

DIETZGEN

INSTRUCTIONS

Slide Rule

No. 1773 SYSTEM DARMSTADT

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Description of the Slide Rule

The Slide Rule **System Darmstadt** is a general purpose slide rule. Its logarithmic scales make possible all the calculations which are met with in mathematics and their practice. It carries no special scales such as would be required for commercial, nautical purpose, reinforced concrete, or any other narrow field of activity.

The scales of the System Darmstadt Slide Rules are grouped as follows:

1. The **Main Scales** A, B, C, D (x) und CI.
2. The **Supplementary Scales** K, P ($\sqrt{1-x^2}$), L, the trigonometrical scales, and the log-log scales LL₁, LL₂, LL₃.

The Main Scales.

Even the simplest general slide rule has the upper scales, **A** and **B**, and the lower scales, **C** and **D**. (Fig. 1)

In addition to these four scales, there is a **reciprocal**, or reversed C, scale on the centre of the slide between B and C. This scale, **CI**, runs from **10 to 1** (Fig. 1).

These five scales are extended a short distance at each end, the extra graduations being a different colour to the main part of the scales.

For all calculations containing only multiplication and division, squares and square roots the three scales C, D, and CI should be used.

The Supplementary Scales

Additional scales are provided to facilitate calculations other than multiplication, division, squares and square roots:

View of the 5 inch Slide Rule No. 1773

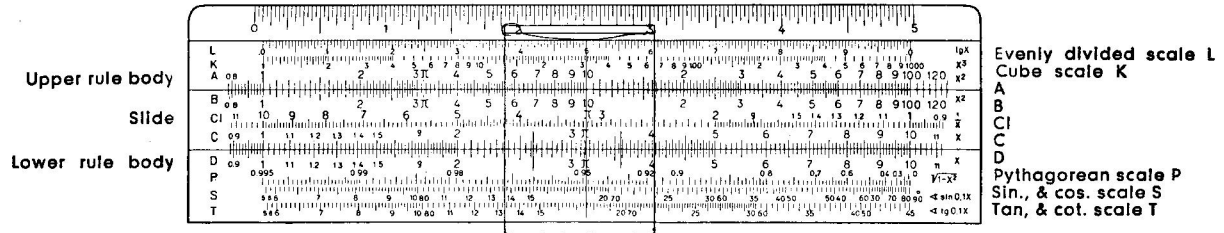


Fig. 1

The **evenly divided scale L** on the upper part of the rule body is used in conjunction with Scale D for reading common logarithms.

The next following is the **cube scale K**. It is graduated from **1 to 1000**, and is used with Scale D.

The **Pythagorean scale P** ($\sqrt{1-x^2}$) is on the rule face below D, with which scale it is to be employed.

The **trigonometrical scales S and T** will be found on the lower part of the rule body.

Finally, there is a **log-log-scale**, graduated in three sections, LL₁, LL₂, LL₃, from **1.01 to 10⁵**, on the back of the slide.

The Cursor

enables these scales to be employed in any combination. The long centre line is generally used, while the two short lines at the sides are provided for a special purpose which will be explained later. (p. 13)

Reading the Scales

On the small slide rules with a graduated length of 5 inch. only the tenths, with the fifths of the latter, i.e. the fiftieths, are marked between 1 and 2. Readings are thus taken from 102—104—106 to 196—198 and 200. From 2 to 5, we find only the tenths, with their respective halves, so that readings are taken from 205—210—215 etc. to 490—495 and 500. From 5 to 10 only the tenths are marked. On the upper scales the subdivision in the interval from 1 to 3 is the same as that between 2 and 5 on the lower scales, whilst that in the interval between 3 and 6 is the same as that between 5 and 10 below. In the interval from 6 to 10 only the fifths are marked. The reading in this case is thus from 62—64 to 96—98 and 100.

How To Calculate With The Slide Rule

As the scales of the slide rule are tables of logarithms, their operation is based on logarithmic laws. It is well known that:

1. **Multiplication** of two factors is carried out by the **addition** of their logarithms.
2. **Division** is carried out by **subtracting** the logarithm of the divisor from the logarithm of the dividend.

The table of logarithms, therefore, replaces every method of calculating by a simpler operation, and the slide rule even avoids these simple operations, since they are graphically carried out. It follows, therefore, that on the slide rule:

Multiplication of two numbers is transformed into addition of two lengths.

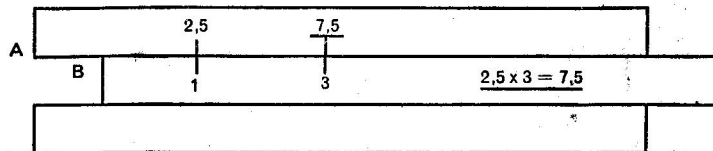
Division of one number by another is changed to subtraction of one length from another.

