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BEGINNER'S SLIDE RULE MANUAL

By

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Bureau of Public School Service
Division of Extension

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

Mirabeau B. Lamar

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CONTENTS

	Preface	5
I.	Introduction	7
II.	Selecting a Slide Rule	9
III.	Parts of a Slide Rule	10
IV.	Adjusting a Slide Rule	11
V.	Care of the Slide Rule	14
VI.	Reading the Scales	16
VII.	Scales on the Slide Rule	18
VIII.	Multiplication	19
IX.	Division	23
X.	Placement of the Decimal Point	25
XI.	Combined Multiplication and Division	29
XII.	Ratios and Proportions	31
XIII.	Squares and Square Roots	32
XIV.	Cubes and Cube Roots	36
XV.	Inverted Scales	38
XVI.	Conclusions	40
XVII.	Practice Problems	40
XVIII.	Answers	44

PREFACE

This elementary slide rule manual was written with the sincere hope that it may be of assistance to the beginner in understanding the basic operations of the slide rule and to enable him to become proficient in these operations. Only the following fundamental operations are explained: multiplication, division, ratios and proportions, squares and square roots, cubes and cube roots, reciprocals, placement of the decimal point, and a combination of these operations. After an individual has become proficient in these operations, he generally has no difficulty in learning the use of the logarithmic, the trigonometric, the log log, and other more advanced scales that are of specific use to a few individuals but not of sufficiently general use to merit describing them in this beginner's slide rule manual. Believing the ten inch straight slide rule to be the most generally used rule, the author has adopted this rule for illustrative examples, however the instructional information that is presented can be applied without modification whatsoever or with only slight modification to any type of slide rule.

Austin, Texas
August, 1952

LEONARDT F. KREISLE

I. INTRODUCTION

The slide rule is a very handy instrument for the purpose of performing rapid calculations. Due to its relatively small size, it is readily portable and easily may be carried about in one's pocket or stored in a desk. There are countless numbers and types of problems that it can be of assistance in solving. It can multiply, divide, give ratios and proportions, raise numbers to powers, take roots of numbers, give the trigonometric and hyperbolic functions of angles, give the logarithms of numbers to any base, indicate the reciprocals of numbers, give the areas of circles, solve certain types of equations directly, and perform many other useful operations at a speed manyfold times greater than that of longhand calculations. It even can be induced to add and subtract.

The first slide rule appeared in 1620 as a result of Gunter's invention of the straight logarithmic scale based upon Napier's invention of logarithms. Even though it did not look like our present-day rules, its principle of operation was the same as that employed by the most modern, complicated slide rules now in existence. This early ancestor of our slide rule consisted of a single scale on which the settings were made by employing dividers to indicate line segments the lengths of which were logarithmically proportional to the magnitudes of numbers. It was rather simple and crude, but it performed its job well. In the centuries that followed, many different types of slide rules have appeared. Some called rectilinear rules are straight; others in the form of a disk are called circular rules; a few have appeared in the form of a cylinder consisting of a number of rotating drums. Other special forms of rules, particularly useful for performing specialized tasks required by engineering, science, industry, or the military forces, have been developed. A few of the many names that have been given to these different types of rules are as follows: polyphase, log log duplex decitrig, log log vector, binary, deci log log, vector hyperbolic, flight calculator, power computer, versalog, and other equally queer sounding names to the beginning slide rule operator.

Figure 1 depicts a few of the straight and circular slide rules currently in popular use. Although the circular rules are used by a large number of individuals, probably the most commonly used rule is the rectilinear rule. Because of this reason, this manual will employ the straight slide rule for its instructional examples.

This publication is designed to enable any interested individual to become an efficient operator of a slide rule. With adequate practice he should become a proficient operator. The beginner should keep his rule before him while he is reading and studying these instructions, should make all settings indicated in the illustrative examples, and should compute the answers for all the exercises a number of times until he

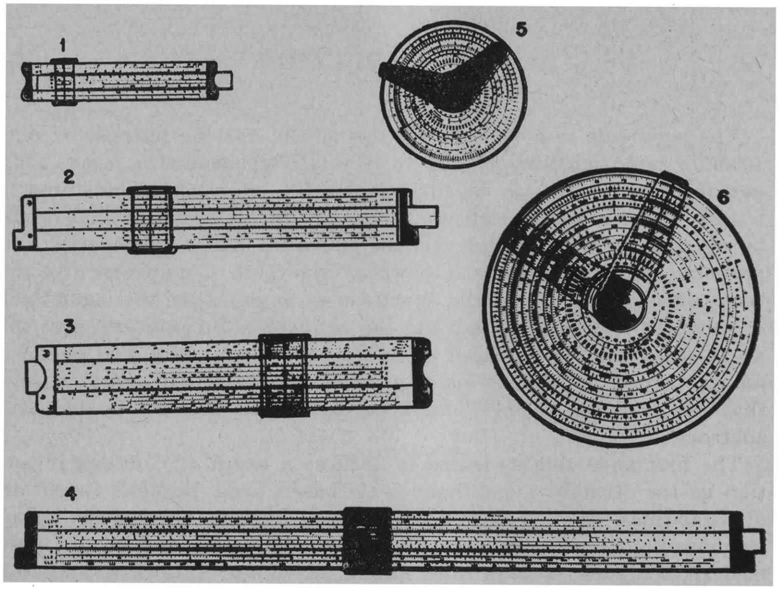

FIG. 1: Examples of Currently Popular Slide Rules
1. 6 Inch Straight Metal Rule
2. 10 Inch Straight Wooden Rule
3. 10 Inch Straight Metal Rule
4. 20 Inch Straight Wooden Rule
5. 4 Inch Circular Metal Rule
6. 8 Inch Circular Metal Rule

consistently obtains the correct answer every time without hesitation in the slide rule operations. The principles involved are rather simple and should be understood with a small amount of study, however a large amount of practice is absolutely necessary before one gains complete confidence in his ability to operate the rule proficiently with an absolute minimum of error. Learning to use a slide rule is like learning algebra; this can not be done overnight or in a week's time, consequently the beginner justifiably should not be too disappointed over his apparent slowness in learning the efficient use of the rule.

Practice exercises are given at the end of instruction concerning a particular operation on the slide rule. In addition a number of additional practice problems of a more complicated nature are given at the end of this manual. Answers to all exercises and problems are given at the end of this bulletin to enable the operator to check the accuracy of his slide rule calculations. These answers were not placed conveniently close to each problem in order to prevent the possibility of an individual observing the answer before he has completed the problem; this is of particular importance in the placement of decimal points.

The slide rule is an inanimate object, consequently it is unable to think. It is capable of doing a great many useful things in the hands of someone who respects it and who will do its thinking. That is the job of the slide rule operator, to do the thinking for the rule.

II. SELECTING A SLIDE RULE

In the selection of a slide rule, it should be borne in mind that a quality instrument together with proficiency in its operation usually result is rapid and accurate calculations saving much time over long-hand calculations and generally over mechanical calculator operations. In general, the cost of the rule corresponds closely to the quality of the slide rule. First class ten inch straight slide rules presently cost between twenty and thirty dollars, depending upon the manufacturer, the case, and the type of rule. In purchasing a slide rule, an individual should purchase the best rule that he is able to afford, realizing that this rule probably will remain his lifelong companion if it is properly cared for.

Slide rules are precision instruments, consequently they should be protected against mechanical and atmospheric damage. This best can be effected by keeping the rule in the case except when it is in use. This case also provides a convenient means of carrying or storing the rule. To purchase a slide rule without a case is like buying a watch without a case.

Slide rules should be purchased from reputable dealers but only after the rule has been inspected carefully for accuracy of construction and calibration of scales or with the understanding that the rule may be returned within a reasonable time should the owner find the rule defective in any manner. Chapter IV on Adjusting a Slide Rule should be studied and applied to a new slide rule before the purchaser makes the final decision to keep a particular rule.

Where an individual is interested in obtaining the most nearly accurate results possible by use of a slide rule, he should purchase a twenty inch straight slide rule which is capable of giving an accuracy of one part in 2000. For almost all calculations necessary in engineering, science, industry, business, and related fields, the ten inch straight slide rule will provide answers of sufficient accuracy, approximately one part is 1000. In many instances the twenty inch rule will give one additional digit accuracy in answer over the ten inch model, however its length makes it unhandy to carry or to store conveniently when the rule is not in use.

The argument whether an individual should purchase a straight or circular slide rule is similar to the controversy concerning the best low-priced automobile; there are many good points on both sides of the discussion. An eight to ten inch diameter circular rule has about the same accuracy on its outer scales as that of a twenty inch straight rule, however almost all the operations on a circular rule require more time to perform than the equivalent operations on any straight slide rule. One of the main advantages of the circular rule over the straight rule is that on the circular rule the operator does not have to decide which index to use in order not to run off the scale. Apparently a majority of proficient operators employing the slide rule in their professional work prefer the rapidity of calculations of the ten inch straight slide rule to that of any other rule.

Straight slide rules are constructed of wood, metal, or plastic. Circular slide rules almost always are constructed of metal, however a few plastic rules have appeared. Generally speaking, a plastic rule is cheaper in cost than the wooden or metallic rules and has a greater tendency to warp with age and cause difficult action of the slide. They also chip rather easily when they are dropped. Wooden rules are affected by high humidity conditions in that the slide sometimes has a tendency to stick, however with a good rule this is the exception rather than the general case. Metallic rules are the most stable insofar as keeping their adjustment is concerned, however many veteran slide rule operators prefer the ease of reading and permanence of scales of the wooden rules to the lithographed or printed scales generally found on metallic rules.

Probably the most satisfactory slide rule for all around use is the ten inch wooden or metallic slide rule produced by a reputable manufacturer; an accompanying case is a necessary accessory. The following manufacturers are among those who produce slide rules of excellent quality:

Eugene Dietzgen Company, 2425 Sheffield Avenue, Chicago, Illinois.
Keuffer & Esser Company, Hoboken, New Jersey.
Pickett & Eckel, Inc., 1111 South Fremont Avenue, Alhambra, California.
Frederick Post Company, Box 803, Chicago, Illinois.
United States Blue Print Paper Co., 207 South Wabash Avenue, Chicago, Illinois.
F. Weber Company, 1220 Buttonwood Street, Philadelphia, Pennsylvania.

If an individual desires a metallic circular slide rule, he will find that the Gilson Slide Rule Company, Stuart, Florida, is among those producing a good rule.

III. PARTS OF A SLIDE RULE

The straight slide rule consists essentially of three main parts, the body, the slide, and the indicator. These are as indicated in Figure 2.

The largest part of the slide rule is the *body* and consists of the two outer pieces of wood or metal held apart on each end by metallic end plates. Both front and reverse faces of the body are covered with plastic or painted and have lithographed, printed, or stamped scales. The body sometimes is referred to as the *stock*.

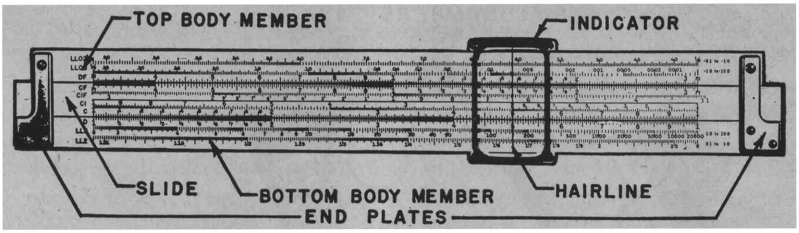

FIG. 2: Main Parts of a Slide Rule

The second part of the slide rule is the *slide*, that long narrow central sliding member which moves between the two members of the body. Like the body, the slide has scales on both of its faces. The slide also is called the *slider*.

