongue projecting from the cursor frame enables readings on the cm. scale to be referred to those on face of the rule. To find, for example, $\sqrt[3]{3{\cdot}5}$ the cursor is set to 3·5 on the L.H. A scale, when the reading under the tongue of the cursor will be 6·8. Dividing by 3 we obtain 2·27, and setting the tongue to this value find 1·52, on the A scale, as the root required. For two-place numbers—*i.e.*, between 10 and 100—the R.H. A scale is used. For three- and four-place numbers the left- and right-hand A scales respectively are used, and the readings taken on the second row of figures on the cm. scale (25 to 50); while for five- and six-place numbers, readings are taken on the third row. The D scale can be used in place of the A scale if obvious modifications are made in the readings of the cm. scale.

THE ANIDO SLIDE RULE.—In this rule an evenly-divided scale above the A scale, reading from left to right, and another below the D scale, reading from right to left, give the logarithms of numbers on the D scale. For numbers greater than unity, the upper scale is used, the lower scale serving for numbers less than unity. The negative values in the latter case can thus be multiplied or divided directly—*i.e.*, without converting the decimal part into a positive quantity.

THE MULTIPLEX SLIDE RULE differs from the ordinary form of rule in the arrangement of the B scale. The right-hand section of this scale runs from left to right as ordinarily arranged, but the left-hand section runs in the reverse direction, and so furnishes a reciprocal scale. At the bottom of the groove, under the slide, there is a scale running from 1 to 1000, which is used in conjunction with the D scale readings being referred thereto by a metal index on the end of the slide. By this means cubes, cube roots, etc., can be read off directly.

THE BEGHIN SLIDE RULE.—We have seen that a disadvantage attending the use of the ordinary C and D scales, is that it is occasionally necessary to traverse the slide through its own length in order to change the indices or to bring other parts of the slide into a readable position with regard to the stock. To obviate this disadvantage, Tserepachinsky devised an ingenious arrangement which has since been used in various rules, notably in the Beghin slide rule made by Messrs. Tavernier-Gravêt of Paris. In this rule the C and D scales are used as in the standard rule, but in place of the A and B scales, we have another pair of C and D scales, displaced by one half the length of the rule. The lower pair of scales may therefore be regarded as running from 10^n to 10^{n+1}, and the upper pair as running from $\sqrt{10} \times 10^n$ to $\sqrt{10} \times 10^{n+1}$. With this arrangement, *without moving the slide more than half its length*, to the left or right, it is always possible to compare *all values between* 1 *and* 10 *on the two scales.* This is a great advantage especially in continuous working.

Another commendable feature of the Beghin rule is the presence of a reversed C scale in the centre of the slide, thus enabling such calculations as $a \times b \times c$ to be made with one setting of the slide. On the back of the slide are three scales, the lowest of which, used with the D scale, is a scale of squares (corresponding to the ordinary B scale), while on the upper edge is a scale of sines from 5° 44′ to 90°, and in the centre, a scale of tangents from 5° 43′ to 45°. On the square edge of the stock, under the cursor groove, is the logarithm scale, while on the same edge, above the cursor groove, are a series of gauge points. All these values are referred to the face scales by index marks on the cursor.

THE "LONG" SLIDE RULE has one scale in two sections along the upper and lower parts of the stock, as in the "Precision" rule. The scale on the slide is similarly divided, but the graduations run in the reverse direction, corresponding to an inverted slide. Hence the rules for multiplication and division are the reverse of those usually followed (page 30). On the back of the slide is a single scale 1—10, and a scale 1—1000, giving cubes of this single scale. By using the first in conjunction with the scales on the stock, squares may be read, while in conjunction with the cube scale, various expressions involving squares, cubes and their roots may be evaluated.

SLIDE RULES FOR SPECIFIC CALCULATIONS.

Engine Power Computer.—A typical example of special slide rules is shown in Fig. 29, which represents, on a scale of about half full size, the author's Power Computer for Steam, Gas, and Oil Engines. This, as will be seen, consists of a stock, on the lower portion of which is a scale of cylinder diameters, while the upper portion carries a scale of horse-powers. In the groove between these scales are two slides, also carrying scales, and capable of sliding in edge contact with the stock and with each other.

This instrument gives directly the brake horse-power of any steam, gas, or oil engine ; the indicated horse-power, the dimensions of an engine to develop a given power, and the mechanical efficiency of an engine. The calculation of piston speed, velocity ratios of

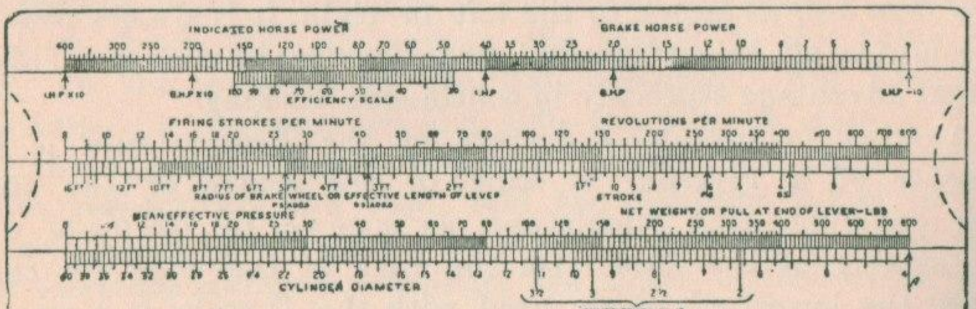


Fig. 29.

pulleys and gear wheels, the circumferential speed of pulleys, and the velocity of belts and ropes driven thereby, are among the other principal purposes for which the computer may be employed.

The Smith-Davis Piecework Balance Calculator has two scales, 11 feet long, having a range from 1d. to £20, and marked so that they can be used either for money or time calculations. The scales are placed on the rims of two similar wheels and so arranged that the divided edges come together. The wheels are mounted on a spindle carried at each end in the bearings of a supporting stand. The wheels are pressed together by a spring, and move as one.

To set the scales one to the other, a treadle gear is arranged to take the pressure of the spring so that when the fixed wheel is held by the left hand the free wheel can be rotated by the right hand in either direction. When the amount of the balance has been set to the combined weekly wage the treadle is released locking the two wheels together, when the whole can be turned and the amounts respectively due to each man read off opposite his weekly wage. The Smith-Davis Premium Calculator is on the same principle, but the scales are about 4ft. 6in. long, and the wheels spring-controlled. Both instruments are supplied by Messrs. John Davis & Son, Ltd., Derby.

ELECTRICAL SLIDE RULE.—Another rule by the same makers, specially useful for electrical engineers, has the usual scales on the working edges of the rule and slide, while in the middle of the slide is placed a scale of cubes. A log-log scale in two sections is provided; the power portion, running from 1·07 to 2, is found on the lower part of the stock, and the upper portion, running from 2 to 10^3, on the upper part of the stock. The uppermost scale on the stock is in two parts, of which that to the left, running from 20 to 100 and marked "Dynamo," gives the efficiencies of dynamos; that on the right, running from 20 to 100, and marked "Motor," gives the efficiencies of electric motors. The lowest scale on the stock, marked "volt," gives the loss of potential in copper conductors. The ordinary upper scale on the stock is marked L (length of lead) at the left, and KW (kilowatts) at the right; the ordinary upper scale on the slide is marked A (amperes) and mm^2 (sectional area) at the left, and HP (horse-power) at the right. Additional lines on the cursor enable the electrical calculations to be made either in British or metric units.