The Decimal Point

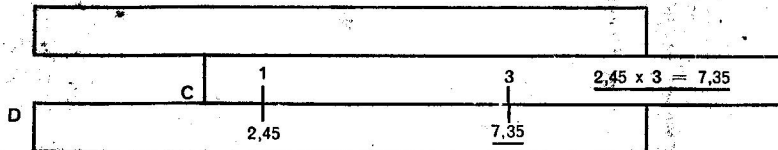
As the upper scales, **A** and **B**, run from 1 to 100, and the lower from 1 to 10, a novice is inclined to think that it is only possible to use the slide rule for numbers within these limits. This is not so, since the position of the decimal point is ignored in slide rule working. For instance, to multiply 320 by 580, it would be possible to multiply 3.2 by 5.8 and increase the answer ten thousand times, or in other words, move the decimal point four places to the right. The graduation 3 on any of the scales may be taken to represent 30, 300, 3,000, etc., or 0.3, 0.03, 0.003, etc. In slide rule working significant figures only are considered, and the position of the decimal point is found from a rough estimate of the size of the answer. In practical problems the number of figures is obvious.

Multiplication

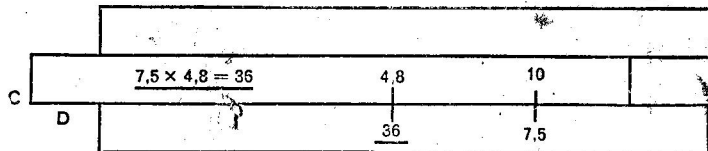
Example: $2.5 \times 3 = 7.5$ (Fig. 2).



Example: $2.45 \times 3 = 7.35$ (Fig. 3).



Example: $7.5 \times 4.8 = 36$ (Fig. 4).



a × b

The left index line 1 of the slide (Scale **B**) is placed under the 2.5 of the upper "body" scale (**A.25**), the cursor line then being placed above the 3 of the upper slide scale (**B 3**). The product (7.5) can then be read off beneath the cursor line on the upper "body" scale (**A 75**). Exactly the same procedure can be adopted on the lower scales.

a × b

The 1 on the slide (**C 1**) is placed above the 2.45 on the lower "body" scale (**D 245**), the cursor line then being placed above the 3 on the lower slide scale (**C 3**). The product (7.35) can then be read off underneath the cursor line on the lower "body" scale (**D 735**).

a × b

When calculations are carried out on the lower scales, it will be found that the second factor of a multiplication problem sometimes cannot be selected within the scope of the lower "body" scale. In this case, **C 10** is placed above the first factor, the cursor line then being placed above the second, after which the result can be read off, as before, beneath the cursor line.

Division

Example: $9.85 \div 2.5 = 3.94$

$\frac{a}{b}$

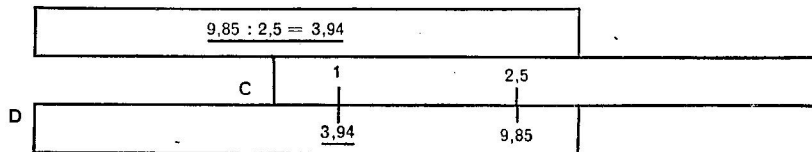


Fig. 5

The denominator 2.5 on the lower slide scale (**C** 25) is placed above the numerator 9.85 on the lower "body" scale (**D** 85) and the quotient (3.94) is read off underneath the beginning of the slide (**C** 1).

This calculatory process can naturally be performed on the upper scales likewise. The result is read off above the right-hand or left-hand extremity of the slide (**B** 1 or **B** 100) on Scale **A**.

How to Form Tables

Example: To convert yards into metres. (82 yds. are 75 m.)

$\frac{a}{b} \div \frac{c}{d} = \frac{e}{f}$

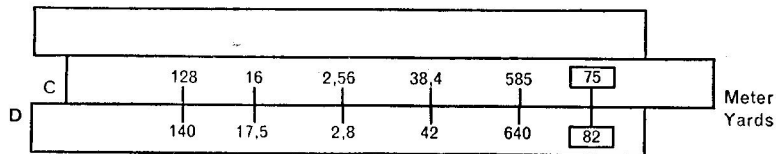


Fig. 6

Place **C** 75 over **D** 82. This automatically produces a comparative Table, from which the following readings can be taken: 42 yds. are 38.4 m.; 2.8 yds. are 2.56 m.; 640 yds. are 585 m.; 16 m. are 17.5 yds.; 128 m. are 140 yds., etc.