The *indicator* is the glass or plastic runner, generally framed in a metallic holder, with a black or red *hairline* placed perpendicular to the direction of sliding of the indicator along the body of the rule. All good rules have double indicators, that is, the indicator consists of the metal frame with two plastic or glass sheets with hairlines, one on the front face and one on the rear face of the rule. The hairlines of the double indicator move together since they are carried by the same indicator. Sometimes the indicator is referred to as the *cursor*.

The calibration marks on both the body and the slide along with the accompanying figures are called the *scales*. It is interesting to note that even though the most commonly used straight slide rule is referred to as being a ten inch rule, its scales generally are twenty-five centimeters in length, approximately 0.16 inch less than ten inches. A few of the modern American slide rules have scales that actually measure ten inches in ength.

IV. ADJUSTING A SLIDE RULE

Before one purchases a slide rule, it is best that he be permitted to make the following adjustments to assure himself of obtaining a rule of highest quality. If he is unable to check the adjustement of a slide rule before purchase, he should have a definite understanding with the dealer that if the rule is defective and can not be placed in adjustment, it may be returned for a rule that can be adjusted correctly.

The purchaser should check the serial number listed on the slide and the body of the rule to be sure that they correspond. Do not mistake model number for the serial number. If one obtains a rule with a slide and body that have different serial numbers, it is possible that these two members will not fit together as well as they should. Some straight slide rules, particularly the metallic kind, do not have serial numbers. Circular rules practically never have serial numbers since they have an extra indicator in place of the slide. Figure 3 indicates the location of the serial numbers on two straight slide rules.

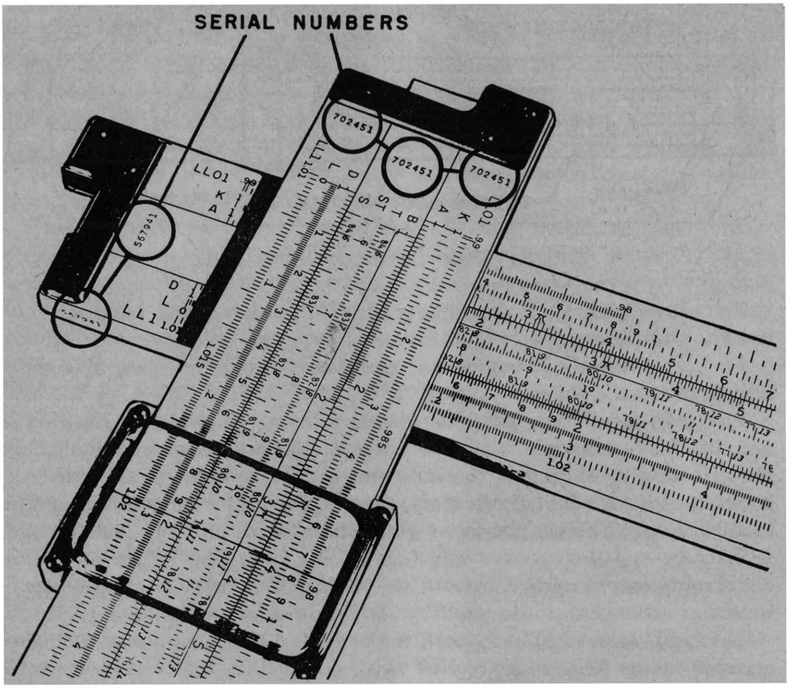

FIG. 3: Slide Rule Serial Numbers

The slide should be placed in the rule in a manner that the front of the slide is on the front face of the rule and the reverse side of the slide is on the reverse face of the rule. Scales generally appearing on the front side of the slide are the *CF*, *CIF*, *CI*, and *C* scales. The front face of the rule generally contains the *L*, *LL1*, *DF*, *D*, *LL2*, *LL3*, *LL'0*, R_1, R_2, or similar scales.

Looking at the front face of the rule, place the slide in the position where the left index (the line at 1 on the extreme left end of the scale) of both the *C* and *D* scales coincide. When this occurs, the right indexes (the line at 1* on the extreme right of the scale) of the same *C* and *D* scales must coincide. If they do not, do not purchase this rule since this can not be corrected by adjustment because the scales on the slide (*C* scale) and the body (*D* scale) differ in length. For a rule to be accurate, the lengths of these two scales must be the same. At the same time that both pairs of indexes of the *C* and *D* scales on the front face of the rule coincide, the two pairs of indexes of the bottom scale of the top member of the reverse face of the body and the top scale of the reverse face of the slide should coincide. If this does not occur, reject the rule for the same reason previously mentioned.

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*On some rules the right index of the *C* and *D* scale is 10 rather than 1.

With the slide in the position where the above four pairs of indexes coincide, alignment of the top member of the body should be checked. The left and right pairs of scale end marks (sometimes called adjustment indexes) of the *DF* and *CF* scales on the front face of the rule should coincide. If they do not (and frequently they do not on new, unadjusted rules), loosen the body adjusting screws indicated by A and B in Figure 4, move the top body member back and forth until

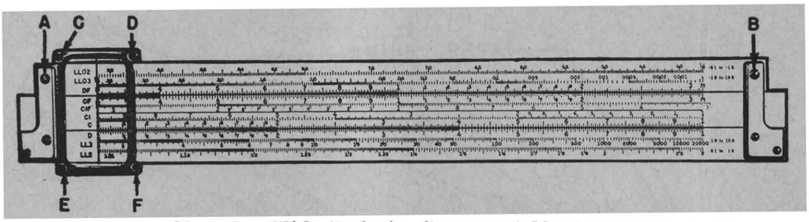


FIG. 4: Slide Rule in Correct Adjustment

these two pairs of indexes coincide, and tighten securely screws A and B. Be sure not to damage the heads of these screws. When this adjustment has been made, turn the rule over without moving the slide relative to the body and note whether the two pairs of indexes of the top scale of the bottom member on the reverse face and the bottom scale of the reverse face of the slide coincide. If they do not, do not attempt to adjust the rule any further; reject the rule.

With the slide set and the rule adjusted where the previously mentioned eight pairs of indexes coincide (four on each side of the rule), the indicator hairline now must be adjusted. Loosen the indicator adjustment screws (C, D, E, and F in Figure 4) on both sides of the rule, adjust the indicator by moving the hairline until it coincides with the vertical pair of coincident indexes on the left end of the front face of the rule, tighten the four indicator adjusting screws on the front side of the indicator, and, without moving the indicator or slide relative to the body of the rule, carefully turn the rule over until the reverse face is up. Adjust the indicator on this side by moving the hairline until it coincides with the corresponding pair of vertical indexes on the left end of the reverse face of the rule; then tighten the four indicator adjusting screws on the reverse face of the indicator. Care should be exerted not to damage the threads and heads of the indicator adjusting screws. With the exception of testing the tightness of the slide, the rule now is in adjustment. Figure 4 illustrates a slide rule that is in correct adjustment.

Move the slide back and forth between the two possible extreme positions of sliding keeping the *C* and *D* scales slightly overlapped. If the slide appears to move with great difficulty, with a wide variation of force required to move it from one end of the rule to the other, or appears to move too freely, the tightness of the slide should be adjusted. A slide is adjusted too loosely if, when the rule is held by one end of the body with the slide in a vertical position, the slide falls under just the effect of gravity. To effect correct tightness of the slide, loosen the two body adjusting screws (A and B in Figure 4) without permitting the top body member to slide relative to the remainder of the rule, insert two equal thickness pieces of thin paper between the slide and the top body member at the two ends of the rule as indicated in Figure 5, press each end of the top body member tightly to the

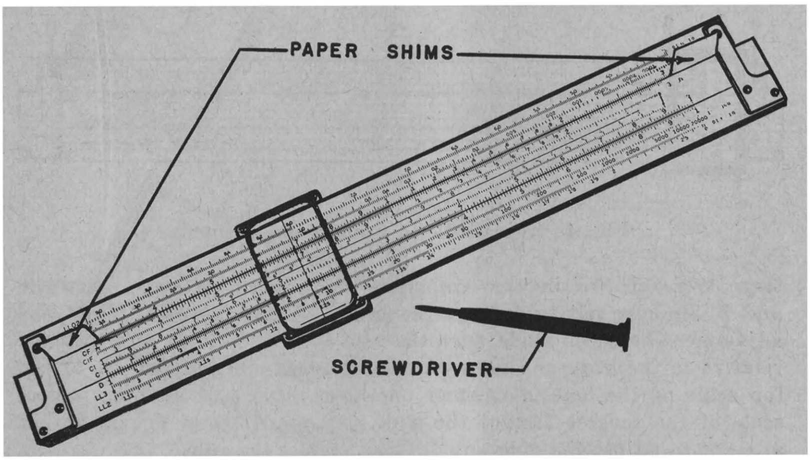


FIG. 5: Adjusting Slide for Tightness

slide, and tighten the body adjusting screws. When this adjustment is made, care must be exercised to be sure that all the previously mentioned pairs of coincident indexes are not put out of adjustment. Tracing paper or tissue paper serves well as a thickness gage. The thickness of the paper employed determines the looseness of the slide. Completely remove the slide from the body, carefully remove all traces of paper, and reinsert the slide correctly in the body.

The slide rule now is in adjustment and ready for efficient operation.

In a few cases, new rules have warped slides or body members. When this occurs, the amount of force required to move the slide from one end to the other is not uniform, even though the above adjustment has been made. If this variation is appreciable, reject the rule.

V. CARE OF THE RULE

Keep the slide rule in its case at all times except when it is in actual operation. This protects the rule against mechanical damage and also reduces the possibility of warping of its members as a result of high humidity. Most individuals prefer a leather case in which to carry or store the rule, however plastic and paper cases also are useful. Regardless of the material of the case, the protection of the case should not be neglected. If a case is not used, scratched scales, broken indicators, chipped scales if the rule is plastic, and warped slides or body members generally result in a surprisingly short time. The slide rule is a precision instrument; it should be treated as such.

Do not store the slide rule where it is subjected to conditions of high temperature or humidity, such as by an open window, in the direct sunlight, or near a source of heat. Warped and discolored scales are a result of these conditions.

Although some individuals rub a bar of soap over the engaging edges of the slide and body of a wooden or plastic slide rule (or castor oil in the case of a metallic rule) in an effort to ease the motion of the slide, this practice should be avoided. Proper adjustment of the rule is the best solution to a sticky or sluggish slide.

With usage and age, the scales of the rule become discolored and dirty. The use of an artgum eraser, carbon tetrachloride cleaner, or both to clean the scales and indicator is surprisingly efficient, however care should be exerted not to damage the scales. The use of soap and water is not recommended except with metallic slide rules, and then only sparingly.

The best manner in which to clean the indicator surfaces adjacent to the rule is to disassemble the indicator, thoroughly clean all parts, and reassemble and adjust the indicator. A makeshift job of cleaning often can be accomplished by placing a strip of paper between the indicator and the slide rule body and, while applying a moderate amount of force to the indicator, move the indicator back and forth across the paper.

In the case of stubborn stains and yellowing due to carelessness or age, the judicious use of a bleaching solution, ammonia, alcohol, dye solvent, naphtha, or similar substance may be found useful, however great caution should be exerted to prevent the possible damage of the calibrating marks on the scales. Frequently these solutions will dissolve the die or ink used to mark the scales or will even dissolve the material from which the scales are made or covered.