THE DAVIS-STOKES FIELD GUNNERY SLIDE RULE.—This rule, which is adapted for calculations involved in "encounter" and "entrenched" field gunnery, is designed for the 18 pr. quick-firing gun. The upper and lower portions of the boxwood stock are united by a flexible centre of celluloid, thus providing grooves front and rear to receive boxwood slides. Each of the nineteen scales is marked with its name, and corresponding scales are coloured red or black. The front edge is bevelled and carries a scale of 1 in 20,000. The rule solves displacement problems, map angles of sight, changes of corrector, and range corrections for changes in temperature, wind and barometer, etc. A special feature for displacement calculations is the provision of a 50-yd. sub-base angle scale, by which the apex angle is read at one setting.

THE DAVIS-MARTIN WIRELESS SLIDE RULE.—In wireless telegraphy it is frequently necessary to determine wave-length, capacity, or self-induction when one or other of the factors of the equation, $\lambda = 59{\cdot}6 \sqrt{LC}$., is unknown. The Davis-Martin wireless rule is designed to simplify such calculations. The upper scale in the stock (inductance) runs from 10,000 to 1,000,000; the adjacent scale on the slide (capacity) runs from 0·0001 to 0·01, but in the reverse direction. The lower scale on the stock (wave-length) runs from 100 to 1000, giving square roots of the upper scale; while on the lower edge of the scale are several arrows to suit the various denominations in which the wage-length and capacity may be expressed.

Farmar's Profit-calculating Rule.—The application of the slide rule to commercial calculations has been often attempted, but the degree of accuracy required necessitates the use of a long scale, and generally this results in a cumbersome instrument. In Farmar's Profit-calculating Rule the money scale is arranged in ten sections, these being mounted in parallel form on a roller which takes the place of the upper scale of an ordinary rule. The roller, which is ¾-in. in diameter, is carried in brackets secured to each end of the stock, so that by rotating the roller any section of the money scale can be brought into reading with the scale on the upper edge of the slide and with which the roller is in contact. This scale gives percentages, and enables calculations to be made showing profit on turnover, profit on cost, and discount. The lower scale on the slide, and that on the stock adjacent to it, are similar to the A and B scales of an ordinary rule. The instrument is supplied by Messrs. J. Casartelli & Son, Manchester.

The McLeod Field Artillery Slide Rule.—This rule is specially designed for the ready solution of the T O B triangle, battery angle of sight, height and distance, bearing and distance, and similar field-artillery problems. Use is made of two log. sin. scales which slide together, thus simplifying the solution of those triangles of which only two sides and the included angle are known.

The T O G Slide Rule.—This rule has four scales, of which B and C (on the slide) are identical and of the ordinary logarithmic form. The A scale has two sets of graduations, one in black, representing the T O G angle; the other in red, used for solving angles of sight, etc. The D scale is graduated in degrees, representing the T G O angle. The rule enables the T O G triangle to be solved from given data by one setting of the slide. Both this rule and the McLeod rule are supplied by Messrs. J. H. Steward Limited, London.

THE "ELECTRO" SLIDE RULE.—This Nestler rule for electrical calculations has the A, B, C, and D scales arranged as in the standard rule, but the A scale is designated "P.S.," and the B scale "K.W." Above the A scale is a similar scale V, but displaced so that 1·73 on this agrees with 1 on A. Under the D scale is another similar scale displaced to enable the calculation of circumferential speeds to be made with one setting of the slide. On the lower or square edge of the stock are a scale of cubes and a log-log scale, these being read by index lines in a tongue projecting from the metal rim of the cursor. The rule is particularly adapted for calculating resistances and fall of potential in electrical conductors, and is of service in many other electrical calculations.

THE COMMERCIAL SLIDE RULE.—In this rule (by Nestler) the A, B, and D scales are alike (1 to 10). The C scale is intended for calculating percentages, interest, and discounts. It includes the interest division for all rates in steps of $\frac{1}{16}$%. Along the centre of the slide is a scale of reciprocals (10 to 1), and another scale giving the reciprocal values of different money, weight, and measure systems in relation to the mark, metre, and kilogram as units. On the reverse side of the slide is a scale of pounds sterling, with equivalents in shillings and pence in adjacent scales. These scales are read against an index mark in the recess at the right-hand end of the stock of the rule.

OTHER NESTLER SLIDE RULES include a rule for facilitating calculations in reinforced concrete construction; and one of special service for the calculations met with in the timber trade.

THE ROYLANCE ELECTRICAL SLIDE RULE.—This rule, by the Keuffel and Esser Company, has the usual A, B, C, and D scales, with a reversed C scale along the middle of the slide. It also carries a series of gauge marks, by means of which the different properties of copper wire may be determined without the use of tables. Various electrical calculations can be readily carried out by the aid of this instrument.

Other special rules by the same makers include the Merchants' Slide Rule; the Surveyors' Slide Rule; the Allan Friction Head Slide Rule; the Chemists' Slide Rule; a Stadio Slide Rule; Crane's Sewer Slide Rule, etc.

CONSTRUCTIONAL IMPROVEMENTS IN SLIDE RULES.

THE attention of instrument makers is now being given to the devising of means for ensuring the smooth and even working of the slide in the stock of the rule. In some cases very good results are obtained by slitting the back of the stock to give more elasticity.

In the rules made by Messrs. John Davis and Son, a metal strip, slightly curved in cross section as shown at **A** (Fig. 30), runs for the full length of the stock to which it is fastened at intervals. Near each end of the rule, openings about 1in. long are made in the metal backing through which the scales on the back of the slide can be read. To prevent warping under varying climatic conditions, both the stock of the rule and the slide

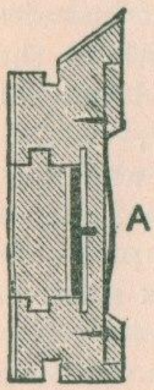


FIG. 30.

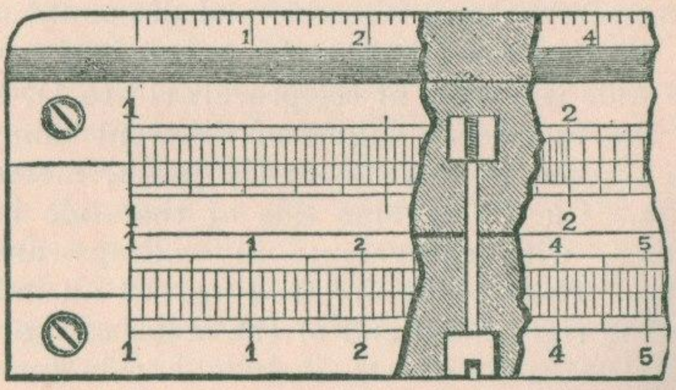


FIG. 31.