Compound calculations

Multiplications and divisions in immediate sequence can easily be made with the Calculating Rule. The intermediate results need not be read off if it is not necessary to know them, and, after the last setting, the correct final result will appear. It is best to begin such calculations with a division, then follow with a multiplication, then another division and again a multiplication and so on.

Example: $13.8 \times 24.5 \times 3.75$
 $17.6 \times 29.6 \times 4.96$

We start by dividing 13.8 by 17.6. Therefore we place

$$\frac{a \times b \times c}{d \times e \times f}$$

A 138 and **B 176** one under the other. Do not read off the answer — approximately 0.8 — but multiply it immediately by 24.5, by placing the cursor-line on **B 245**. Similarly, no reading is taken of the answer — about 19 — and it is simply divided by 29.6. For this purpose, keep the cursor-line firmly in its position and slide **B 296** under it. Once again, the result (0.65) is not “read” but multiplied at once by 3.75, this being done by placing **B 375** under it. The result is merely “retained” by the cursor-line, as before, and divided by 4.96, by sliding **B 496** under the cursor-line. Only then do we read off the figures of the final answer, 491, above **B 10** and **B 100** — and our rough calculation shows us that the actual answer is 0.491.

The Reciprocal Scale CI

1. In order to find the reciprocal value $1 \div a$ for any given number a , find a on **C** (or **CI**) and read above it on **CI** (or below it on **C**) the reciprocal value. Reading off is done therefore without any movement of the slide and entirely by setting the cursor line. (Fig. 7)

Examples: $1 \div 8 = 0.125$; $1 \div 5 = 0.2$; $1 \div 4 = 0.25$; $1 \div 3 = 0.333$ (Fig. 7).

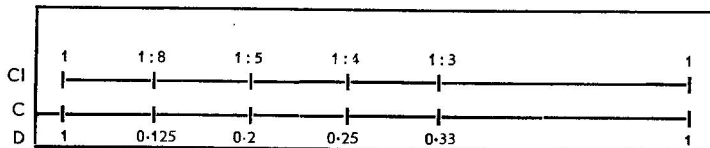


Fig. 7

$$\frac{1}{a}$$

2. To find $1 \div a^2$ move the cursor to **a** on scale **CI** and read above it on **B** the result.

Example: $1 \div 2.44^2 = 0.168$.

Estimated answer — less than $\frac{1}{5} = 0.2$.

$\frac{1}{a^2}$

Example: Find the resistance **R** of an appliance having a power of 1320 Watts and drawing a current of 6 A.

Solution: $R = P \times \frac{1}{I^2} = 1320 \times \frac{1}{6^2} = 36.7 \Omega$

3. To find $1 \div \sqrt{a}$, set the cursor line to **a** on scale **B** and find below it on **CI** the result.

Example: $1 \div \sqrt{27.5} = 0.191$.

Estimated answer — less than $\frac{1}{5} = 0.2$.

$\frac{1}{\sqrt{a}}$

Example: Change a single phase alternating current of 120 V into direct current by means of a transformer.

Solution: $V_d = \frac{2V}{\sqrt{2}} = \frac{1}{\sqrt{2}} \times 2V = \frac{1}{\sqrt{2}} \times 240$

Result above D 240 = 169.6 V or B 2 above D 240, under C 1 = 169.6 V.

4. To find $1 \div a^3$, set the cursor line over **a** on scale **CI** and the answer will be found under the cursor line on scale **K**.

Example: $1 \div 2.26^3 = 0.0866$.

Estimated answer — less than $\frac{1}{8} = 0.125$

$\frac{1}{a^3}$

5. To find $1 \div \sqrt[3]{a}$, move the cursor line to **a** on scale **K** and read the answer under the cursor line on **CI**.

Example: $1 \div \sqrt[3]{13} = 0.425$.

Estimated answer — less than $\frac{1}{2} = 0.5$.

$$\frac{1}{\sqrt[3]{a}}$$

6. **Products of three factors** can generally be reached with one setting of the slide. One sets, by means of the cursor, the first two factors against each other on **D** and **CI** respectively, moves the cursor to the third factor on **C** and reads below it on **D**, the final product.

Example: $0.66 \times 20.25 \times 2.38 = 31.8$.

$$a \times b \times c$$

Estimated answer — more than $0.6 \times 20 \times 2.5 = 30$.

Example: What is the area of an ellipse with semi-axes of 15.4 inches and 6.2 inches?

Solution: $A = a b \pi = 15.4 \times 6.2 \times 3.14 = 300$ square inches.

