TENTH EDITION

# MANUAL A

OF

# Modern Surveying Instruments

AND THEIR USES

TOGETHER WITH A

## CATALOGUE & PRICE LIST

OF

SCIENTIFIC INSTRUMENTS

MADE BY

## The A. Lietz Company

Established 1882

632-634 Commercial Street

SAN FRANCISCO, CALIFORNIA

908

50 CENTS

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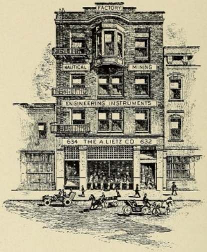


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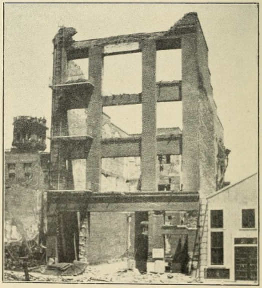

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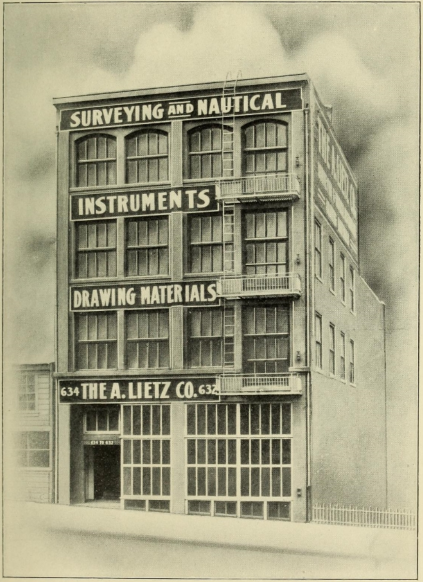


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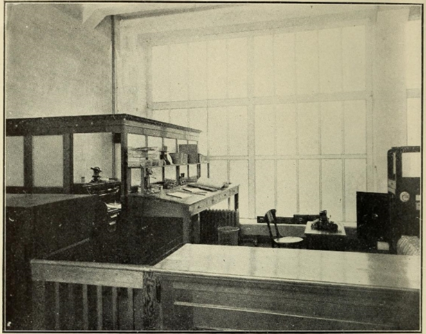

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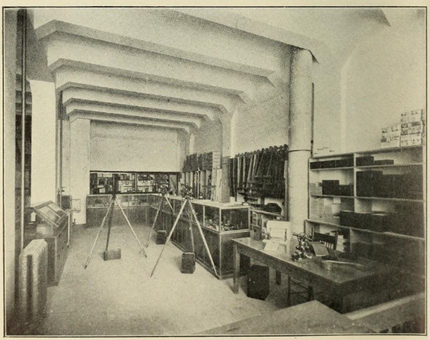

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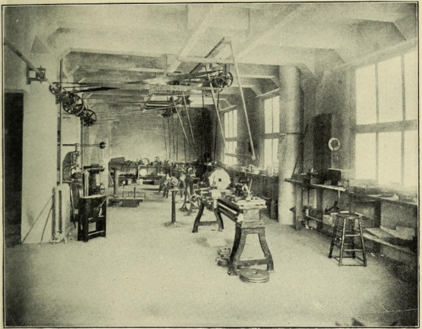

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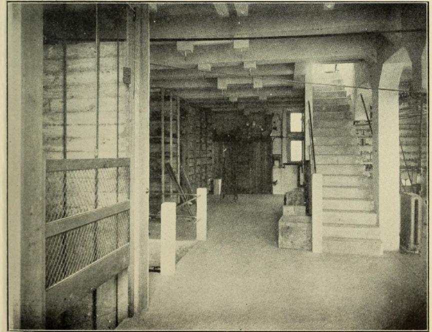
Second Floor.



STORE-ROOM.

No. 2.

# REMARKS ON THE PRINCIPLE OF THE LOGARITHMIC SLIDE SCALE.

Written in 1885, but entirely revised for this Manual in 1893.