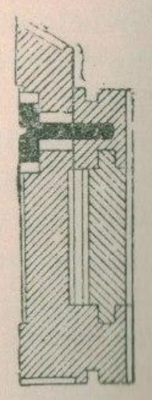


FIG. 32.

are of composite construction. The base of the stock is of mahogany, while the grooved sides, firmly secured to the base, are of boxwood. Similarly the centre portion of the slide is of mahogany, and the tongued sides of boxwood. Celluloid also enters into the construction, a strip of this material being laid along the bottom of the groove in the stock. A fine groove runs along the centre of this strip in order to give elasticity and to allow the sides of the stock to be pressed together slightly to adjust the fitting of the slide. As a further means of adjustment, the makers fit metal clips at each end of the rule, so that by tightening two small screws the stock can be closed on the slide when necessary.

In the "GLIDER" SLIDE RULE, by the same makers, a narrow slot runs along the middle of the slide to within a $\frac{1}{4}$in. of each end. Fixed in this slot is a narrow waved band of spring steel which presses apart the two sides of the slide, so that when withdrawn it assumes a slightly bowed form. The pressure thus provided ensures an exceptionally smooth movement of the slide throughout its entire path.

Fig. 31 shows a method of adjustment sometimes employed.

In the rule made by the Keuffel and Esser Company of New York, one strip is made adjustable (Fig. 32).

SMALL SLIDE RULES WITH MAGNIFYING CURSORS.—Several makers now supply 5-in. rules having the full graduations of a 10-in. rule, and fitted with a magnifying cursor (Fig. 33). This forms a compact instrument for the pocket, but owing to the closeness of the graduations it is not usually possible to make a setting of the slide without using the cursor. This, of course,

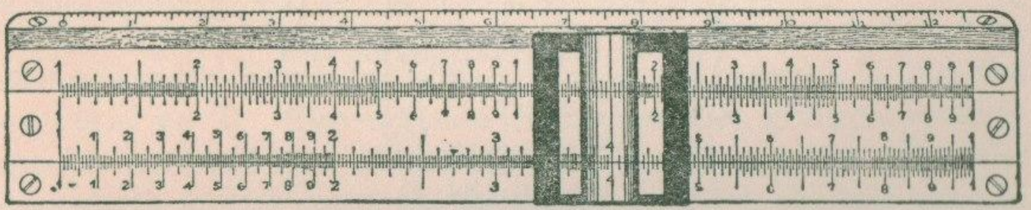


FIG. 33.

involves more movements than with the ordinary instrument. It is also very necessary to use the magnifying cursor in a *direct* light, if accurate readings are to be obtained. If these slight inconveniences are to be tolerated, the principle could be extended, a 10-in. rule being marked as fully as a 20-in., and fitted with a magnifying cursor. The author has endeavoured, but without success, to induce makers to introduce such a rule.

The magnifying cursor, supplied by Messrs. A. G. Thornton, Limited, has a lens which fills the entire cursor. It has a powerful magnifying effect, and the change from the natural to the magnified reading is less abrupt than with the semi-circular lens.

In one form of 10-in. rule, supplied by Mr. W. H. Harling, London, the body of the rule is made of well-seasoned cane, with the usual celluloid facings. The rule has a metal back, enabling the fit of the slide to be regulated. This backing extends the full length of the rule, openings about 1 in. long being provided at each end, enabling the scales on the back of the slide to be set with greater facility than is possible with the notched recesses usually provided.

IMPROVED CURSORS.—In some slide-rule operations, notably in those involved in solving quadratic and cubic equations, it not infrequently happens that readings are obscured by the frame of the cursor. Frameless cursors have been introduced to obviate this defect. A piece of thick transparent celluloid is sometimes employed, but this is liable to become scratched in use. Fig. 34 shows a recent form of frameless glass cursor made by the Keuffel and Esser Company, Hoboken, N.J., which is satisfactory in every way.

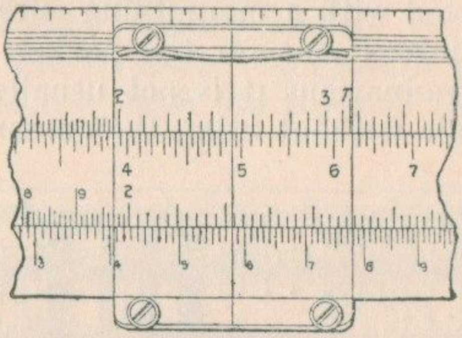


FIG. 34.

Cursors having three hair lines are now fitted to some rules, the distance apart of the lines being equal to the interval 0·7854 − 1 on the A scale.

THE ACCURACY OF SLIDE RULE RESULTS

THE degree of accuracy obtainable with the slide rule depends primarily upon the length of the scale employed, but the accuracy of the graduations, the eyesight of the operator, and, in particular, his ability to estimate interpolated values, are all factors which affect the result. Using the lower scales and working carefully, the error should not greatly exceed 0·15 per cent. with short calculations. With successive settings, the discrepancy need not necessarily be greater, as the errors may be neutralised; but with rapid working the percentage error may be doubled. However, much depends upon the graduation of the scales. Rules in which one or more of the indices have been thickened to conceal some slight inaccuracy should be avoided. The line on the cursor should be sharp and fine, and both slide and cursor should move smoothly or good work cannot be done. Occasionally a little vaseline or clean tallow should be applied to the edges of the slide and cursor.

That the percentage error is constant throughout the scale is seen by setting 1 on C to 1·01 on D, when under 2 is 2·02 ; under 3, 3·03 ; under 5, 5·05, etc., the several readings showing a uniform error of 1 per cent.

A method of obtaining a closer reading of a first setting or of a result on D has been suggested to the author by Mr. M. Ainslie, B.Sc. If any graduation, as 4 on C, is set to 3 on D, it is seen that 4 main divisions on C (40-44) are equal in scale length to 3 main divisions on D (30-33). Hence, very approximately, 1 division on C is equal to 0·75 of a division on D, this ratio being shown, of course, on D under 10 on C. Suppose $\sqrt{4{\cdot}3}$ to be required. Setting the cursor to 4·3 on A, it is seen that the root is something more than 2·06. Move the slide until a main division is found on C, which exactly corresponds to the interval between 2 and the cursor line, on D. The division 27-28 just fits, giving a reading under 10 on C, of 74. Hence the root is read as 2·074. For the higher parts of the scale, the subdivisions, 1-1·1, etc., are used in place of main divisions. The method is probably more interesting than useful, since in most operations the inaccuracies introduced in making settings will impose a limit on the reliable figures of the result.

For the majority of engineering calculations, the slide rule will give an accuracy consistent with the accuracy of the data usually available. For some purposes, however, *logarithmic section paper* (the use of which the author has advocated for the last twenty years) will be found especially useful, more particularly in calculations involving exponential formulæ.

THE SOLUTION OF ALGEBRAIC EQUATIONS.