7. **Compound multiplication and division**

Example: $\frac{36.4}{3.2 \times 4.6} = 2.472$

One sets by means of the cursor the figures 3-6-4 on **D** against 3-2 on **C**. It is not necessary to read the intermediary result. Move the cursor line over 4-6 on scale **CI**, which is the same as multiplying by $\frac{1}{4.6}$ (= reciprocal value $\frac{1}{c}$). The result of 2.472 is then found under the cursor line on scale **D**.

Example: An alternating current motor of 220 V has a power input of 2860 W with a current of 16 A; find the power factor ($\cos \varphi$).

Solution: $\cos \varphi = \frac{P}{V \cdot I} = \frac{2860}{220 \times 16} = 0.812 \quad (\varphi = 35.7^\circ)$

$$\frac{a}{b \times c}$$

Squares And Square Roots

Both the upper scales are graduated to half length. The change over from **D** to **A**. (or from **C** to **B**) gives the **square** of the number to which **D** (or **C**) has been set. **Square roots** are extracted by reversing this procedure (Fig. 8).

Example:

a² Given the side of a square (47 inches).
Find the area.

$$A = 47^2 = 2209 \text{ sq. in.}$$

Example:

√ b What is the diameter of a shaft if P = 50 HP
and V = 400 r.p.m.?

$$d = 12 \times \sqrt[4]{\frac{P}{V}} = 12 \times \sqrt{\sqrt{\frac{50}{400}}} = 7.138$$

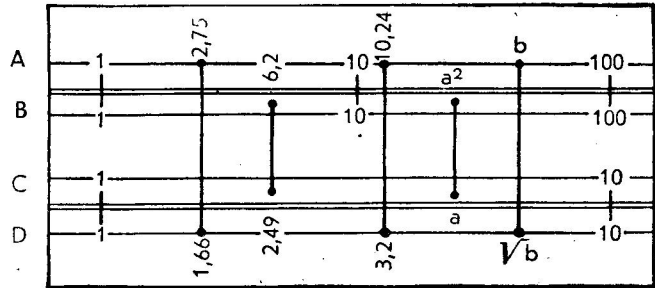


Fig. 8

In extracting a square root it is essential to set the number on the correct half of the upper scale for \sqrt{x} and $\sqrt{10x}$ do not differ merely in the position of the decimal point. If the figures 6..2 be set to the left, the root of 6.2 appears below, while if they are set to the right the root of 62 is obtained. One must thus proceed in accordance with the numbers as shown (1...10...100). If the number lies outside the scale range 1 to 100, it should be factorised by hundreds to bring the significant figures within these limits.

$$\text{Example: } \sqrt{1922} = \sqrt{100 \times 19.22} = 10 \times \sqrt{19.22} = 10 \times 4.38 = 43.8$$

$$\sqrt{0.000071} = \sqrt{71 : 1\,000\,000} = \sqrt{71 : 1\,000} : 1000 = 8.43 : 1000 = 0.00843$$

Cubes And Cube Roots

Scale **K** is graduated in the ratio 1:3. In passing over from Scale **D** to **K** the number is raised to the **third power**, while passing from **K** to **D** gives the **cube root**, as shown in Fig. 9. When setting the number for a cube root on Scale **K** it is necessary to watch the values 1...10...100...1000.

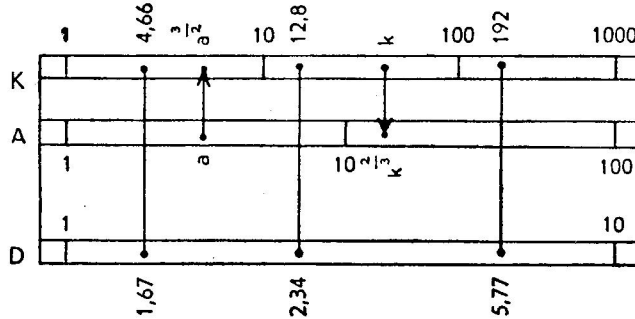


Fig. 9

If the number does not lie within the scale range 1...1000, it must be factorised by thousands to bring it within these limits.

$$\text{Example: } \sqrt[3]{1260000} = \sqrt[3]{1000^2 \times 1.26} = 10^2 \times \sqrt[3]{1.26} = 100 \times 1.08 = 108$$

$$\sqrt[3]{0.32} = \sqrt[3]{320 \div 1000} = \sqrt[3]{320} \div 10 = 6.84 \div 10 = 0.684.$$

If the cube scale be employed with Scale **A**, powers having the exponents $\frac{3}{2}$ and $\frac{2}{3}$ may be found (Fig. 9).

The Pythagorean Scale

This scale represents the function $y = \sqrt{1-x^2}$. It is employed in combination with Scale D ($= x$), the latter having the range of values 0.1 to 1.