By HUBERT VISCHER, C. E.

The employment of mechanical devices for performing computations has attracted the attention of arithmeticians for a couple of centuries past, and to no class of persons is it of more direct interest than to those engaged in technical callings. These endeavors have been pursued upon several distinct lines, and we may notice by way of classification:

1st. The endeavor to perform desired arithmetical operations by devices distinctly mechanical in their nature, seeking by skillful combination of mechanical elements to carry out the ordinary sequence followed by the computer in making the calculation. We may here mention the celebrated machine of Babbage; and as a more recent illustration, the "Arithmometer" of Thomas, an instrument of only moderate cost, and one coming constantly into greater use.

2d. The use of geometrical figures representing the mathematical relations existing between mutually dependent quantities. This method, first suggested by the development of the Des Cartian geometry, has, in very recent times, been developed into a new science, graphostatics—which does not merely seek to present the deductions of analytical reasoning graphically, but starting at the elements, builds up methods of its own in which the arithmetical conceptions of magnitudes fall more and more into the background and are replaced by operations which are mechanical in application, if not in their conception.

Besides these two methods, we have another, somewhat partaking in nature of both, yet embodying a distinct principle of its own, that of the Logarithmic Slide Scale.

It is here proposed to take a cursory survey of this field, which is of wide application and certainly of interest, being an important agent for the saving of time-robbing computations. It is worthy of more general attention than it has received in this country; though in Europe, the slide-rule is recognized as the engineer's daily pocket companion.

The slide-rule rests upon two most simple principles: first, that magnitudes in general may be represented by the length of lines; second, that these lines, when measured off upon one another, may represent by the length of a resulting line, either a summation or a difference of the magnitude which the lines represent. The first principle is made use of in the logarithmic graduation of the scales; the second principle finds application in the sliding motion which we impart to the scales. Slide-rules have been constructed of many kinds and for many special purposes, but they will all be found to reduce to these two elementary principles.

The use of the logarithmic graduation here, as in all other cases where logarithms are employed, is due to the desire to reduce arithmetical calculations by one step in the scale of operations; thus replacing multiplication and division by addition and subtraction, and reducing involution and evolution to multiplication and division.

The method in which the logarithmic graduation is carried out is explained



most easily by taking a special case, and we refer to the scale *AB A′B′* on Fig. 1. The length of this scale, measured between the two extreme outer limits, marked 1, 1, is assumed as a *unit of length;* and what the absolute length of this unit is, is perfectly immaterial. We may, for purposes of illustration, assume it to be just one foot long. As a preliminary step, let us first imagine this length divided off into say 1,000 equal parts. Before proceeding further, however, let us recall to mind the well-known property of "periodical repetition" peculiar to the Briggs system, whereby all numbers represented by the same numerals, grouped in the same order, are represented by the same logarithm, independent of the characteristic or mantissa.

It is clear that with the aid of a table of logarithms and using our scale of equal divisions, we may at once assign to any logarithm in the table a place on the scale, such that its distance from the zero (or left-hand end of the scale), may correctly represent the value of the logarithm, plotted in our unit or standard of length. Doing this for all logarithms, commencing at the number 1, and progressing by any suitable interval (say 1–100 of unity), let us mark each so determined point by a cross-line on the scale, and (in order to preserve it for future use) mark opposite the cross-line the *number* corresponding to the logarithm which the cross-line fixes.

Having done this, we reach the right-hand end of our scale, when in our table we reach the number 10. It is apparent that our scale represents graphically a table of logarithms for all whole numbers between 1 and 10, with suitable subdivisions, and corresponds in all particulars to the printed table from which it was constructed. But it is equally clear that if we agree to consider the scale as representing the fractional part of the logarithm only, and without reference to the "characteristic," we may at once extend its range so as to embrace the whole field of positive numbers without any reservation. The "characteristic" of the logarithm, however, only determines the position of the decimal point in its number. Therefore, this stipulation about dropping the characteristic implies, conversely, that our scale shall only give us the numerals which express a number, without reference to a decimal point; so that, if we read 2, 3, 5 on the scale, we may read this as 235, or as 235 with any number of zeros affixed or prefixed to it; as 0.00235 or as 2350, for example. In slide-rule calculations there must always be some foreign means employed for correctly assigning the position of the decimal point, a matter which will be referred to again later on.