THE slide rule finds an interesting application in the solution of equations of the second and third degree; and although the process is essentially one of trial and error, it may often serve as an efficient substitute for the more laborious algebraic methods, particularly when the conditions of the problem or the operator's knowledge of the theory of equations enables some idea to be obtained as to the character of the result sought. The principle may be thus briefly explained :—If 1 on C is set to x on D (Fig. 35), we find $x(x) = x^2$ on D under x on C. If, however, with the slide set as before, instead of reading under x, we read under $x + m$ on C, the result on D will now be $x(x + m) = x^2 + mx = q$. Hence to solve the equation $x^2 + mx - q = 0$, we reverse the

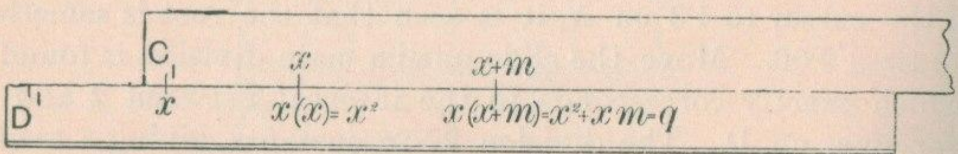


FIG. 35.

above process, and setting the cursor to q on D, we move the slide until the number on C under the cursor, and that on D under 1 on C, *differ by m.* It is obvious from the setting that the *product* of these numbers $= q$, and as their difference $= m$, they are seen to be the roots of the equation as required. For the equation $x^2 - mx + q = 0$, we require m to equal the *sum* of the roots. Hence, setting the cursor as before to q on D, we move the slide until the number on C under the cursor, and that on D under 1 on C, are *together equal to m*, these numbers being the roots sought. The alternative equations $x^2 - mx - q = 0$, and $x^2 + mx + q = 0$ are deducible from the others by changing the signs of the roots, and need not be further considered.

Ex.—Find the roots of $x^2 - 8x + 9 = 0$.

Set the cursor to 9 on D, and move the slide to the right until when 6·64 is found under the cursor, 1·355 on D is under 1 on C. These numbers are the roots required.

The upper scales can of course be used; indeed, in general they are to be preferred.

Ex.—Find the roots of $x^2 + 12{\cdot}8x + 39{\cdot}4 = 0$.

Set the cursor to 39·4 on A, and move the slide to the right until we read 7·65 on B under the cursor, and 5·15 on A over 1 on B. The roots are therefore $-$ 7·65 and $-$ 5·15.

With a little consideration of the relative value of the upper and lower scales, the student interested will readily perceive how equations of the third degree may be similarly resolved. The subject is not of sufficient general importance to warrant a detailed examination being made of the several expressions which can be dealt with in the manner suggested; but the author gives the following example as affording some indication of the adaptability of the method to practical calculations.

Ex.—A hollow copper ball, 7·5in. in diameter and 2lb. in weight, floats in water. To what depth will it sink?

The water displaced $= 27 \cdot 7 \times 2 = 55 \cdot 4$ cub. in. The cubic contents of the immersed segment will be $\frac{\pi}{3}(3rx^2 - x^3)$, r being the radius and x the depth of immersion. Hence $\frac{\pi}{3}(3rx^2 - x^3) = 55 \cdot 4$, and $11 \cdot 25\,x^2 - x^3 = 52 \cdot 9$.

To solve this equation we place the cursor to 52·9 on A, and move the slide until the reading on D under 1 and that on B under the cursor together amount to 11·25. In this way find 2·45 on D under 1, with 8·8 on B under the cursor c, c, as a pair of values of which the sum is 11·25. Hence we conclude that $x = 2 \cdot 45$in. is the result sought.

With the rule thus set (Fig. 36) the student will note that the slide is displaced to the right by an amount which represents x on D, and therefore x^2 on A; while the length on B from 1 to the

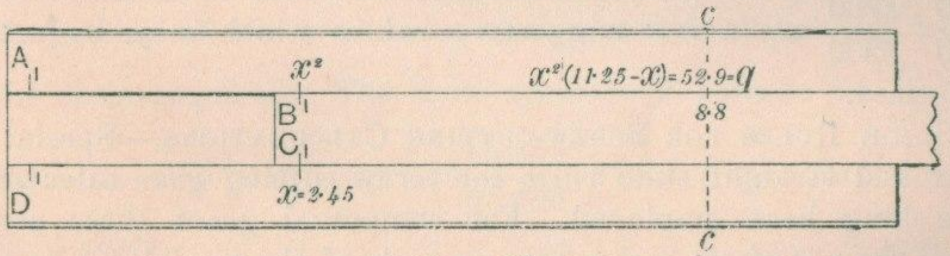


FIG. 36.

cursor line represents $11 \cdot 25 - x$. Hence the upper scale setting gives $x^2(11 \cdot 25 - x) = 11 \cdot 25x^2 - x^3 = 52 \cdot 9$ as required.

When in doubt as to the method to be pursued in any given case, the student should work synthetically, building up a simple example of an analogous character to that under consideration, and so deducing the plan to be followed in the reverse process.

SCREW-CUTTING GEAR CALCULATIONS.

THE slide rule has long found a useful application in connection with the gear calculations necessary in screw-cutting, helical gear-cutting, and spiral gear work.

SINGLE GEARS.—For simple cases of screw-cutting in the lathe it is only necessary to set the threads per inch to be cut to the threads per inch in the guide screw (or the pitch in inches in each case, if more convenient). Then any pair of coinciding values on the two scales will give possible pairs of wheels.

Ex.—Find wheels to cut a screw of $1\frac{5}{8}$ threads per inch with a guide screw of 2 threads per inch.

Setting 1·625 on C to 2 on D, it is seen that 80 (driver) and 65 (driven) are possible wheels.

COMPOUND GEARS.—When wheels so found are of inconvenient size, a compound train is used, consisting (usually) of two drivers and two driven wheels, the product of the two former and the product of the two latter being in the same ratio as the simple wheels. Thus with 60 and 40 as drivers, and 65 and 30 as driven, we have, $\frac{60 \times 40}{65 \times 30} = \frac{2400}{1950} = \frac{2}{1{\cdot}625}$ as before.

With the slide set as above, values convenient for splitting up into suitable wheels are readily obtainable. Thus, $\frac{1600}{1300}$; $\frac{2400}{1950}$; $\frac{4000}{3250}$; $\frac{4800}{3900}$ are a few suggestive values which may be readily factorised.

SLIDE RULES FOR SCREW-CUTTING CALCULATIONS.—Special circular and straight slide rules for screw-cutting gear calculations have long been employed. For compound gears these usually entail the use of six scales, two on each of the two slides and two on the stock. The upper scale on the stock may be a scale of threads per inch to be cut, the adjacent scale (on the upper slide) a scale of threads per inch in the guide screw. Setting the guide screw-graduation to the threads to be cut, the lower slide is adjusted until a convenient pair of drivers is found in coincidence on the central pair of scales, while a pair of driven wheels are in coincidence on the two lower scales.

Some years ago, a slide rule was introduced by which compound gears could be obtained with a single slide. Assuming the set of wheels usually provided – 20 to 120 teeth advancing by 5 teeth – the products of 20×25, 20×30, etc., up to 115×120 were calculated. These products were laid out along each of the two lower scales. The upper scales were a scale of threads per inch to be cut and a scale of the threads per inch of various guide screws. Setting the guide screw-graduation to the threads to be cut, any coinciding graduations on the lower scales gave the required pairs of drivers and driven wheels.