Examples: $x = 0.8$ $y = 0.6$ (Fig. 10)
 $\sin \alpha = 0.134$, $\cos \alpha = 0.991$

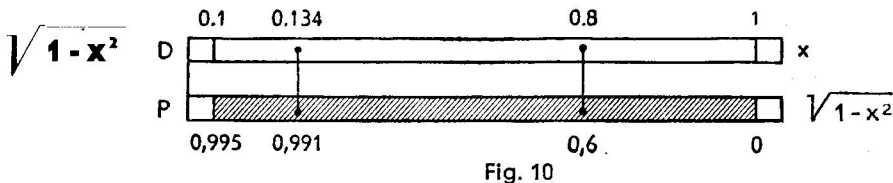


Fig. 10

Example:

Determine the effective current and wattless current of a circuit which absorbs 35 A at 220 V.

$\cos \varphi = 0.8$

$$I_e = I \times \cos \varphi = 35 \times 0.8 = 28 \text{ (A)}$$

$$I_w = I \times \sin \varphi = 35 \times 0.6 = 21 \text{ (A)}$$

The Mantissa Scale

This scale is used with Scale D for reading **common logarithms**, and may be used in place of a **three-figure table**. Naturally, it only gives the mantissae, the characteristic being found in the usual way.

Example: $\log 52 = 1.716$ (Fig. 11).

$\lg x$

$\log x = 3.574$ $x = 3750$.

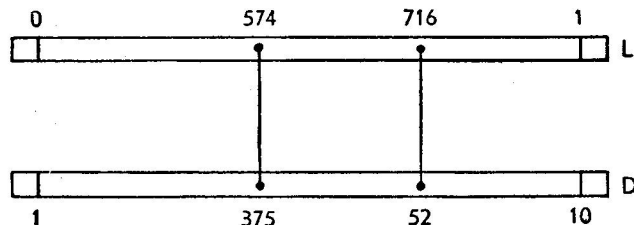


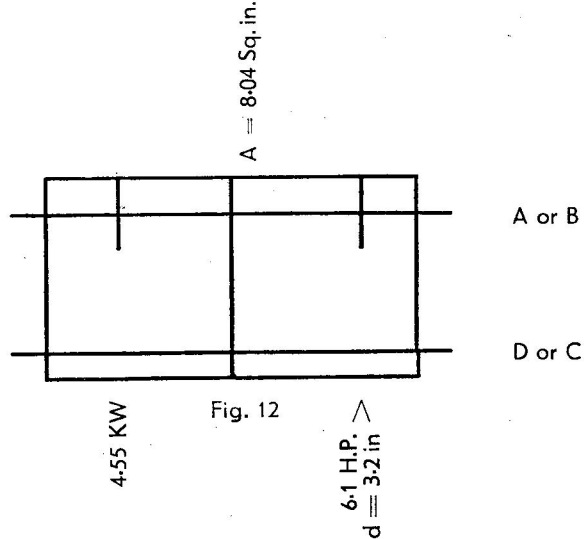
Fig. 11

The Cursor

The three lines on the cursor can be employed as a scale. When the short right-hand line is set to a **diameter** on C or D, the centre line will give the **area** on B or A respectively (Fig. 12); and when the right-hand line is on any given **horse-power**, the left-hand line indicates the corresponding **kilowatts**.

HP—kw

d—A



The Trigonometrical Scales

Use of the Scales as Tables

Reading the sin-cos table from left to right, with the **Black Numbers**, we obtain a **Sine Table** on Scale D.

With large angles the reading becomes uncertain; in this case it is more accurate if the red numbers are used and read on Scale P. In Fig. 13 $\sin 76^\circ$ is given as 0.97 on Scale D, and as 0.9703 on P.