It is alarming how many slide rules each year are damaged by cigarettes. Careless smokers and operating slide rules are not winning combinations.

After each cleaning of the rule, the adjustment of the rule should be checked and the necessary corrective adjustments applied.

Handle the slide rule carefully. Exert caution not to drop it nor to step on it accidentally.

The individual who respects his slide rule and treats it with as much care as he would treat a valuable camera or watch will find that the rule will remain useful throughout his lifetime. He probably will have his name printed on the rule and the case to effect positive identification.

VI. READING THE SCALES

Every potential user of a slide rule has some experience in measuring distance by use of a yardstick, rule, scale, or tape calibrated in inches. A slide rule is similar to a yardstick in that the numbers appearing on its scales are a measure of the magnitude of numbers rather than the magnitude of distances. On a yardstick, the numbers appearing on the calibration indicate inches, however between these there are several unnumbered lines indicating fractions of an inch (divisions less than an inch). Like a yardstick, the figures on a slide rule scale indicate numbers, and the division lines between numbers indicate magnitude of numbers between the printed figures appearing on the scales. On the yardstick, the division of the scale is uniform. On a slide rule, with the exception of the logarithm scale (generally called the *L* scale), the divisions are not uniform; this is due to the logarithmic background upon which the operating principles of the slide rule are based.

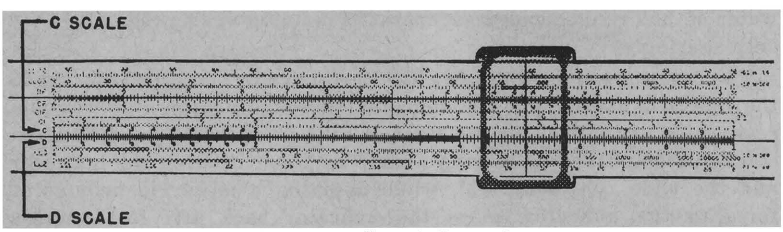


FIG. 6: *C* and *D* Scales

Figure 6 depicts the *C* and *D* scales of the slide rule. These scales are the most generally used scales on the rule; they are employed for multiplication, division, ratios, proportions, and similar calculations. Since these scales are typical, they will be used to demonstrate the location of a number on the slide rule by correct reading of the scales.

As odd as it may appear to the beginner, with few exceptions the decimal point has absolutely nothing to do with the location of a number on the scales of a slide rule; it is the sequence of digits that determines this location. On either the *C* or *D* scales, the location of 2, 20, 2000, 2000000, 0.002, or two with any number of zeros either before or after it will fall at exactly the same position on the scale!

Figure 7 indicates the location of several numbers on a *C* or *D* scale. It is observed by inspecting these scales on the rule that these two scales are identical in length and calibration. Note that the *C* and *D* scales are divided into ten main divisions, indicated by the numbers 1, 2, 3, ...8, 9, 1 (or 10 on some slide rules). Between 1 and 2 on most rules, the space is further divided into ten subdivisions (numbered 1, 2, 3, ...8, 9, 2) and each subdivision is further separated into ten

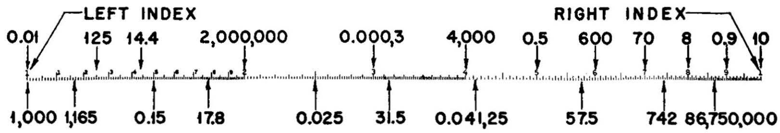


FIG. 7: Location of Numbers on *C* or *D* Scale

unnumbered divisions. On most rules the space between 2 and 3 or between 3 and 4 is divided into ten divisions (not numbered as between 1 and 2 because of the closeness of the divisions on the scale) and each division is further subdivided into five sections (contrasting to ten between 1 and 2). The space on most rules between 4 and 5, 5 and 6, 6 and 7, 7 and 8, or 9 and 1 (or 10 on some rules) is divided into ten unnumbered divisions, each of which is further subdivided into two subdivisions(rather than ten as between 1 and 2 or five as between 2 and 3 or 3 and 4). The reason that the space between two adjacent numbers on the *C* and *D* scales is not equal to the space between any other two adjacent numbers is that the scale is divided logarithmically rather than uniformly. After an individual has mastered finding the location of numbers on the *C* and *D* scales, he generally has no difficulty in locating the positions of numbers on the other scales. Study and restudy Figure 7 very carefully until by logical reasoning (rather than memory) you agree with the location of the scales;1165, 0.04125, 74.2, and 86,750,000 as shown in Figure 7 are good examples of this.

Remember that the decimal point has no bearing upon the position of a number located on the *C* or *D* scales, only the sequence of the digits determine this location.

The word *index* is used to refer to a particular position on the *C*, *D*, *CF*, *DF*, and several other scales. The left index of the *C* or *D* scale is the line at 1 at the extreme left end of the scale. The right index of the *C* or *D* scale is the line at 1 (10 on some rules) at the extreme right end of the scale. Although the extreme left and right ends of the *CF* and *DF* scales frequently are referred to as being adjustment indexes (as was done in Chapter IV on Adjusting a Slide Rule), the true index is the line at 1 near the center of the *CF* and *DF* scales. See Figure 8 for the location of these indexes.

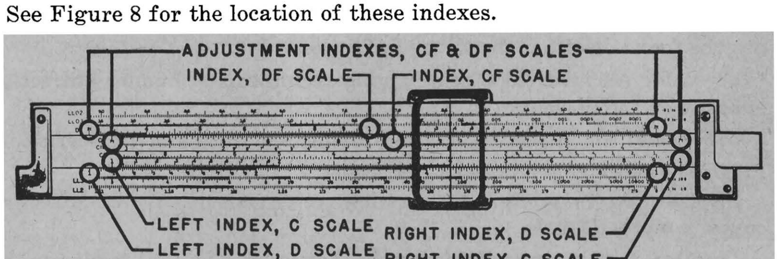


FIG. 8: Location of Indexes

Exercise 1

1. Make a sketch of the *C* or *D* scale indicating the general method of dividing the scale.
2. Indicate the position of the main numbers on your sketch of item 1.
3. On the *C* and *D* scales of your slide rule, locate the correct position of the following:

1.01	286	5.05
1,020	30.1	5,675
0.014,2	0.039,3	0.078,5
0.000,016,9	35,200	0.000,083,5
1,970,000	3,904,250	94.3
2.01	0.004,48	98,300

VII. SCALES ON THE SLIDE RULE

Except for the same model rule made by the same manufacturer, it is very seldom that two slide rules happen to have the same number and kind of scales on them. If this should occur, the placement of the scales on the rule probably would differ. Because of this, no attempt will be made at this time to locate the position of various scales on the slide rule. To the left of each scale is one or more letters and numbers to indicate the name of the scale; a careful inspection of these letters and numbers will enable you to locate any scale that you desire.

Below, the scales are listed according to their most generally known names. In each case the most important uses of these scales is given.

C and *D* scales: Used for multiplication and division, or a combination of multiplication and division; also useful for ratios and proportions.

CF and *DF* scales: Folded at π, otherwise identical to the *C* or *D* scales. In conjunction with the *C* and *D* scales, the *CF* and *DF* scales permit direct calculations involving multiplication and division by π. In mose cases when the slide has been run in the wrong direction and the answer can not be read on either the *C* or *D* scales, the answer may be found on either the *CF* or *DF* scales.

CI scale: An inverted *C* scale giving reciprocals of numbers directly opposite on the *C* scale.

CIF scale: an inverted *CF* scale giving reciprocals of numbers appearing directly opposite on the *CF* scale.

DI scale: An inverted *D* scale giving reciprocals of numbers directly opposite on the *D* scale.

L scale: A uniformly divided scale that is used in conjunction with the *D* scale to give the mantissas of logarithms to the base ten.

A and *B* scales (sometimes called R_1 and R_2 or $\sqrt{}$ scales): Used in conjunction with the *D* scale to obtain the squares and square roots of numbers.

K scale (sometimes called $\sqrt[3]{}$ scale): Used in conjunction with the *D* scale to obtain the cubes and cube roots of numbers.

Log log scales (*LL1, LL2, LL3, LL0, LL00, LL000, LL/0, LL/1, LL/2,* and *LL/3*): Used in conjunction with the *D* scale to obtain powers, fractional powers, decimal powers, and roots of numbers both less than and greater than one. They also are used to obtain the logarithms of any number to any base as well as a direct means of obtaining logarithms to the base e.

Trig scales (*T, ST, S, Sec C, ST* and *Cos S*): Used in conjunction with the *D* scale to obtain the natural trigonometric functions of angles.

Hyperbolic scales (*Th, Sh 1,* and *Sh 2*): Used to obtain the hyperbolic functions of angles. These scales are particularly useful in solving vector equations.

In addition to the scales listed above, a number of scales containing special information may appear on a slide rule.

VIII. MULTIPLICATION

Multiplication of two or more numbers generally is accomplished by use of the *C* and *D* scales, however the *CF* and *DF* scales are useful for this purpose.

Let us attempt to multiply 2 by 3 by use of the *C* and *D* scales. Locate 2 on the *D* scale, move the slide until the left index of the *C* scale coincides with the 2 on the *D* scale, slide the indicator until its hairline coinsides with 3 on the *C* scale, and read the answer 6 on the *D* scale directly under the hairline. Without moving the slide move the indicator until the hairline coincides with 4 on the *C* scale; reading 8 on the *D* scale under the hairline indicates that 2 (on the *D* scale) times 4 (on the *C* scale) equals 8 (on the *D* scale). This is shown in Figure 9.

Now try multiplying 3 times 3. Find 3 on the *D* scale, move the slide until the left index of the *C* scale coincides with the 3 on the *D* scale, slide the indicator until the hairline coincides with 3 on the *C* scale, and read the answer 9 under the hairline on the *D* scale. Without moving the slide, attempt to multiply 3 by 5 by moving the indicator until the hairline coincides with 5 on the *C* scale; of course this can not be done since it is off the rule. If the indicator could have been placed with the hairline on 5 on the *C* scale and if the *D* scale were repeated to the right of the rule, the correct answer 15 could have been read under the hairline on the *D* scale extended as shown in Figure 10. This is not practical. In multiplying 3 by 5, if the *right* index of the *C* scale has been placed over 3 on the *D* scale and the indicator moved until the hairline coincided with 5 on the *C* scale, the

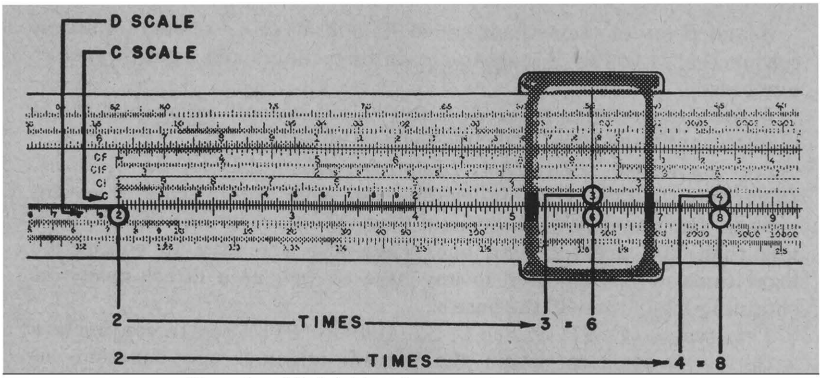


FIG. 9: Multiplication on *C* and *D* Scales

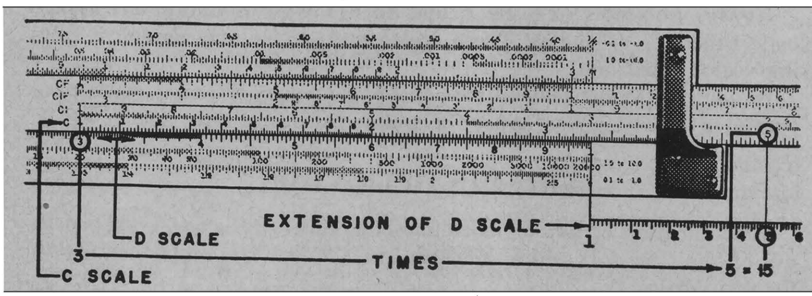


FIG. 10: Multiplication on *C* and *D* Scales

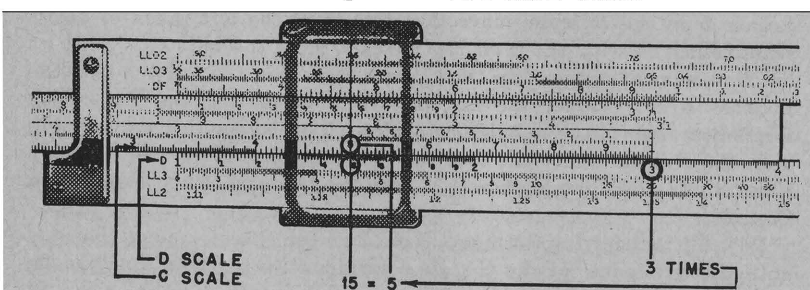


FIG. 11: Multiplication on *C* and *D* Scales

correct answer 15 could have been read under the hairline on the *D* scale. This is shown in Figure 11.