FRACTIONAL PITCH CALCULATIONS.—The author has long advocated the use of the slide rule for determining the wheels necessary for cutting fractional pitch threads, and it is gratifying to find its value in this connection is now being appreciated. For the best results a good 20-in. rule is desirable, but with care very close approximations can be found with an accurate 10-in. rule. In any case a magnifying cursor or a hand reading-glass is of great assistance.

Ex.—Find wheels to cut a thread of 0·70909-in. pitch; guide screw, 2 threads per inch.

To 0·70909 on D, set 0·5 (guide screw pitch in inches) on C. To make this setting as accurately as possible, the method described on page 112 may be used. Set 10 on C to about 91 on D, and note that the interval 77-78 on C represents 0·91 of the interval 70-71 on D. Set the cursor to 78 on C and bring 5 to the cursor. The slide is then set so that 5 on C agrees with 7·091 on D.

Inspection of the two scales shows various coinciding factors in the ratio required. The most accurate is seen to be $\frac{55 \text{ on C}}{78 \text{ on D}}$.

These values may be split up into $\frac{55\times50}{65\times60}$ to form a suitable compound train of gears.

GAUGE POINTS AND SIGNS ON SLIDE RULES.

MANY slide rules have the sign $\frac{\text{Prod.}}{-1}$ at the right-hand end of the D scale, while on the left is $\frac{\text{Quot.}}{+1}$. It is somewhat unfortunate that these signs refer to rules for determining the number of digits in products and quotients, which are used to a considerable extent on the Continent, and conflict with those used in this country. By the Continental method the number of digits in a product is equal to the sum of the digits in the two factors, if the result is obtained on the LEFT *of the first factor;* but if the result is found on the RIGHT of the first factor, it is equal to this sum -1. The sign $\frac{\text{Prod.}}{-1}$ at the *right*-hand end of the D scale provides a visible reminder of this rule.

Similarly for division :—The number of digits in a quotient is equal to the number of the digits in the dividend, minus those in the divisor, if the quotient appears on the RIGHT *of the dividend*, and to this difference $+1$, if the quotient appears on the LEFT of the dividend. The sign $\frac{\text{Quot.}}{+1}$ at the *left*-hand end of the D scale provides a visible reminder of this rule.

The sign $\overset{+\,|\,-}{\longleftarrow\!|\!\longrightarrow}_{-\,|\,+}$ found at both ends of the A scale is of general application but of questionable utility. It is assumed to represent a fraction, the vertical line indicating the position of the decimal point. If the number 455 is to be dealt with in a multiplication on the lower scales, we may suppose the decimal point moved two places to the left, giving 4·55, a value which can be actually found on the scale. If we use this value, then to the number of digits in this result, as many must be added as the number of places (two in this case) by which the decimal point was moved. If the point is moved to the right, the number of places must be subtracted. Similarly, in division, if the decimal point in the divisor is moved *n* places to the left, then *n* places must be subtracted at the end of the operation; while if the point is moved through *n* places to the right, then *n* places must be added. The sign referred to, which, of course, applies to all scales, completely indicates these processes and is submitted as a reminder of the procedure to be followed by those using the method described.

The signs π, c, c', and M are explained in the Section on "Gauge Points," p. 53.

On some rules additional signs are found on the D scale. One, locating the value $\frac{180 \times 60}{\pi} = 3437 \cdot 74$ and hence giving the number of minutes in a radian, is marked ϱ'. Another, representing the value $\frac{180 \times 60 \times 60}{\pi} = 206265$, and hence giving the number of seconds in a radian is marked ϱ''. A third point, marked $\varrho_{''}$ placed at the value $\frac{200 \times 100 \times 100}{\pi} = 636620$, is used when the newer graduation of the circle is employed.

These gauge points are useful when converting angles into circular measure, or *vice versa*, and also for determining the functions of small angles.

A gauge point is sometimes marked at 1146 on the A and B scales. This is known as the "Gunner's Mark," and is used in artillery calculations involving angles of less than 20°, when, for the purpose in view, the tangent and circular measure of the angle may be regarded as equal. For this constant, the angle is taken in minutes, the auxiliary base in feet, and the base in yards. The auxiliary base in feet on B is set to the angle in minutes on A when over 1146 on B is the base in yards on A. The value $\frac{1}{1146} = \frac{\pi \times 3}{180 \times 60}$.

TABLES AND DATA.

MENSURATION FORMULAE.

Area of a parallelogram = base × height.

Area of rhombus = $\frac{1}{2}$ product of the diagonals.

Area of a triangle = $\frac{1}{2}$ base × perpendicular height.

Area of equilateral triangle = square of side × 0·433.

Area of trapezium = $\frac{1}{2}$ sum of two parallel sides × height.

Area of any right-lined figure of four or more unequal sides is found by dividing it into triangles, finding area of each and adding together.

Area of regular polygon = (1) length of one side × number of sides × radius of inscribed circle; or (2) the sum of the triangular areas into which the figures may be divided.

Circumference of a circle = diameter × 3·1416.

Circumference of circle circumscribing a square = side × 4·443.

Circumference of circle = side of equal square × 3·545.

Length of arc of circle = radius × degrees in arc × 0·01745.

Area of a circle = square of diameter × 0·7854.

Area of sector of a circle = length of arc × $\frac{1}{2}$ radius.

Area of segment of a circle = area of sector − area of triangle.

Side of square of area equal to a circle = diameter × 0·8862.

Diameter of circle equal in area to square = side of square × 1·1284.

Side of square inscribed in circle = diameter of circle × 0·707.

Diameter of circle circumscribing a square = side of square × 1·414.

Area of square = area of inscribed circle × 1·2732.

Area of circle circumscribing square = square of side × 1·5708.

Area of square = area of circumscribing circle × 0·6366.

Area of a parabola = base × $\frac{2}{3}$ height.

Area of an ellipse = major axis × minor axis × 0·7854.

Surface of prism or cylinder = (area of two ends) + (length × perimeter).

Volume of prism or cylinder = area of base × height.

Surface of pyramid or cone = $\frac{1}{2}$(slant height × perimeter of base) + area of base.

Volume of pyramid or cone = $\frac{1}{3}$(area of base × perpendicular height).

Surface of sphere = square of diameter × 3·1416.

Volume of sphere = cube of diameter × 0·5236.

Volume of hexagonal prism = square of side × 2·598 × height.

Volume of paraboloid = $\frac{1}{2}$ volume of circumscribing cylinder.

Volume of ring (circular section) = mean diameter of ring × 2·47 × square of diameter of section.

SPECIFIC GRAVITY AND WEIGHT OF MATERIALS.

Metals.