$\sin a$

$\cos a$

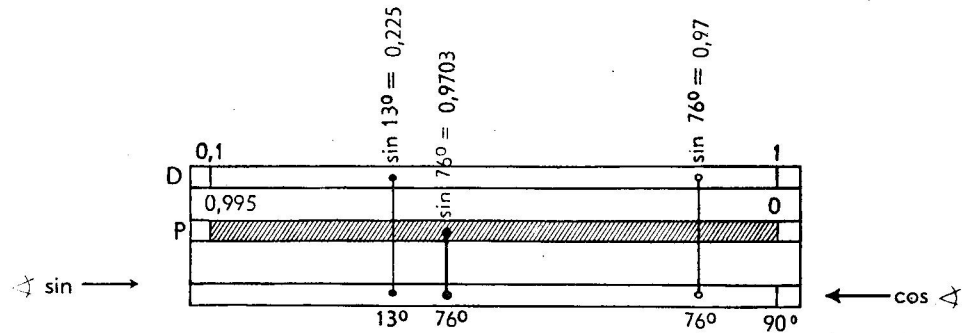
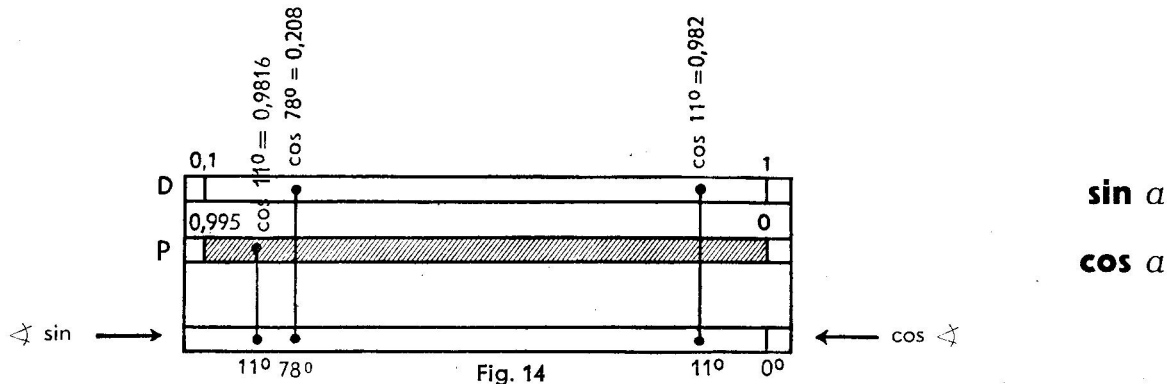


Fig. 13

Reading the **Red Numbers** from right to left, we obtain a **Cosine Table** on D.

With small angles the reading is not exact: it is more accurate if read on Scale P with the black numbers. In Fig. 14 $\cos 11^\circ$ is shown on D as 0.982, and more accurately as 0.9816 on P.



Reading **black numbers** on the tan-cot scale from left to right, we obtain a **tangent table** on Scale D. Reading **red numbers** from right to left, we obtain a **cotangent table** on D.

It would appear as if only tangents of angles below 45° and cotangents of angles over 45° can be read. But as tangent and cotangent values are reciprocal, the use of Scale CI permits all values to be read as shown in the examples of Fig. 15. The procedure is summarised in the following:

Tangents	under 45° over 45°	black numbers and D or C red numbers and CI
Cotangents	under 45° over 45°	black numbers and CI red numbers and D or C

Tan a

Cot a

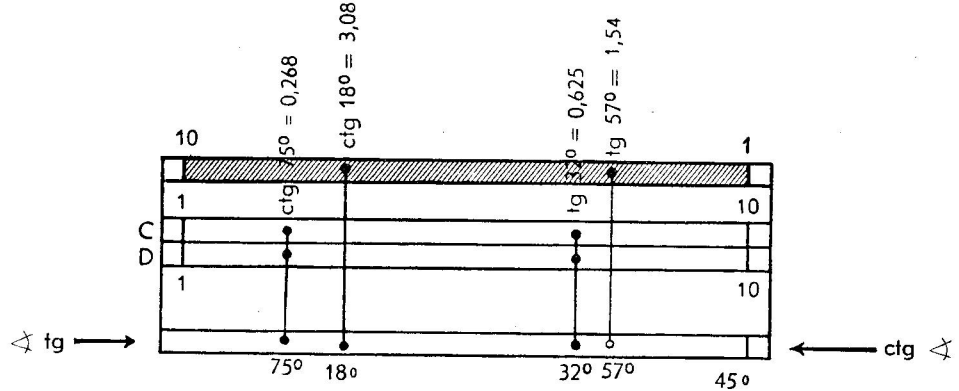


Fig. 15

The trigonometrical functions can be read in this way down to $5^{\circ}.7$. Then, $\sin 5^{\circ}.7 \approx \tan 5^{\circ}.7 \approx 0.1$. The following relationship can be used for still smaller angles: $\sin \alpha \approx \tan \alpha \approx \text{arc } \alpha \approx 0.01745 \alpha^{\circ}$.

The mark ϱ has been placed at 1-7-4-5 on the C and D scales; it is employed as shown in Fig. 16. For instance, $\sin 3^{\circ} \approx \tan 3^{\circ} \approx \text{arc } 3^{\circ} \approx 0.0524$. The error is less than 0.25%.

(The symbol \approx means "approximately equals".)