In multiplying on the *C* and *D* scales, it makes no difference whether the left or right index is employed to so long as the answer falls on the rule on the readible portion of the *D* scale. This means that the slide rule operator best should develop an intuition telling him which index to use, that is, which direction to move the slide. With little practice, the selection of the correct index becomes almost automatic.

Note that in the above operations the decimal point location was neglected. Had we desired to multiply 20 by 300, 0.003 by 30, or 300 by 50, our slide rule operations would have been identical to the three indicated above. The only difference is that we would have placed the decimal point in a different location in the answer. How to find the correct position of the decimal point will be discussed in Chapter X; for the time being we shall resort to reasoning.

Had we so desired, we could have employed the *DF* and *CF* scales to multiply, the *CF* scale corresponding to the *C* scale and the *DF* scale corresponding to the *D* scale. Figure 12 indicates the use of the

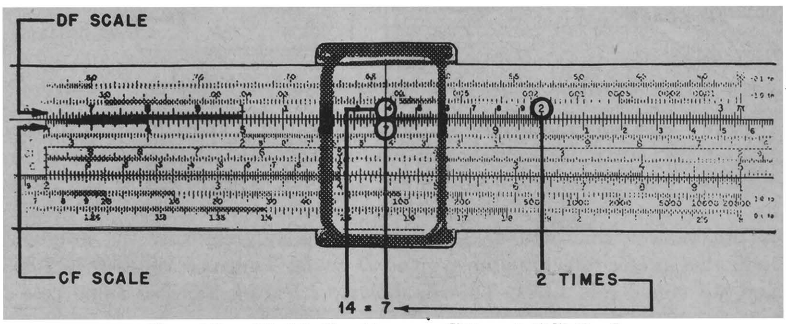


FIG. 12: Multiplication on *CF* and *DF* Scales

folded scales to multiply 2 times 7 showing that 2 (on the *DF* scale) times 7 (on the *CF* scale) gives 14 (on the *DF* scale). Note that the indexes of the *CF* and *DF* scales used for multiplication (or division) are at the Figure 1 near the center of these scales and that in multiplying 2 times 7, the index of the *CF* scale was placed to coincide with 2 on the *DF* scale, the indicator was moved until the hairline coincided with 7 on the *CF* scale, and the answer 14 was read under the hairline on the *DF* scale.

For rapidity of calculations, particularly when the *C* and *D* scales are used and the wrong index of the *C* scale has been used (the one that gives an answer off the *D* scale), the use of the *CF* and *DF* scales in conjunction with the *C* and *D* scales is recommended. Let us attempt to multiply 135 by 8 by use of the *C* and *D* scales. Place the left index of the *C* scale to coincide with 135 on the *D* scale. With this setting of the slide, it is impossible to slide the indicator hairline to 8 on the *C* scale, however by jumping to the *CF* and *DF* scale without moving the slide any more, when the hairline is moved to 8 on the *CF* scale, the answer 1080 can be read under the hairline on the *DF* scale. This is shown in Figure 13.

If the product of more than two numbers is desired, multiply the first two numbers together, multiply this product by the next number, and repeat this process until all numbers have been multiplied together. In order to multiply $2 \times 3 \times 4$ multiply 2 by 3 to obtain 6, then multiply this 6 by 4 in order to obtain the answer 24.

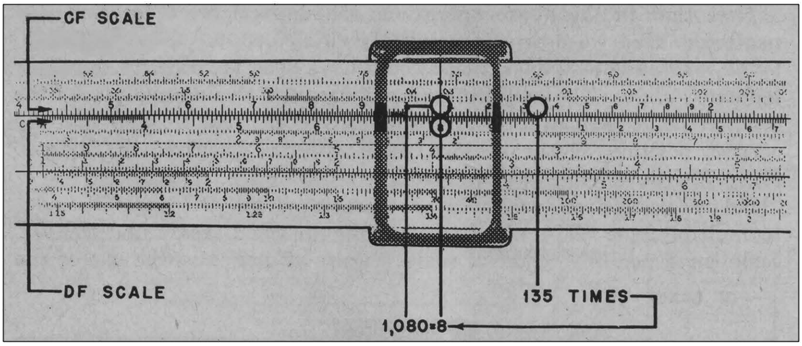


FIG. 13: Multiplication on *CF* and *DF* Scales

If it is desired to multiply a number by π, the *D* and *DF* scales or the *C* and *CF* scales are extremely useful since no setting of the slide need be made when these scales are employd. Regardless of the indicator hairline setting, wherever the hairline crosses the *DF* scale is the answer that will be obtained by multiplying π by the number indicated under the hairline o nthe *D* scale. Thus 2.5 times π is 7.85 and 0.5 times π is 1.571. This is shown in Figure 14. The same rela-

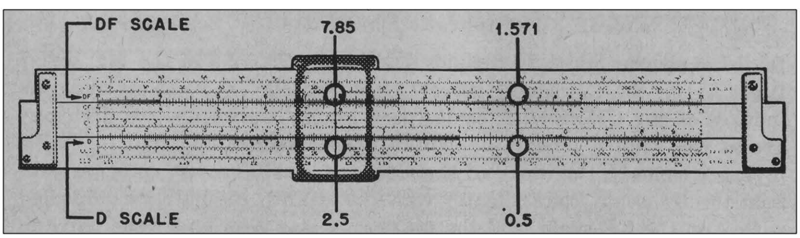


FIG. 14: Multiplication by π by Use of *DF* and *D* Scales

tionship existing between the *DF* and *D* scales also exists between the *CF* and *C* scales in that any number on the *C* scale times π may be read directly above on the *CF* scale.

Exercise 2

a. By use of just the *C* and *D* scales, perform the following multiplications:

1. 2×3.5
2. 17×41
3. 9.5×2
4. 3.75×5
5. 64×400
6. 0.16×0.05
7. 1,080×0.000,3
8. 63.5×18.12
9. 2×3×8
10. 17×35×0.035

b. By use of just the *CF* and *DF* scales, perform the multiplications indicated above.

c. By combining the use of the *CF* and *DF* scales with the *C* and *D* scales, perform the multiplications indicated above.

IX. DIVISION

Division, being the reverse of multiplication, is treated as such on the slide rule. As in multiplication, the *C*, *D*, *CF* and *DF* scales are employed in division.

Division actually is simpler than multiplication since the slide rule operator need not bother about which is the correct index of the *C* scale to be used in order to obtain an answer that falls on the readible portion of the *D* scale.

Let us attempt to divide 15 by 3 by use of the *C* and *D* scales. The indicator is moved until the hairline coincides with 15 on the *D* scale, the slide is moved until 3 on the *C* scale coincides with the hairline, and the answer 5 is read on the *D* scale under whichever index of the *C* scale happens to fall over the *D* scale. In this case the right index of the *C* scale is employed. 15 (on the *D* scale) divided by 3 (on the *C* scale gives 5 (on the *D* scale). This is shown in Figure 15.

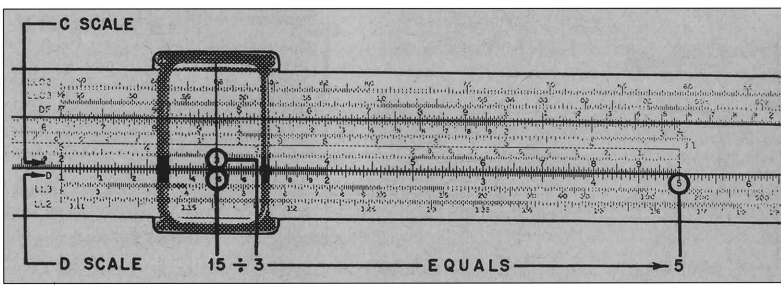


FIG. 15: Division on *C* and *D* Scales

In dividing 4 by 14, set the indicator hairline to coincide with 4 on the *D* scale, move the slide until 14 on the *C* scale coincides with the hairline, and read the answer of approximately 0.286 on the *D* scale under the left index of the *C* scale.

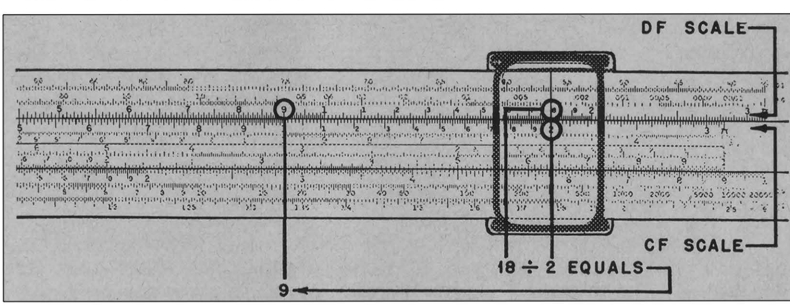


FIG. 16: Division on *CF* and *DF* Scales

Figure 16 illustrates the use of the *CF* and *DF* scales to divide. In this case, 18 is divided by 2 to give 9. The indicator hairline is set to coincide with 18 on the *DF* scale, the slide is moved until the 2 on the *CF* scale coincides with the hairline, and the answer 9 is read on the *DF* scale directly above the index of the *CF* scale.

Sometimes the slide rule operator finds it advantageous to use a combination of the *C* and *D* scales and the *CF* and *DF* scales on order to perform division operations in much the same manner that he finds it advantageous to employ these same scales for multiplication.

If it is desired merely to divide a number by π, the *DF* and *D* scales or the *CF* and *C* scales are useful since no setting of the slide need be made when these scales are used. Regardless of the indicator setting, wherever the hairline crosses the *D* scale is the answer that will be obtained by dividing the number indicated on the *DF* scale under the hairline by π. Thus 4 divided by π is 1.273, 12 divided by π is 3.82, and 2 divided by 10 π is 0.0637. This is shown in Figure 17. The *CF* and *C* scales may be used in the same manner as the *DF* and *D* scales in order to obtain the value of any number divided by π.