Metal.	Specific Gravity.	Weight of 1 Cub. Ft (Lb.).	Weight of 1 Cub. In. (Lb.).
Aluminium, Cast	2·56	160	0·0927
Aluminium, Bronze	7·68	475	0·275
Antimony	6·71	418	0·242
Bismuth	9·90	617	0·357
Brass, Cast	8·10	505	0·293
,, Wire	8·548	533	0·309
Copper, Sheet	8·805	549	0·318
,, Wire	8·880	554	0·321
Gold	19·245	1200	0·695
Gun-metal	8·56	534	0·310
Iron, Wrought (mean)	7·698	480	0·278
,, Cast (mean)	7·217	450	0·261
Lead, Milled Sheet	11·418	712	0·412
Manganese	8·012	499	0·289
Mercury	13·596	849	0·491
Nickel, Cast	8·28	516	0·300
Phosphor Bronze, Cast	8·60	536·8	0·310
Platinum	21·522	1342	0·778
Silver	10·505	655	0·380
Steel (mean)	7·852	489·6	0·283
Tin	7·409	462	0·268
Zinc, Sheet	7·20	449	0·260
,, Cast	6·86	428	0·248

Miscellaneous Substances.

Substance.	Specific Gravity.	Weight of 1 Cub. In. (Lb.).	Substance.	Specific Gravity.	Weight of 1 Cub. In. (Lb.).
Asbestos	2·1-2·80	·076-·101	Sand-stone	2·3	·083
Brick	1·90	·069	Slate	2·8	·102
Cement	2·72-3·05	·0984-·109	Wood—		
Clay	2·0	·072	Beech	0·75	·0271
Coal	1·37	·0495	Cork	0·24	·0087
Coke	0·5	·0181	Elm	0·58	·021
Concrete	2·0	·072	Fir	0·56	·0203
Fire-brick	2·30	·083	Oak	·62-·85	·025-·031
Granite	2·5-2·75	·051-·100	Pine	0·47	·017
Graphite	1·8-2·35	·065-·085	Teak	0·80	·029

ULTIMATE STRENGTH OF MATERIALS.

Material.	Tension in lb. per sq. in.	Compression in lb. per sq. in.	Shearing in lb per sq. in.	Modulus of Elasticity in lb. per sq. in.
Cast Iron - -	11,000 to 30,000	50,000 to 130,000	...	14,000,000 to 23,000,000
,, aver.	16,000	95,000	11,000	...
Wrought Iron -	40,000 to 70,000	...	...	26,000,000 to 31,000,000
,, aver.	50,000	50,000	40,000	...
Soft Steel - -	60,000 to 100,000	...	...	30,000,000 to 36,000,000
Soft Steel - aver.	80,000	70,000	55,000	...
Cast Steel - aver.	120,000	...	...	15,000,000 to 17,000,000
Copper, Cast - -	19,000	58,000	...	...
,, Wrought -	34,000	...	...	16,000,000
Brass, Cast - -	18,000	10,500	...	9,170,000
Gun Metal - -	34,000	...	...	11,500,000
Phosphor Bronze -	58,000	...	43,000	13,500,000
Wood, Ash - -	17,000	9,300	1,400	...
,, Beech- -	16,000	8,500	...	...
,, Pine - -	11,000	6,000	650	1,400,000
,, Oak - -	15,000	10,000	2,300	1,500,000
Leather - -	4,200	...	...	25,000

POWERS, ROOTS, ETC., OF USEFUL FACTORS.

n	$\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\frac{1}{\sqrt{n}}$	$\sqrt[3]{n}$	$\frac{1}{\sqrt[3]{n}}$
$\pi = 3·142$	0·318	9·870	31·006	1·772	0·564	1·465	0·683
$2\pi = 6·283$	0·159	39·478	248·050	2·507	0·399	1·845	0·542
$\frac{\pi}{2} = 1·571$	0·637	2·467	3·878	1·253	0·798	1·162	0·860
$\frac{\pi}{3} = 1·047$	0·955	1·097	1·148	1·023	0·977	1·016	0·985
$\frac{4}{3}\pi = 4·189$	0·239	17·546	73·496	2·047	0·489	1·612	0·622
$\frac{\pi}{4} = 0·785$	1·274	0·617	0·484	0·886	1·128	0·923	1·084
$\frac{\pi}{6} = 0·524$	1·910	0·274	0·144	0·724	1·382	0·806	1·241
$\pi^2 = 9·870$	0·101	97·409	961·390	3·142	0·318	2·145	0·466
$\pi^3 = 31·006$	0·032	961·390	29,809·910	5·568	1·796	3·142	0·318
$\frac{\pi}{32} = 0·098$	10·186	0·0095	0·001	0·313	3·192	0·461	2·168
$g = 32·2$	0·031	1036·84	33,386·24	5·674	0·176	3·181	0·314
$2g = 64·4$	0·015	4147·36	267,090	8·025	0·125	4·007	0·249

HYDRAULIC EQUIVALENTS.

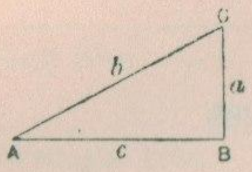
1 foot head = 0·434 lb. per square inch.
1 lb. per square inch = 2·31 ft. head.
1 imperial gallon = 277·274 cubic inches.
1 imperial gallon = 0·16045 cubic foot.
1 imperial gallon = 10 lb.
1 cubic foot of water = 62·32 lb. = 6·232 imperial gallons.
1 cubic foot of sea water = 64·00 lb.
1 cubic inch of water = 0·03616 lb.
1 cubic inch of sea water = 0·037037 lb.
1 cylindrical foot of water = 48·96 lb.
1 cylindrical inch of water = 0·0284 lb.
A column of water 12 in. long 1 in. square = 0·434 lb.
A column of water 12 in. long 1 in. diameter = 0·340 lb.
Capacity of a 12 in. cube = 6·232 gallons.
Capacity of a 1 in. square 1 ft. long = 0·0434 gallon.
Capacity of a 1 ft. diameter 1 ft. long = 4·896 gallons.
Capacity of a cylinder 1 in. diameter 1 ft. long = 0·034 gallon.
Capacity of a cylindrical inch = 0·002832 gallon.
Capacity of a cubic inch = 0·003606 gallon.
Capacity of a sphere 12 in. diameter = 3·263 gallons.
Capacity of a sphere 1 in. diameter = 0·00188 gallon.
1 imperial gallon = 1·2 United States gallon.
1 imperial gallon = 4·543 litres of water.
1 United States gallon = 231·0 cubic inches.
1 United States gallon = 0·83 imperial gallon.
1 United States gallon = 3·8 litres of water.
1 cubic foot of water = 7·476 United States gallons.
1 cubic foot of water = 28·375 litres of water.
1 litre of water = 0·22 imperial gallon.
1 litre of water = 0·264 United States gallon.
1 litre of water = 61·0 cubic inches.
1 litre of water = 0·0353 cubic foot.

EQUIVALENTS OF POUNDS AVOIRDUPOIS.