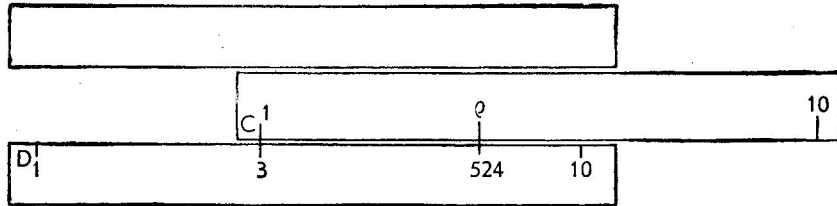


Fig. 16

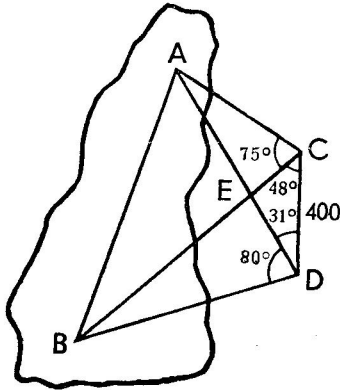


Fig. 17

Example: Find the distance between two points A and B, lying in a moor and therefore inaccessible. Outside the moor the distance $CD = 400$ yds. and the angles marked in the accompanying diagram are measured. (Fig. 17)

Calculation of I. EA:

$$EA = \frac{EC \times \sin 75^\circ}{\sin 26^\circ} = \frac{400 \times \sin 31^\circ \times \sin 75^\circ}{\sin 101^\circ \times \sin 26^\circ} = 462;$$

Calculation of II. EB:

$$EB = \frac{ED \times \sin 80^\circ}{\sin 21^\circ} = \frac{400 \times \sin 48^\circ \times \sin 80^\circ}{\sin 101^\circ \times \sin 21^\circ} = 833;$$

Calculation of III. AB:

$$AB^2 = EA^2 + EB^2 - 2 \times EA \times EB \times \cos 101^\circ = EA^2 + EB^2 + 2 \times EA \times EB \times \cos 79^\circ = 213,444 + 693,889 + 769,692 \times 0.191 = 907,333 + 147,011 = 1,054,344;$$

$$AB = \sqrt{1,054,344}; \quad \mathbf{AB = 1,027 \text{ yds.}}$$

Calculation with Trigonometrical Scales

If it is desired to convert the sine of an angle to the cosine (or vice versa), the angle need not be read. On Scales D and P these pairs of values are shown one under the other. In converting from tangent to cotangent the reading of the angles is likewise dispensed with, as the corresponding values appear one under the other on C and Cl. It is only when converting sines or cosines to tangents or cotangents that the angle need be read. In converting sines and cosines to tangents and cotangents it is of advantage to adopt the form

$$\operatorname{tg} x = \frac{\sin x}{\sqrt{1 - \sin^2 x}} \quad \text{and} \quad \operatorname{cot} x = \frac{\cos x}{\sqrt{1 - \cos^2 x}}$$

Example: Given the actual efficiency 32 kW and $\cos \varphi = 0.81$.
Find the wattless efficiency.

Solution: $\text{ctg } \varphi = \frac{\cos \varphi}{\sqrt{1 - \cos^2 \varphi}}$. Set the cursor line over D 81 ($\cos \varphi = 0.81$) and read on the P scale 0.587 ($\sqrt{1 - \cos^2 \varphi}$), then set C 587 over D 81 and read above C 1 the answer $\text{ctg } \varphi = 1.38$ and over D 10 $\text{tg } \varphi = 0.724$.

Now set the cursor line over D 32 and read on the C scale the result 23.2 kVA wattless efficiency.

As the functions can be found either on D or on CI, further calculation (multiplication and division) can in many cases be carried out immediately. It is only when the value is read on P that it has to be transferred to the main scales.

The Log-Log-Scale (Exponential Scale) LL_1, LL_2, LL_3

This scale has manifold applications, but only the most important methods of calculating are given here. The following rule will be found helpful:

The slide is used inverted so that the three sections of the log-log scale move between Scales A and D.

There is a tenth power relationship between each pair of adjacent sections of the log-log scale, which makes the reading of tenth roots and tenth powers extremely easy.

a^{10}	Example: $1.204^{10} = 6.4$,	reading between 2nd and 3rd sections
	$1.035^{10} = 1.41$,	" " 1st " 2nd "
$\sqrt[10]{a}$	$\sqrt[10]{75} = 1.54$	" " 3rd " 2nd "
	$\sqrt[10]{1.248} = 1.0224$	" " 2nd " 1st "

These examples show that, with the log-log scale, the position of the decimal point is definitely fixed.

Powers of e

The **exponents** must be set on Scale **D**. If they are used in combination with the **lowest** section of the log-log scale, the graduations on D must be read as **1 to 10**; with the **middle** section they must be read as **0.1 to 1**; and with the **upper** section as **0.01 to 0.1**.