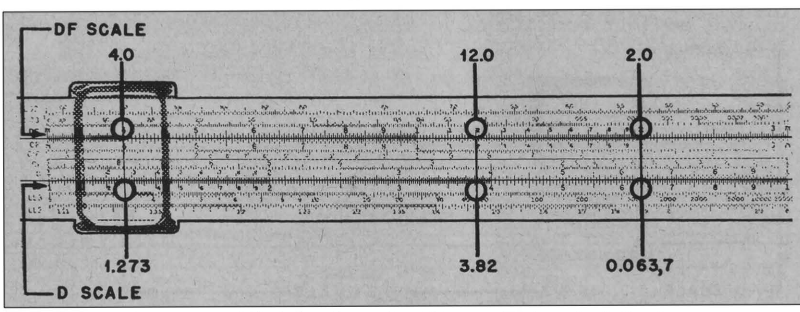


FIG. 17: Division by π by Use of *DF* and *D* Scales

Exercise 3

a. By use of the *C* and *D* scales, perform the following divisions:

1. $\frac{25}{5}$

2. $\frac{76}{5.85}$

3. $\frac{102}{0.0109}$

4. $\frac{99.6}{22.3}$

5. $\frac{125}{10}$

6. $\frac{18}{6.67}$

7. $\frac{34}{53.85}$

8. $\frac{1,785}{47.4}$

9. $\frac{0.003,47}{18.9}$

10. $\frac{46.53}{0.0086}$

b. By use of the *CF* and *DF* scales, perform the divisions indicated above in item a.

X. PLACEMENT OF THE DECIMAL POINT

With the exception of the use of the log log and the hyperbolic scales, the operator does not obtain the decimal point directly from the scales of the slide rule. The only scales of the slide rule having decimal points are the log log scales and the hyperbolic function scales; only the vector rules have this last scale. There are many methods employed to determine the location of the decimal point in the answer; these include guessing, expressing numbers in terms of a number between one and ten times ten to some power, logarithm characteristic method, significant digit method, and other more complicated methods.

The method of guessing is by far the quickest, however it also is the most inaccurate. Expressing numbers in terms of powers of ten is the time-proven method of decimal placement, however it is slower than some other methods. The logarithm characteristic method and the significant digit method are almost identical, either one having approximately the same merit.

Believing that the quickest reliable method is the best method to use for purposes of illustration, the author decided to employ the significant digit method of decimal placement in this simplified slide rule manual. This decision was made after exhaustive examination of the slide rule methods employed by The University Interscholastic League Slide Rule Contest winners over a period of four years indicated that a majority of these winners employed the significant digit method of decimal placement.

The first significant digit is defined as that digit other than zero which first occurs in the number. The first significant digit of 83.4 is 8 and that of 0.004,28 is 4.

In order to understand the significant digit method, it is necessary that the slide rule operator have experience in indicating the position of the decimal point with reference to the first significant digit of the number. In the number 793.45, there are three digits before the decimal point, therefore one could refer to there being plus three digits before the decimal, or simply +3. in the number 0.002,54, there are two zeros after the decimal point and before the first significant digit, therefore one could refer to there being minus two significant digits in this number, or simply—2.

Exercise 4

By use of the method given above, practice indicating the location of the decimal point with reference to the first significant digit in the following numbers:

1. 0.004,37	*6.* 76,400
2. 12,060	*7.* 125,744,030
3. 25,000	*8.* 0.000,004,09
4. 0.925	*9.* 3.14
5. 8,564	*10.* 0.065,72

Now let us attempt to employ this significant digit rule by determining the location of a decimal point in an answer. Let us multiply 55 by 3. If the *C* and *D* scales are used, the right index of the *C* scale is set to coincide with 55 on the *D* scale, the indicator hairline is moved to coincide with 3 on the *C* scale, and the answer 165 is read on the *D* scale under the hairline. Up to now we have paid very little attention to the direction in which the slide extends with reference to the body of the rule, that is, to the right or the left. In the above example the slide extends to the left. 55 has +2 significant digits before the decimal and 3 has +1 significant digit before the decimal; +2 added algebraically to +1 gives +3, the number of digits in the answer before the decimal point. In our example above, to indicate +3 digits in the answer before the decimal, we would place the decimal after the 5 as 165.0.

If, when multiplying two numbers together by use of the *C* and *D* scales, the slide moves to the left, the algebraic addition of the number of significant digits relative to the decimal in the two numbers being multiplied together gives the number of significant digits in the product relative to the decimal.

When the slide moves to the right instead of the left, a *correction* of —1 must be made. If, when multiplying two numbers together by use of the *C* and *D* scales, the slide extends to the right, algebraically add the total number of significant digits relative to the decimal in the two numbers being multiplied together and *subtract one* in order to obtain the number of significant digits in the product relative to the decimal. To illustrate this, let us multiply 2 by 4. The slide moves to the right when we use the *C* and *D* scales, therefore according to the rule above, the number of digits in the answer before the decimal would be +1 (for the 2) plus +1 (for the 4) minus 1 (correction for the slide extending to the right) equals +1, making the answer 8.0.

Below are several multiplications determined by use of the *C* and *D* scales. The direction of slide motion when these scales are used is as indicated. The number of digits relative to the decimal point along with correction for slide extending to the right is shown. Study and restudy these examples until you completely understand them and agree with them, then go to practice exercise 5.

For the slide extending to the *left* of the rule:

a. $66 \times 400 = 26{,}400$	Problem
$(+2) + (+3) = (+5)$	Decimal Placement

b. 0.055×0.002=0.000,110 Problem
(—1)+(—2)=(—3) Decimal Placement

For the slide extending to the *right* of the rule:

c. 155×3=465 Problem
(+3)+(+1)—1=(+3) Decimal Placement

d. 12,500×0.000,4=5.00 Problem
(+5)+(—3)—1=(+1) Decimal Placement

Exercise 5

Determine the correct answers to the problems given below, paying particular attention to the location of the decimal.

1. 17.34×0.003,57	*6.* 0.354×0.098
2. 192×46.8	*7.* 125×52
3. 37×12	*8.* 144×778.26
4. 109.5×0.000,018,4	*9.* 0.004,32×0.333
5. 10,200,000×3.1416	*10.* 123.4×567,893

If it is desired to determine the decimal placement when three or more numbers are multiplied together, determine the decimal placement for the product of the first two numbers, take this product and multiply it by the next number, and determine the decimal placement for this multiplication. Continue this process until all multiplications have been completed and the final decimal placement has been determined. This method permits the slide rule operator to carry the decimal with him step by step; this he generally does in his head.

The decimal placement rules for dividing are almost the reverse of the multiplication rules. They are as follows.

If, when dividing two numbers by use of the *C* and *D* scales, the slide moves to the left, subtract the number of significant digits in the divisor relative to the decimal from the number of significant digits in the dividend relative to the decimal in order to obtain the number of digits in the quotient relative to the decimal.

If, when dividing two numbers by the use of the *C* and *D* scales, the slide moves to the right, subtract the number of significant digits in the divisor relative to the decimal from the number of significant digits in the dividend relative to the decimal and *add one* to obtain the number of digits in the quotient relative to the decimal.

Below are several divisions determined by use of the *C* and *D* scales. The direction of slide motion is indicated and the number of digits relative to the decimal is given. Study and restudy these examples until you completely understand and agree with them, then go to practice exercise 6.

For the slide extending to the *left* of the rule:

a. $\frac{250}{5}=50$ Problem

$(+3)-(+1)=(+2)$ Decimal Placement

b. $\frac{0.003,5}{70}=0.000,05$ Problem

$(-2)-(+2)=(-4)$ Decimal Placement

For the slide extending to the *right* of the rule:

c. $\frac{465}{3}=155$ Problem

$(+3)-(+1)+1=+3$ Decimal Placement

d. $\frac{824}{0.04}=20,600$ Problem

$(+3)-(-1)+1=+5$ Decimal Placement

Exercise 6

Determine the correct answers to the problems given below, paying particular attention to the location of the decimal.

1. $\frac{17.34}{0.003,57}$	*6.* $\frac{0.354}{0.098}$
2. $\frac{192}{46.8}$	*7.* $\frac{125}{52}$
3. $\frac{37}{12}$	*8.* $\frac{144}{778.26}$
4. $\frac{109.5}{0.000,018,4}$	*9.* $\frac{0.004,32}{0.333}$
5. $\frac{10,200,000}{3.141,6}$	*10.* $\frac{123.4}{567,893}$

If a complicated division problem is encountered, requiring several operations of the slide rule, the decimal place must be carried along step by step in order for one to place the decimal in the final answer.

After an individual becomes proficient in the placement of decimals in multiplication and division problems when only the *C* and *D* scales are employed, he generally has no difficulty in determining his own decimal placement rules when other scales are employed. Determining these rules will be left to the ingenuity of the slide rule operator, especially since almost every operator has a different method of remembering decimal place rules for scales other than the *C* or *D* scales.

If a problem is encountered involving both multiplication and division, in the mind of the operator it should be broken down into a series of multiplication or division problems, carrying the decimal step by step, in order to determine the decimal placement in the final answer.

The method of writing the problem determines to some extent the ease at which the decimal rules may be applied. For numbers less than one, a zero should precede the decimal point giving a clear indication that the number is less than one, thus .25 preferably should be written 0.25, .0035 as 0.003,5, etc. In order to aid the counting of digits relative to the decimal, frequently it is found desirable to point off the number into groups of three, beginning at the decimal, by use of commas. Thus 27640 should be written 27,640, 0.03582 as 0.035,82, etc. The problem

$$\frac{139460 \times .02468}{12.0507}$$

might be more readily solved on the slide rule were it written as

$$\frac{139{,}460 \times 0.024{,}68}{12.050{,}7}.$$

Exercise 7

Rewrite the problems below to conform to the suggestions made above:

1. $8432 \times .000043$

2. 17.43×1924.06

3. $\frac{186720}{.12345}$

4. $\frac{12000000}{1728}$

5. $\frac{144 \times 2143}{.0062}$

6. $\frac{2 \times 4030}{1728}$

7. $\frac{182 \times .096}{43714}$

8. $\frac{.19 \times 2400}{18000}$

9. $\frac{2 \times .1}{.01}$

10. $\frac{9876543 \times 2101}{23.456 \times .000078}$

XI. COMBINED MULTIPLICATION AND DIVISION

The slide rule may be used quite readily to solve many problems involving a combination of multiplication and division. A few examples will illustrate this point.

It is desired to find the value of

$$\frac{127 \times 3.93}{4.75 \times 98.7},$$

one method of solution is to multiply together the two numbers in the numerator, multiply together the two numbers in the denominator, and then divide the numerator by the denominator to obtain the answer. Generally this is not the most time-saving procedure. If just the *C* and *D* scales are employed, perhaps the quickest method is to divide 127 by 4.75, multiply this quotient by 3.93, and divide this product by 98.7 to obtain the answer. These operations on the slide rule may be explained as follows. Set 475 on the *C* scale to coincide with 127 on the *D* scale (thereby dividing 127 by 475). Without moving the slide, move the indicator hairline until it coincides with 393 on the *C* scale (thereby multiplying by 393). Without moving the indicator, move the slide until 987 on the *C* scale coincides with the hairline (thereby dividing by 987). Read the answer 1065 on the *D* scale under the right index of the *C* scale. Of course no attempt was made in this illustration to place the decimal correctly in the answer. In order to accomplish this, the previously described decimal placement rules should have been applied for each step of the calculations, yielding a (+1) significant digit relative to the decimal in the answer, making the correct answer 1.065.