	10		100			1000				10,000				100,000			
	qr.	lb.	cwt.	qr.	lb.	ton	cwt.	qr.	lb.	ton	cwt.	qr.	lb.	ton	cwt.	qr.	lb.
1	0	10	0	3	16	0	8	3	20	4	9	1	4	44	12	3	12
2	0	20	1	3	4	0	17	3	12	8	18	2	8	89	5	2	24
3	1	2	2	2	20	1	6	3	4	13	7	3	12	133	18	2	8
4	1	12	3	2	8	1	15	2	24	17	17	0	16	178	11	1	20
5	1	22	4	1	24	2	4	2	16	22	6	1	20	223	4	1	4
6	2	4	5	1	12	2	13	2	8	26	15	2	24	267	17	0	16
7	2	14	6	1	0	3	2	2	0	31	5	0	0	312	10	0	0
8	2	24	7	0	16	3	11	1	20	35	14	1	4	357	2	3	12
9	3	6	8	0	4	4	0	1	12	40	3	2	8	401	15	2	24

TRIGONOMETRICAL FUNCTIONS.

RIGHT-ANGLED TRIANGLES.



$\text{Sin. } A = \frac{a}{b}$ $\quad$ $\text{Sec. } A = \frac{b}{c}$ $\quad$ $\text{Tan. } A = \frac{a}{c}$

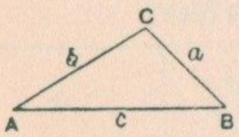
$\text{Cos. } A = \frac{c}{b}$ $\quad$ $\text{Cosec. } A = \frac{b}{a}$ $\quad$ $\text{Cotan. } A = \frac{c}{a}$

$\text{Versin. } A = \frac{b-c}{b}$ $\quad$ $\text{Coversin. } A = \frac{b-a}{b}$

Given.	Required.	Formulæ.		
a,b	A,C,c	$\text{Sin. } A = \frac{a}{b}$	$\text{Cos. } C = \frac{a}{b}$	$c = \sqrt{(b+a)(b-a)}$
a,c	A,C,b	$\text{Tan. } A = \frac{a}{c}$	$\text{Cotan. } B = \frac{a}{c}$	$b = \sqrt{(a^2+c^2)}$
A,a	$C,c,b,$	$C = 90° - A$	$c = a \times \text{Cotan. } A$	$b = \frac{a}{\text{Sin. } A}$
A,b	C,a,c	$C = 90° - A$	$a = b \times \text{Sin. } A$	$c = b \times \text{Cos. } A$
A,c	C,a,b	$C = 90° - A$	$a = c \times \text{Tan. } A$	$b = \frac{c}{\text{Cos } A}$

OBLIQUE-ANGLED TRIANGLES.

$s = {}^1/_2(a+b+c)$



Given.	Formulæ.
A,B,C,a	$\text{Area} = (a^2 \times \text{Sin. } B \times \text{Sin. } C) \div 2 \text{ Sin. } A$
A,b,c	$\text{Area} = {}^1/_2(c \times b \times \text{Sin. } A)$
a,b,c	$\text{Area} = \sqrt{s(s-a)(s-b)(s-c)}$

Given.	Required.	Formulæ.
A,C,a	c	$c = a\frac{\text{Sin. } C}{\text{Sin. } A}$
A,a,c	C	$\text{Sin. } C = \frac{c \text{ Sin. } A}{a}$
a,c,B	A	$\text{Tan. } A = \frac{a \text{ Sin. } B}{c - a \text{ Cos. } B}$
a,b,c	A	$\text{Sin. } {}^1/_2 A = \sqrt{\frac{(s-b)(s-c)}{b \times c}}$; $\text{Cos. } {}^1/_2 A = \sqrt{\frac{s(s-a)}{b \times c}}$; $\text{Tan. } {}^1/_2 A = \sqrt{\frac{(s-b)(s-c)}{s(s-a)}}$

COMPOUND ANGLES.

$\text{Sin. } (A+B) = \text{Sin. } A \text{ Cos. } B + \text{Cos. } A \text{ Sin. } B.$

$\text{Sin. } (A-B) = \text{Sin. } A \text{ Cos. } B - \text{Cos. } A \text{ Sin. } B.$

$\text{Cos. } (A+B) = \text{Cos. } A \text{ Cos. } B - \text{Sin. } A \text{ Sin. } B.$

$\text{Cos. } (A-B) = \text{Cos. } A \text{ Cos. } B + \text{Sin. } A \text{ Sin. } B.$

$\text{Tan. } (A+B) = \frac{\text{Tan. } A + \text{Tan. } B}{1 - \text{Tan. } A \text{ Tan. } B}.$

$\text{Tan. } (A-B) = \frac{\text{Tan. } A - \text{Tan. } B}{1 + \text{Tan. } A \text{ Tan. } B}.$

SLIDE RULE DATA SLIPS, COMPILED BY C. N. PICKWORTH, WH.SC.

(It is suggested that this page be removed by cutting through the above line, and selected portions of the Sectional Data Slips attached to the back of the Slide Rule.)

$\frac{1}{32}$	0·03125	$\frac{11}{32}$	0·34375	$\frac{11}{16}$	0·6875
$\frac{1}{16}$	0·0625	$\frac{3}{8}$	0·375	$\frac{23}{32}$	0·71875
$\frac{3}{32}$	0·09375	$\frac{13}{32}$	0·40625	$\frac{3}{4}$	0·75
$\frac{1}{8}$	0·125	$\frac{7}{16}$	0·4375	$\frac{25}{32}$	0·78125
$\frac{5}{32}$	0·15625	$\frac{15}{32}$	0·46875	$\frac{13}{16}$	0·8125
$\frac{3}{16}$	0·1875	$\frac{17}{32}$	0·53125	$\frac{27}{32}$	0·84375
$\frac{7}{32}$	0·21875	$\frac{9}{16}$	0·5625	$\frac{7}{8}$	0·875
$\frac{1}{4}$	0·25	$\frac{19}{32}$	0·59375	$\frac{29}{32}$	0·90625
$\frac{9}{32}$	0·28125	$\frac{5}{8}$	0·625	$\frac{15}{16}$	0·9375
$\frac{5}{16}$	0 3125	$\frac{21}{32}$	0 65625	$\frac{31}{32}$	0·96875

Circ. of circle = 3·1416 d.
Area ,, ,, = 0 7854 d^2.
Sq. eq. area to cir., s = 0·886 d.
Circle eq. to sq., d = 1·128 s.
Sq. inscbd. in circ., s = 0·707 d.
Circsb. circ. of sq., d = 1·414 s.
Area of ellipse = 0·7854 $a \times b$.
Surface of sphere = 3·1416 d^2.
Volume ,, ,, = 0·5236 d^3.
,, cone = 0·2618 $d^2 h$.

Radian = 180°/π = 57·29 deg.
Base of nat. or hyp. log. = e = 2·7183.
Nat. or hyp. log = com. log. × 2·3026.
g (at London) 32 18 ft. per sec., per sec.
Abs. temp. = deg. F. + 461° = deg. C. + 274°.
C.° = 5/9 (F.° − 32°); F.° = 9/5 C.° + 32°.
Cal. pr.—Ther. units per lb.: Coal, 14,300; petrol'm, 20,000; coal gas per cu. ft., 700.
Sp. heat:—Wt. iron, 0·1138; C.I., 0·1298; copper, brass, 0·095; lead, 0·0314.