Inverted Slide.

Example: $e^{1.61} = 5$.

Set the cursor line to 1.61 on D and read the answer, 5, on the lowest log-log section.

Example: $e^{0.61} = 1.84$.

Set the cursor line over 61 on D (0.61) and read 1.84 on the middle section.

Example: $e^{0.029} = 1.0294$.

Set the cursor over 29 (0.029) on D and read 1.0294 on the upper section.

If the power exponent is negative, adopt the form $e^{-n} = \frac{1}{e^n}$, first calculating with the positive n and then finding the reciprocal.

Example: Calculate the elastic force in the running on band of a band brake, of which the band passes round the drum twice.

Solution: $T_{\text{running off}} = 22 \text{ lbs}$; $\alpha = 2 \times 360^\circ = \text{arc } 4 \pi = 12.56$;

Coefficient of friction $\mu = 0.18$;

$$T_{\text{running on}} = T_{\text{running off}} \times e^{\mu \times \alpha} = 22 \times e^{2.261} = 22 \times 9.60 = 211.2 \text{ lbs.}$$

Roots of e

$\sqrt[n]{e}$

Example: $\sqrt[4]{e} = e^{\frac{1}{4}} = e^{0.25} = 1.284.$

If the exponent of the root be changed to a power exponent, as in the above example, the solution is as in the foregoing. The conversion of the exponents is read from the reciprocal scales. It is, however, possible to find the root directly by means of Scale CI.

Set 4 on CI under one of the index lines at the back of the rule (at the left-hand end, for instance). Then the answer 1.284, will be found on the middle section over 1 on D.

Hyperbolic Logarithms

Hyperbolic logarithms are found by reading from the log-log scale to scale D or C.

log_e a

Example: $\text{Log}_e 25 = 3.22.$

Set the cursor line on 25 on the lowest log-log section and read $\log_e 25 = 3.22$ on D. With this setting we obtain a table of hyperbolic logarithms. There is no movement of the slide.

Example: $\text{Log}_e 1.31 = 0.27.$

Set the cursor line over 1.31 on the middle section and read the numbers 2-7 on D. This means 0.27, since it is on the middle section.

Proceed in the same way when reading to the right.

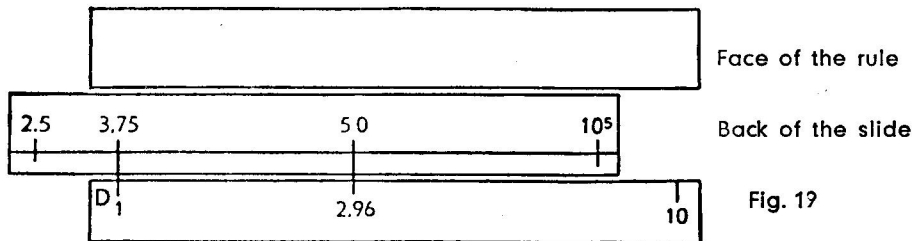
Example: $\text{Log}_e 1.0145 = 0.0144.$

The procedure is exactly as before; the numbers 1-4-4 read on D, must be taken as 0.0144, as the uppermost section was used in setting.

Powers With Fractional Exponents

Example: $3.75^{2.96} = 50$

Set 3.75 (on the lowest log-log section) over 1 on D, move the cursor line over 296 on D and read the answer, 50, directly above (Fig. 19). a^n



Example: $1.89^{6.05} = 47.1$.

Set 1.89 over 10 on D, using the cursor. Move the cursor over 605 on D and read the answer, 47.1, above it. By this method, the change over from the middle section to the lowest is more noticeable.

Example: $1.0525^{29.4} = 4.5$.

Set 1.0525 over 10 on D, using the cursor. Move the cursor over 294 on D and read the answer, 4.5, above it on the log-log scale.

In the last example, we passed from the highest to the lowest section of the log-log scale. Had the exponent been 2.94, the change over would have been to the middle section (Answer = 1.1623).

There should be no difficulty in selecting the answer on the sections of the log-log scale, as it can be estimated easily.

Roots With Fractional Exponents

When the root exponent is changed to a power exponent by means of the reciprocal scale, the problem is solved as above. It is possible, however, to obtain the answer without the conversion.

$$\sqrt[n]{a} \quad \text{Example: } \sqrt[4.4]{23} = 2.04.$$

Set 23 on the log-log scale (lower section) over 4.4 on D and read the answer, 2.04 (central section) over D 10.

$$\text{Example: } \sqrt[2.08]{1.0268} = 1.0128.$$

By means of the cursor line set 1.0268 on the log-log scale (upper section) over D 2.08 and read the answer 1.0128 over D 1.

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