If the above problem were solved by longhand procedures, an answer of 1.064,597,6+ would be obtained. Our answer found by the slide rule is equal to the longhand answer rounded off to four significant digits. In most cases, four significant digit accuracy exceeds the degree of accuracy required, hence the use of a slide rule is justified. If an exact answer is desired, carried out to a large number of significant digits, then a calculator or longhand calculations should be used.

As another example of combined multiplication and division, find the value of

$$\frac{0.025{,}7\times 93.1\times 4{,}170}{0.086{,}6\times 27.6}$$

One method of solution is to divide 0.025,7 by 0.086,6, multiply this quotient by 93.1, divide this by 27.6, and multiply this by 27.6 to obtain the answer, 4,170, as read from the *D* scale. Longhand calculations give an answer of 4,174.379+.

Exercise 8

In order to become proficient in the use of the *C* and *D* scales and the decimal point rules in problems involving combined multiplication and division, it is suggested that you find the correct answers, including decimal, of the following problems:

1. $\frac{36\times 51\times 17}{25\times 16\times 37}$

2. $\frac{96.1\times 48.5\times 0.033}{21.7\times 16.4\times 45}$

6. $\frac{48.3\times 17.7\times 39.3}{0.000{,}733\times 0.000{,}044{,}1\times 96{,}400{,}000}$

7. $\frac{0.012\times 0.033\times 41.4\times 76.3}{36.2\times 0.000{,}339\times 0.442}$

3. $\dfrac{0.002{,}77\times 0.046{,}2}{0.003{,}66}$ *8.* $\dfrac{4.14\times 2.41\times 0.0178}{0.013\times 0.016\times 9.5\times 48.2}$

4. $\dfrac{484\times 5.99\times 63.3}{41.2\times 0.067{,}7}$ *9.* $\dfrac{40{,}000\times 58{,}100\times 0.061{,}3}{0.002{,}4\times 78{,}000\times 209}$

5. $\dfrac{0.098{,}8\times 0.136\times 44.4}{100.4\times 0.007{,}7\times 39.5}$ *10.* $\dfrac{200{,}000\times 48{,}100\times 0.000{,}072}{48.2\times 0.000{,}393\times 750{,}000}$

Had you desired, you could have employed the *CF* and *DF* scales along with the *C* and *D* scales to solve the problems above. Whether or not to use the *CF* and *DF* scales depends mainly upon the desire of the slide rule operator and the proficiency of his operations.

XII. RATIOS AND PROPORTIONS

The ratio of two numbers is the quotient of one number divided by another number, thus the ratio of 14 to 7 is 14 ÷ 7 and may be written as

Ratio of 14 to $7=14\div 7=\dfrac{14}{7}=2.$

A statement of equality between two ratios becomes a proportion. An example of a proportion is

$$\frac{14}{7}=\frac{26}{13}\ .$$

This may be expressed in a slightly different form:

$$14:7=26:13\ .$$

If it is desired to solve for x in the following proportion

$$3:2=15:x\ ,$$

the problem could be rewritten as

$$\frac{3}{2}=\frac{15}{x}$$

and solved for x:

$$x=\frac{2\times 15}{3}=10\ .$$

This could be accomplished by elementary division and multiplication procedures on the slide rule. Set 3 on the *C* scale to coincide with 2 on the *D* scale, slide the indicator hairline until the hairline coincides with 15 on the *C* scale, and read that x equals 10 on the *D* scale under the hairline. Without moving the slide, if the indicator hairline were moved to 6, 7.5, and 9 on the *C* scale, the values of x read on the *D* scale under the hairline would be 4, 5, and 6 respectively. We then may write

$$\frac{3}{2}=\frac{15}{10}=\frac{6}{4}=\frac{7.5}{5}=\frac{9}{6}\,.$$

If we desired, we could have jumped to the *CF* and *DF* scales without moving the slide and have read that

$$\frac{3}{2}=\frac{12}{8}=\frac{11}{7.33}\,.$$

Thus when a ratio has been set between two numbers on the *C* and *D* scales, the same ratio will exist between all pairs of coinciding numbers on the *C* and *D* scales as well as between all pairs of coinciding numbers on the *CF* and *DF* scales. Figure 18 illustrates the slide rule set to give the results indicated in the above examples.

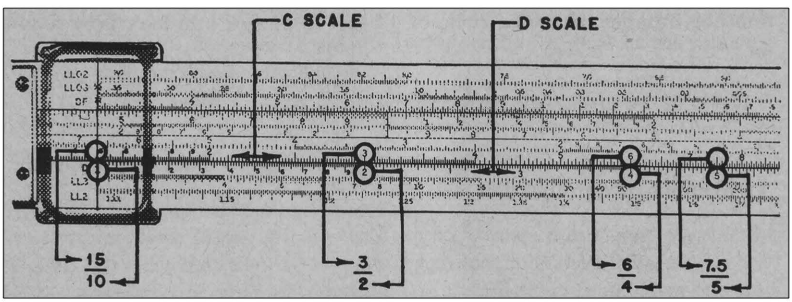


FIG. 18: Ratios by Use of *C* and *D* Scales

Exercise 9.

Find the value of x, y, and z in the following problems:

1. 5:4=3:x=7.5:y
2. 17.8:14.2=19.52:x=2:y
3. x:125=92:y=182:258
4. 6:31=5:y=17,351:z
5. 1:2=2:x=3:y
6. 4:55=x:66=77:z
7. 28.4:x=41:6=z:18
8. 5:25=2:x=z:150
9. 0.0048:x=0.002,5:25=0.009:z
10. 100:x=55:5=75:z

XIII. SQUARES AND SQUARE ROOTS

The determination of squares and square roots on a slide rule varies depending upon which scales appearing on the rule. In general there are two different types of square root or square scales used, those on rules having *A* and *B* scales and those on rules having R_1 and R_2 or two $\sqrt{}$ scales.

For Rules Having A and B Scales

The *A* and *B* scales are identical in calibration, just as the *C* and *D* scales are identical and the *CF* and *DF* scales are identical. The *A* and *B* scales each consist of two *D* scales that have been reduced to half length and placed end on end, with the *A* and *B* scales each having approximately one-half as many calibration lines as the *D* scale. This is shown in Figure 19.

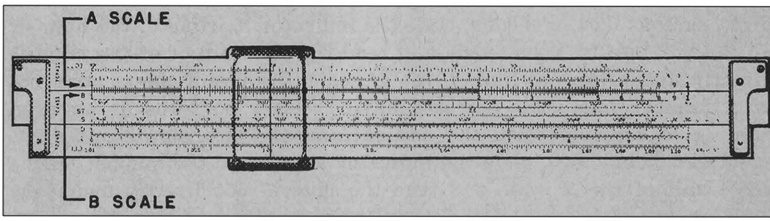


FIG. 19: *A* and *B* Scales

If one desires, he may multiply and divide by use of only the *A* and *B* scales, however the accuracy of his answer will be less than that obtained by using the *C* and *D* scales. This is not the intended use of the *A* and *B* scales.

As far as determining the squares and square roots of numbers is concerned the slide may be removed from the rule since it is not used in these operations. This is shown in Figure 20.

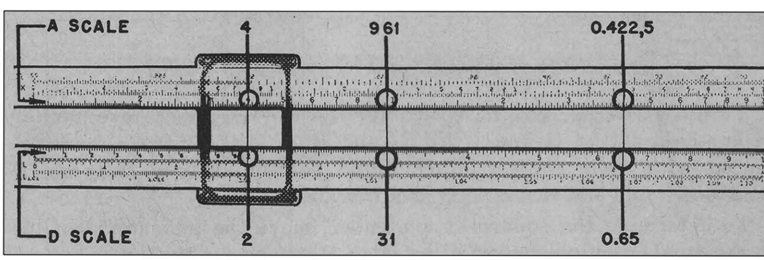


FIG. 20: Squares and Square Roots by Use of *A* and *D* Scales

In order to determine the square of a number, slide the indicator hairline until it coincides with the number on the *D* scale and read the square of the number directly under the hairline on the *A* scale. Thus 2^2 is 4, 31^2 is 961, and 0.65^2 is 0.422,5. The decimal point in the answer is determined by reasoning. See Figure 20.

Determining the square root of a number is the reverse of the above procedure, however care must be taken to locate the number on the correct half of the *A* scale. If it is desired to determine the square root of a number greater than one and having an odd number of digits before the decimal, such as 9 or 125, slide the indicator hairline to this number on the left half of the *A* scale and read the square root directly under the hairline on the *D* scale. If it is desired to determine the square root of a number greater than one and having an even number of digits before the decimal, such as 25 or 4900, slide the indicator hairline to the number on the right half of the *A* scale and read the square root directly under the hairline on the *D* scale. If it is desired to obtain the square root of a number less than one and having an odd number of zeros between the decimal and the first significant digit, such as 0.04 or 0.0009, slide the indicator hairline to the number on the left half of the *A* scale and read the square root of the number directly under the hairline on the *D* scale. To obtain the square root of a number less than one and having either no zeros or an even number of zeros between the decimal and the first significant digit, such as 0.25 or 0.009, slide the indicator hairline to the number on the right half of the *A* scale and read the square root directly under the hairline on the *D* scale. The decimal point in the square root is determined by reasoning. Even though it was pointed out that the slide could be removed from the rule (since it is not used) when squares and square roots are determined, most slide rule operators leave the slide in the rule and disregard it. Figure 20 indicates the solution of a number of squares and square roots as determined by using the *A* and *D* scales.

The problems given in exercise 10 should be practiced until the individual has no difficulty whatsoever in determining squares and square roots of numbers, both in the digits of the answer and the decimal placement.

For Rules Having R_1 and R_2 or Two $\sqrt{}$ Scales

Note that the R_1 and R_2 scales (or the two $\sqrt{}$ scales) are similar to one-half of the *D* scale; the R_1 and R_2 *scales* (or two $\sqrt{}$ scales) placed with their ends together would be similar to a complete *D* scale but would be twice as long as a *D* scale.

To determine the square of a number, move the indicator hairline to the number on whichever of the R_1 or R_2 scales (or the top or bottom $\sqrt{}$ scale) on which the number appears and read the square directly under the hairline on the *D* scale. Note that the slide is not used and could have been removed from the rule if the operator so desired.

Determining the square root of a number is the reverse of the above procedure, however care must be taken to locate the square root on the correct scale (either the R_1 or R_2 scale or the first or second $\sqrt{}$ scale). If is is desired to determine the square root of a number greater than one and having an odd number of digits before the decimal (such as 2 or 625), set the indicator hairline on the number on the *D* scale and read the square root under the hairline on the R_1 scale (or first $\sqrt{}$ scale). To determine the square root of a number greater than one and having an even number of digits before the decimal (such as 16 or 4,900), set the indicator hairline on the number on the *D* scale and read the square root under the hairline on the R_2 scale (or second $\sqrt{}$ scale). To determine the square root of a number less than one and having an odd number of zeros between the decimal and the first significant digit (such as 0.04 or 0.000,9), set the hairline on the number on the *D* scale and read the square root under the hairline on the R_1 scale (or first $\sqrt{}$ scale). To find the square root of a number less than one and having either no zeros or an even number of zeros between the decimal and the first significant digit (such as 0.25 or 0.007), set the hairline on the number on the *D* scale and read the answer under the hairline on the R_2 scale (or second $\sqrt{}$ scale). The decimal point is determined by reasoning.