Inch = 25·4 mil'metres ; mil'metre = 0·03937 in.
Foot = 0·3043 metres ; metre = 3·2809 feet.
Yard = 0·91438 metre ; metre = 1·0936 yards.
Mile = 1·6093 kilomtrs. ; kilomtr. = 0·6213 mile.
Sq. in. = 6·4513 sq. cm.; sq. cm. = 0·155 sq. in.
Sq. ft. = 9·29 sq. decmtr.; sq. decmtr. = 0·1076 sq. ft.
Sq. yd. = 0·836 sq. metre ; sq. metre = 1·196 sq. yds.
Sq. ml. = 258·9 hectares ; hectare = 0·00386 sq. ml.
Cu. in. = 16 386 c.cm.; c.cm. = 0·06102 cu. in.
Cu. ft. = 0·0283 c.metre ; c.metre = 35·316 cu. ft.

Grain = 0·0648 gramme ; gram. = 15·43 grs.
Ounce = 28·35 grams.; ,, = 0·03527 oz.
Pound = 0·4536 kilogm.; kilogm. = 2·204 lb.
Ton = 1·016 tonnes ; tonne = 0·9842 ton.
Mile per hr. = 1 466 ft., or 44·7 cm., per sec.
Lb. per cu. in. = 0·0276 kilogram per cu. cm.
Kilogram per cu. cm. = 36·125 lb. per cu. in.
Lb. per cu. ft. = 16·019 kilog. per cu. mtre.
Grain per gall. = 0 01426 gramme per litre.
Gramme per litre = 70·116 grains per gall.

Ultimate Strength.	Lb. per Sq. In. Tens'n.	Comp'n.
Wt. iron..	50,000	50,000
Cast ,, ..	16,000	95,000
Steel	80,000	70,000
Copper ..	21,000	50,000
Brass	18,000	10,500
Lead	2,500	7,000
Pine	11,000	6,000
Oak	15,000	10,000

Weight of Metals	Cub. In.	Cub Ft.	12 Cu. In.
Wt. iron..	0·277	480	3 33
Cast ,,	0 260	450	3·12
Steel	0·233	490	3·40
Copper ..	0·318	550	3·82
Brass	0 300	520	3 61
Zinc	0·248	430	2·98
Alumin'm.	0·096	168	1·16
Lead ..	0·411	710	4 93

Lb. per sq. in. = 2·31 ft. water = 2·04 in. mercury = 0 0703 kilo per sq. cm.
Atmosphere = 14·7 lb. per sq. in. = 33·94 ft. water = 1·0335 ,, ,,
Ft. hd. water = 0·433 lb. per sq. in. = 62·35 lb. per sq. ft. = 0 0304 ,, ,,
Cub. ft. of water = 62 35 lb. = 0·0278 ton = 28·315 litres = 7·48 U.S galls.
Gall (Imp.) = 277·27 cu. in. = 0·1604 cu. ft. = 10 lb. water = 4 544 litres.
Litre = 1·76 pints = 0 22 gall. = 61 cu. in. = 0·0353 cu. ft. = 0 264 U.S. gall.
Horse-power = 33,000 ft.-lb. per min. = 0·746 kilowatt = 42·4 heat units per min.
Heat unit = 778 ft.-lb. = 1055 watt-sec. = 107·5 kilogrammetres = 0·252 calorie.
Foot-pound = 0·00129 heat unit = 1 36 joules = 0·1383 kilogrammetres.
Kilowatt = 1·34 H.P. = 44,240 ft.-lb. per min. = 3412 heat units per hour.

INDEX.

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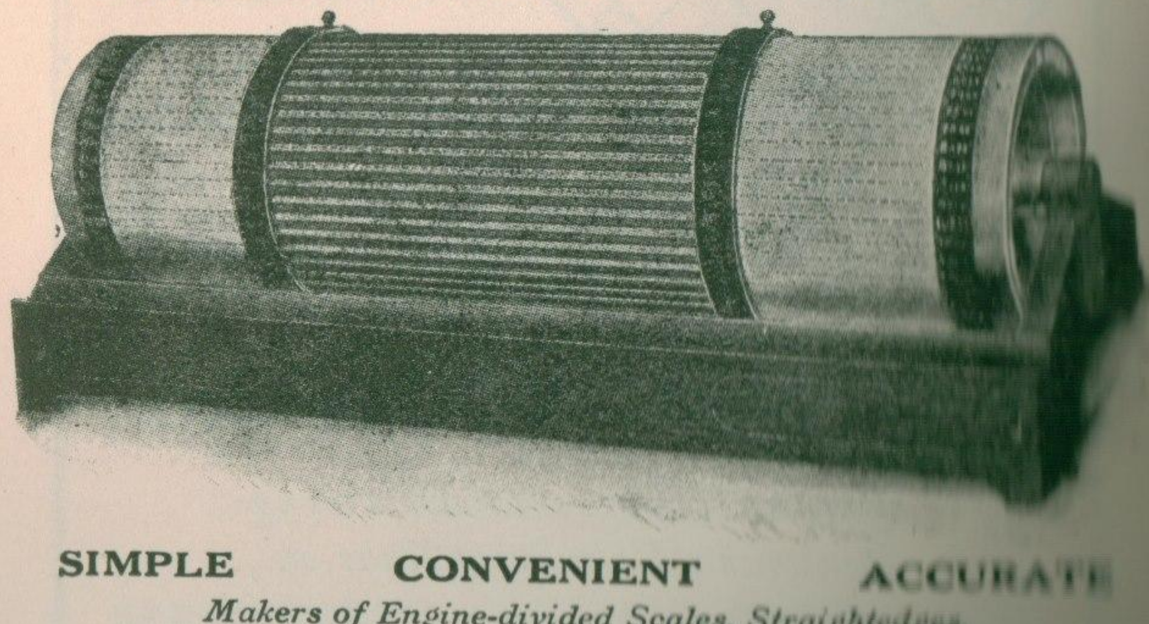

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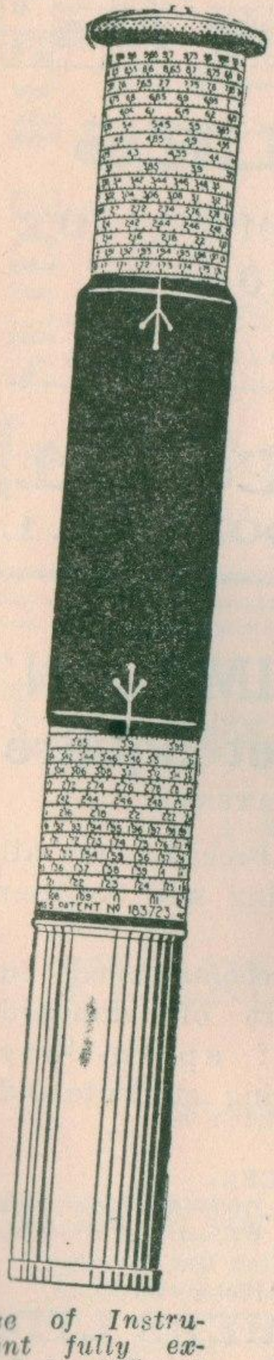

Size of Instrument fully extended, 10" × 1⅛"; closed, 6" × 1⅛".