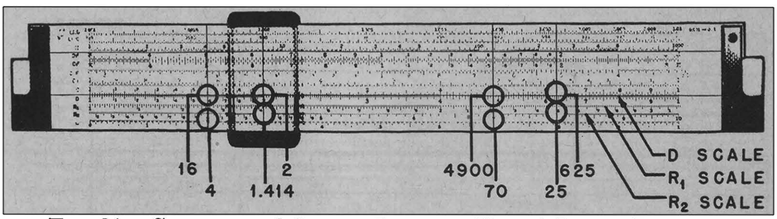


FIG. 21: Squares and Square Roots by Use of R_1 and R_2 Scales

Figure 21 indicates a number of squares and square roots that may be obtained by use of the R_1 and R_2 scales. Figure 22 indicates the same information only by use of the two $\sqrt{}$ scales.

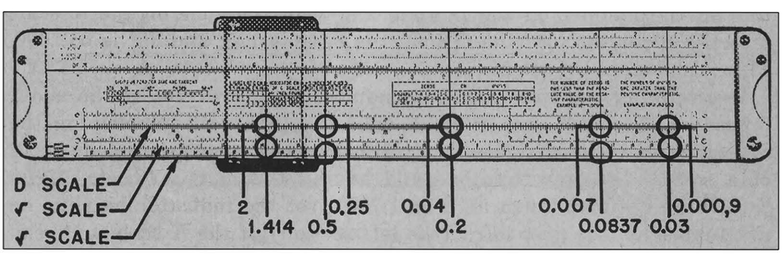


FIG. 22: Squares and Square Roots by Use of the Two $\sqrt{}$ Scales

Exercise 10

Obtain the squares and square roots indicated in the following problems. Be sure to locate the decimal in the answer.

1. $\sqrt{4}$	*6.* $(19.6)^2$
2. $\sqrt{16}$	*7.* $(0.031)^2$
3. $\sqrt{144}$	*8.* $(17{,}241)^2$
4. $\sqrt{0.915}$	*9.* $(5.01)^2$
5. $\sqrt{0.00025}$	*10.* $(0.002{,}32)^2$

XIV. CUBES AND CUBE ROOTS

Determining the cubes and cube roots of numbers is very similar to determining the squares and square roots of numbers except the *K* or the $\sqrt[3]{}$ scales are used in place of the R_1, R_2, or the $\sqrt{}$ scales. These scales are used in conjunction with the *D* scale, decimal placement is determined by reasoning, and the slide does not enter into the operations.

For Rules Having a K Scale

The *K* scale is just like taking three *D* scales that have been shrunk to one-third their regular size and placing them one on end. This is shown in Figure 23.

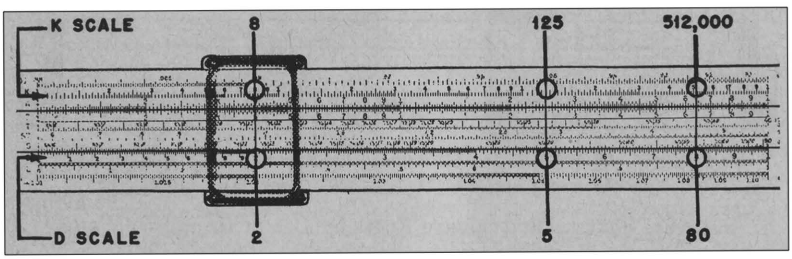


FIG. 23: Cubes and Roots by Use of *K* and *D* Scales

In order to determine the cube of a number, set the indicator hairline on the number on the *D* scale and read the cube on the *K* scale directly under the hairline. Thus 2^3 is 8, 5^3 is 125, and 80^3 is 512,000. This is shown in Figure 23.

Determining the cube root of a number is the reverse of the above procedure, however care must be taken to locate the number on the correct third of the *K* scale. If it is desired to determine the cube root of a number greater than one and having 1, 4, 7, 10, 13, etc. digits before the decimal (such as 8 or 1,728), set the indicator hairline on the number on the first third (the left section) of the *K* scale and read the cube root on the *D* scale under the hairline. To determine the cube root of a number greater than one and having 2, 5, 8, 11, 14, etc. digits before the decimal (such as 27 or 25,000), set the hairline on the number on the second third (central section) of the *K* scale and read the cube root on the *D* scale under the hairline. The cube root of a number greater than one and having 3, 6, 9, 12, 15, etc. digits before the decimal (such as 125 or 175,000) may be found by setting the hairline on the number on the last third (right section) of the *K* scale and reading the answer on the *D* scale under the hairline. To determine the cube root of a number less than one and having 2, 5, 8, 11, 14, etc. zeros between the decimal and the first significant digit (such as 0.008 or 0.000,009), set the hairline on the number on the first third (left section) of the *K* scale and read the cube root on the *D* scale under the hairline. To find the cube root of a number less than one and having 1, 4, 7, 10, 13, etc. zeros between the decimal and the first significant digit (such as 0.06 or 0.000,08), set the hairline on the number on the second third (center section) of the *K* scale and read the cube root on the *D* scale under the hairline. To obtain the cube root of a number less than one and having 0, 3, 6, 9, 12, 15, etc. zeros between the decimal and the first significant digit (such as 0.85 or 0.000,72) set the hairline on the number on the last third (right section) of the *K* scale and read the cube root on the *D* scale under the hairline. Once the digits of the cube root have been determined, the decimal point location easily may be located by reasoning.

The problems in exercise 11 dealing with cubes and cube roots should be practiced until the individual has no difficulty whatsoever in determining the correct answer, both in sequence of digits and decimal point location.

For Rules Having Three $\sqrt[3]{}$ Scales

The three $\sqrt[3]{}$ scales placed end on end would equal one *D* scale, however the total length would be three times as great as the length of the *D* scale. This is shown in Figure 24. Since the three $\sqrt[3]{}$ scales are used in conjunction with the *D* scale, the slide is unused in determining cubes and cube roots.

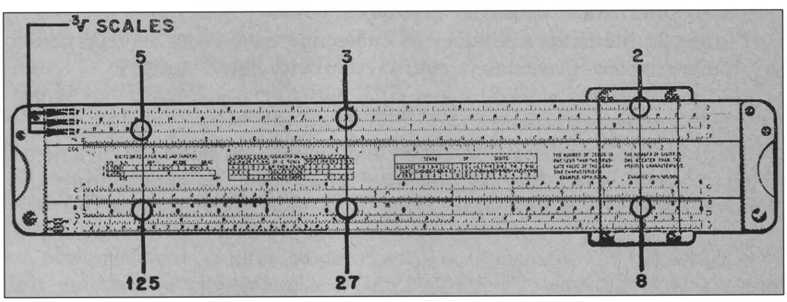


FIG. 24: Cubes and Cube Roots by Use of the Three $\sqrt[3]{}$ Scales

In order to determine the cube of a number, set the hairline on the number on whichever $\sqrt[3]{}$ scale the number appears and read the cube directly on the *D* scale under the hairline. Thus 2^3 is 8, 3^3 is 27, and 5^3 is 125. This is shown in Figure 24. The decimal is located by reasoning.

Determining the cube root of a number is the reverse of the above procedure, however care must be exerted to locate the cube root on the correct one of the three $\sqrt[3]{}$ scales as determined by the relative position of the decimal point and the first significant digit in the original number. If it is desired to determine the cube root of a number greater than one and having 1, 4, 7, 10, 13, etc. digits before the decimal (such as 8 or 1,728), set the hairline on the number on the *D* scale and read the cube root on the first (top) $\sqrt[3]{}$ scale under the hairline. The cube root of a number greater than one and having 2, 5, 8, 11, 14, etc. digits before the decimal point (such as 27 or 25,000) may be found by setting the hairline on the number on the *D* scale and reading the cube root of the number on the second (or middle) $\sqrt[3]{}$ scale under the hairline. To determine the cube root of a number greater than one and having 3, 6, 9, 12, 15, etc. digits before the decimal (such as 125 or 175,000), set the hairline on the number on the *D* scale and read the cube root on the third (or bottom) $\sqrt[3]{}$ scale under the hairline. Cube roots of numbers less than one and having 2, 5, 8, 11, 14, etc. zeros between the decimal and the first significant digit (such as 0.008 or 0.000,009) may be determined by setting the indicator hairline on the number on the *D* scale and reading the cube root on the first (or top) $\sqrt[3]{}$ scale under the hairline. Cube roots of numbers less than one and having 1, 4, 7, 10, 13, etc. zeros between the decimal and the first significant digit (such as 0.06 or 0.000,08) are determined by setting the hairline on the number on the *D* scale and reading the cube root on the second (or center) $\sqrt[3]{}$ scale under the hairline. To find the cube root of a number less than one and having 0, 3, 6, 9, 12, 15, etc. zeros between the decimal and the first significant digit (such as 0.85 or 0.000,72) set the indicator hairline on the number on the *D* scale and read the cube root on the third (or bottom) $\sqrt[3]{}$ scale under the hairline. The decimal point is determined by reasoning.

Figure 24 indicates a number of cubes and cube roots as determined by the use of the $\sqrt[3]{}$ scales in conjunction with the *D* scale.

Exercise 11

The following problems on cubes and cube roots should be practiced until the individual has no difficulty whatsoever in determining the correct answer, both in magnitude and decimal point location:

1. $(5)^3$	*6.* $\sqrt[3]{27}$
2. $(12.6)^3$	*7.* $\sqrt[3]{0.486}$
3. $(436)^3$	*8.* $\sqrt[3]{12{,}144}$
4. $(0.058)^3$	*9.* $\sqrt[3]{0.0068}$
5. $(0.33)^3$	*10.* $\sqrt[3]{12{,}460{,}149}$

XV. INVERTED SCALES

The *CI*, *CIF*, and *DI* scales yield further simplification to solving problems involving multiplication and division. They are of particular assistance in obtaining the reciprocals of numbers.

By inspecting the *CI* and *C* scales, one will find that the *CI* scale is exactly the reverse of the *C* scale; these two scales are equal in length.

The *CI* and *C* scales have the property that regardless of the indicator setting, the number on one of the scales under the hairline is the reciprocal of the number on the other scale under the hairline. This is shown in Figure 25.

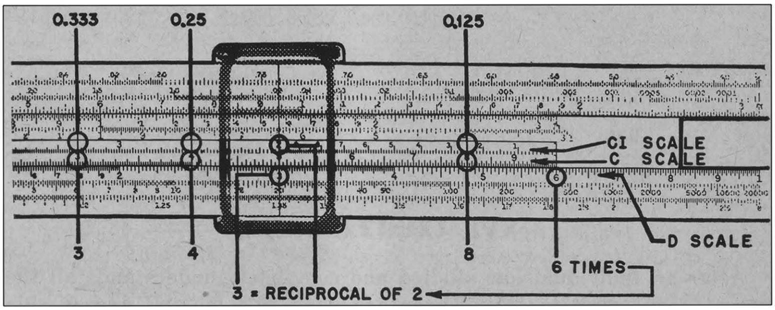


FIG. 25: Reciprocals by Use of *CI* and *C* Scales
Answer to Exercise 1:

The *DI* and *D* scales and the *CIF* and *CF* scales have the same properties of finding reciprocals as have the *CI* and *C* scales.

On many rules the *CI, DI,* and *CIF* scales are in red to warn the operator that they are reciprocal scales.

To illustrate the use of these scales, consider the problem of 6 divided by 2. This may be rewritten as 6 times the reciprocal of 2; this is done on the slide rule by the following operations. Set the right index of the *C* scale over 6 on the *D* scale, slide the indicator until the hairline coincides with 2 on the *CI* scale, and read the answer 3 on the *D* scale under the hairline. This is shown in Figure 25.

The problem $6 \div 2\pi$ may be rewritten as 6 times the reciprocal of 2π. This may be accomplished on the slide rule by setting the left index of the *C* scale over 6 on the *D* scale, sliding the indicator until the hairline coincides with 2 on the *CIF* scale, and reading the answer 0.955 under the hairline on the *D* scale.

The proficient slide rule operator soon determines for himself short-cut methods of employing the *CF, DF, CI, DI,* and *CIF* scales along with the *C* and *D* scales to cut the number of slide rule operations to a minimum and consequently reducing the time required to perform the calculations. This however is something that can be learned only over a reasonable period of time rather than a few days or weeks.

Exercise 12

To practice the use of the inverted (or reciprocal as they sometimes are called) scales, determine the answers to the following problems by use of several different combinations of scales:

1. $625 \div 25$

6. $\dfrac{756}{25\pi}$

2. $\frac{2}{18}$

3. $\frac{100}{2\pi}$

4. $\frac{1}{750}$

5. $\frac{1{,}920}{62.4}$

7. $9.04 \div 39.1$

8. $\frac{1}{0.042}$

9. $0.00691 \div 89.75$

10. $\frac{1{,}230{,}000}{1{,}920\pi}$

XVI. CONCLUSION

After an individual has studied and completely understands all the instructions given in this elementary slide rule manual and is able to perform all slide rule operations more or less automatically without hesitation, he then may classify himself as an efficient slide rule operator. When, after considerable additional practice, he finds that he relies upon his slide rule for almost all calculations and does very few longhand calculations, he has become a proficient slide rule operator. When he catches himself employing the slide rule to multiply 2 times 3, then indeed has he become a slave of the rule. Perhaps this is undesirable, however this indicates the complete confidence of the operator in his slide rule, a situation that must exist if one expects to depend upon slide rule calculations in his profession.

There are many other scales appearing on the advanced modern slide rule which have not been covered in these elementary instructions, the log log scales and the trigonometric function scales being perhaps the most useful of these. A proficient slide rule operator should experience no difficulty in learning the use of these scales should he have a genuine need for them, however the average individual generally has very little use for these complicated scales and complex calculations that they are capable of performing.

XVII. PRACTICE PROBLEMS

1. 326.419×63.4

2. $0.005{,}23 \times 391.4$

3. $418.7 \times 0.001{,}22 \times \pi \times 63{,}402 \times 0.009{,}18$

4. $26.8 \times 0.007{,}87 \times 5{,}210$

5. $\frac{913 \times 7.68}{89.5}$

6. $\frac{5.92 \times 0.008{,}74}{20.45}$

7. $\dfrac{1}{0.007{,}465 \times \pi \times 92.83}$

8. $\dfrac{2{,}860}{0.003{,}42 \times 19.65 \times 0.041{,}6 \times 0.048{,}6}$

9. $\dfrac{1}{1{,}600 \times \pi \times 0.040{,}03}$

10. $\dfrac{8{,}460 \times 7{,}230}{6{,}241 \times 92.20}$

11. $\left(\dfrac{3}{0.078{,}2}\right) \times \left(\dfrac{\pi}{19.2}\right) \times 2{,}983$

12. $\dfrac{0.412 \times 27.6 \times 1{,}305}{66.7 \times 0.96 \times 27{,}500}$

13. $\dfrac{6.67 \times 67.4 \times 11.34}{32.8}$

14. $\dfrac{\left(\dfrac{\pi}{14.92}\right)}{0.020{,}8 \times (17.3)^3}$

15. $\dfrac{286}{19{,}650 \times 0.041{,}6 \times 0.048{,}6 \times 0.003{,}42}$

16. $\dfrac{0.046 \times 0.000{,}713 \times 68.1}{234 \times 9.68 \times 5.1 \times \pi}$

17. $(\pi)^2 \times 0.000{,}032{,}9 \times 18{,}650{,}000$

18. $0.000{,}000{,}912 \times 71{,}432{,}710 \times \dfrac{1}{\left(\dfrac{1}{(\pi)^2}\right)} \times \left(\dfrac{16.1}{49.8}\right)^2$

19. $\dfrac{(891)^3 \times \pi \times (406)^2}{(10)^3 \times (406)^3 \times 8{,}910}$

20. $\dfrac{2 \times 32.2 \times \pi \times 0.005{,}9 \times 0.98 \times (2.916)^2}{4}$

21. $\dfrac{0.119{,}23 \times (17.8)^2 \times 0.628}{2.607 \times (\pi)^2}$

22. $\dfrac{6.298{,}4 \times 0.000{,}047}{\pi \times (3.16)^3 \times 2}$

23. $\dfrac{(\pi)^3\times(0.004{,}3\times7)^2}{0.028\times4{,}917}$

24. $\dfrac{(2.14)^2\times(6.28)^3}{\pi\times(0.146)^2\times987}$

25. $\dfrac{1{,}004\times(2.160)^2\times(4.87)^3}{(4.87)^2\times(2.17)^3\times1{,}004}$

26. $\dfrac{1}{6.09\times72.1\times(0.094\times4)^3\times3.02}$

27. $\dfrac{0.034\times\pi\times(4.27)^3}{0.008{,}3\times(7.19)^2}$

28. $\left(\dfrac{0.063\times\pi}{92}\right)^3$

29. $\dfrac{0.001{,}64\times\left(\dfrac{\pi}{2.75}\right)^3\times7{,}240\times3}{(1.732)^2\times0.002{,}93}$

30. $\pi\times2\times\sqrt{\dfrac{12\times18.1}{32.2}}$

31. $\dfrac{666\times0.022\times44.4}{1{,}004\times\sqrt{\pi}}$

32. $64.3\times\sqrt{\dfrac{1}{17.2}}$

33. $\dfrac{\sqrt[3]{4{,}750}\times3.141{,}6}{(\pi)^3\times\sqrt{71.8}}$

34. $\dfrac{\left(\dfrac{1}{62.4}\right)\times\sqrt[3]{31.006}}{9.869{,}7\times\left(\dfrac{\pi}{429}\right)}$

35. $\dfrac{12\times(12)^2\times(12)^3}{\sqrt{902{,}500}}$

36. $\dfrac{(72)^2\times(72)^3}{\sqrt{7{,}123{,}360}}$

37. $\dfrac{1}{\sqrt{40.9}\times 0.018{,}4\times 0.043{,}1}\times\dfrac{\pi}{16{,}218}$

38. $\dfrac{(0.038)^3\times\pi\times(1{,}000)^3\times\sqrt{7{,}000}}{(94)^3\times(94)^2}$

39. $\sqrt[3]{(\pi)^2}$

40. $\dfrac{100}{\sqrt{17.8}\times 29.17}$

41. $\dfrac{(24)^3\times(785)^2}{\sqrt{962}}$

42. $\dfrac{1{,}634.278\times\sqrt[3]{\pi}}{0.008{,}85}$

43. $\dfrac{\left(\dfrac{17.9}{2.08}\right)^2}{(0.039)^3\times\sqrt[3]{11.543}}$

44. $\sqrt[3]{\sqrt{8{,}303{,}766{,}000}}$

45. $\sqrt{\dfrac{0.021{,}8\times\sqrt{83.9}}{(31.6)^3\times 0.000{,}000{,}067}}$

46. $\sqrt[3]{\sqrt{\dfrac{49.7\times 0.032}{(\pi)^3}}}$

47. $\sqrt{\dfrac{\pi\times 98.6}{1{,}492\times(29)^2}}$

48. $\dfrac{\left(\dfrac{6.28}{84.9}\right)\times\left(\dfrac{0.043{,}7}{91.4}\right)}{4.17\times\sqrt{870.25}}$

49. $\sqrt{\dfrac{\pi\times 934}{\sqrt[3]{93{,}400}}}$

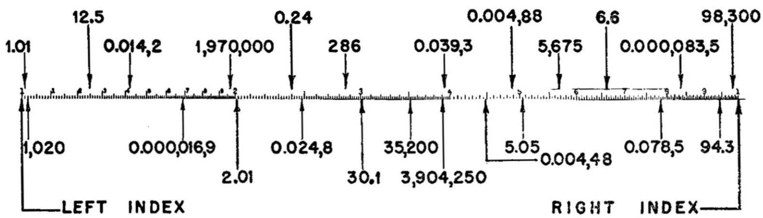
50. $\sqrt[8]{\left(\frac{8.496\times\pi}{4.248}\right)^2}$

XVIII. ANSWERS

The following answers to the exercises and the practice problems are shown after they have been *rounded off to three significant digits,* the accuracy generally expected of a ten inch straight slide rule. In many cases, a careful operator will be able to read from his rule answers that are more nearly correct (more than three digit accuracy) than those given below.

Exercise 1.

Below is a sketch of a typical *C* or *D* scale of a straight slide rule indicating the calibration marks and numbers generally found on this type of rule. Superimposed on the sketch are the locations of the eighteen numbers requested in part 3 of this exercise.



Answer to Exercise 1:

Exercise 2.

1. 7.00
2. 697
3. 19.0
4. 18.8
5. 25,600
6. 0.008,00
7. 0.324
8. 1,150
9. 48.0
10. 20.8

Exercise 3.

1. 5.00
2. 13.0
3. 9,360
4. 4.47
5. 12.5
6. 2.70
7. 0.631
8. 37.7
9. 0.000,184
10. 5,410

Exercise 4.

1. —2
2. +5
3. +5
4. 0
5. +4
6. +5
7. +9
8. —5
9. +1
10. —1

Exercise 5.

1. 0.061,9
2. 8,990
3. 444
4. 0.002,01
5. 32,000,000
6. 0.034,7
7. 6,500
8. 112,000
9. 0.001,44
10. 70,100,000

Exercise 6.

1. 4,860
2. 4.10
3. 3.08
4. 5,950,000
5. 3,250,000
6. 3.61
7. 2.40
8. 0.185
9. 0.013,0
10. 0.000,217

Exercise 7.

1. 8,432×0.000,043

2. 17.43×1,924.06

3. $\dfrac{186{,}720}{0.123{,}45}$

4. $\dfrac{12{,}000{,}000}{1{,}728}$

5. $\dfrac{144.0\times 2{,}143}{0.006{,}2}$

6. $\dfrac{2.0\times 4{,}030}{1{,}728}$

7. $\dfrac{182.0\times 0.096}{43{,}714}$

8. $\dfrac{0.19\times 2{,}400}{18{,}000}$

9. $\dfrac{2.0\times 0.1}{0.01}$

10. $\dfrac{9{,}876{,}543\times 2{,}101}{23.456\times 0.000{,}078}$

Exercise 8.

1. 2.11
2. 0.009,61
3. 0.035,0
4. 65,800
5. 0.019,5
6. 10,800
7. 231
8. 1.86
9. 3,640
10. 48.8

Exercise 9.

1. x=2.40; y=6.00
2. x=15.4; y=1.60
3. x=88.2; y=130
4. y=25.8; z=89,700
5. x=4.00; y=6.00
6. x=4.80; z=1,060
7. x=4.16; z=123
8. x=10.0; z=30.0
9. x=48.0; z=90.0
10. x=9.09; z=6.82

Exercise 10.

1. 2.00
2. 4.00
3. 12.0
4. 0.956
5. 0.015,8
6. 384
7. 0.000,961
8. 297,000,000
9. 25.1
10. 0.000,005,38

Exercise 11.

1. 125
2. 2,000
3. 82,900,000
4. 0.000,195
5. 0.035,9
6. 3.00
7. 0.786
8. 23.0
9. 0.189
10. 232