It is now practically shown what constitutes the construction of the logarithmic scale,—only one, however, of an infinite variety of possible logarithmic scales. Any series or group of numbers may be made the basis of a similar scale. Thus, by means of their logarithms, we may construct logarithmic scales for the natural sines or tangents of angles (see scales E and F, Fig. 2), or for any other function of angles; or, as the choice of the length of our unit was left perfectly open, we may plot scales to any enlarged or reduced scale, which latter observation is important, as it forms the basis of all operations embodying involution and evolution in the slide-scale calculations (as will at once appear clear by remembering that these operations, logarithmically speaking, imply multiplication and division).

Returning, however, to our constructed scale, Fig. 1, let us conceive it severed longitudinally along its central line by a cut, *a b*, so as to fall into two identical scales, AA' and BB'. Furthermore, let us regard these scales as free to slide laterally to the right or the left, along their common line of contact, *a b*. With this motion we at once obtain the means of performing *any desired multiplication or division.* This is clear, if we consider that the divisions upon our scale are magnitudes logarithmically plotted, and that, therefore, an addition or subtraction, as far as these are concerned, executes a multiplication or division as regards their numbers (which are, by-the-by, the only records on the scale). With this capacity of motion, we have attained the simplest form of the slide-rule. A single setting of the slide performs a multiplication or division; if desired, a combination of both, *i. e.*, a proportion; and in many cases not simply for a single set of numbers, but for a whole series of sets of numbers at one and the same operation. The details of manipulation are not entered into here, having only the principles of the slide-rule in view. If desired, these can all be found described at length in the printed directions furnished with the scales. Be it remarked, however, that although the whole operation has been essentially a logarithmic one, we lose sight entirely of logarithms having been used at all. This is always the case in operations with the slide-rule. In fact, the peculiar merits of the slide-rule can hardly be better expressed than by pointing out this unconscious gaining of all the advantages of using logarithms, while saved the labor of taking them from tables. While the whole conception of the slide-rule is logarithmic in its nature, save as a means of understanding its construction and in studying out particular modes of application to meet special cases, this is lost sight of entirely in its use.

The slide-rule, as constructed by the firm of Dennert & Pape (in Altona, Germany), is shown in figures 1 and 2; the latter being an isometrical view of the scale in order to better show its working parts. These are as follows: A thin slab of boxwood, called the "slide," upon the edges of which two scales, *B* and *C* are engraved. The slide being fitted with tongue-and-grooved edges at its sides, is free to move between two other boxwood surfaces also bearing scales, *A* and *D*. The latter are parts of the same piece of wood, being connected with each other underneath the slide, and both of these (together with the connecting boxwood member) form the "rule," into which the slide is recessed laterally while left perfect freedom of motion lengthwise, in both directions. Scales *A* and *B*, as has been shown, are exact duplicates of one another, as are also scales *C* and *D*, thus forming two pair of scales. The latter pair, in principle of graduation correspond to the former pair entirely, but are graduated to one-half the scale (or length of unit) of *A* and *B*. This reduction in scale would make each of the upper scales one-half the length of the lower pair, were it not that we utilize the remaining half by engraving thereon another duplicate set of the smaller scales, placed alongside of the former; thus making the total length of the upper *double pair* exactly that of the single lower pair. Each half of either "double scale" is not to be regarded as separate from its neighbor, but as joined to it, so as to form one continuous scale; the idea being to allow the double scales to represent all numbers for an interval of two whole powers of 10, while the lower scales represent all numbers for half that interval; if the lower scale embraces, for instance, the period from 1 to 10, then the upper similarly represents the period from 1 to 10 on the first (or left hand) halves, while the second (right hand) halves simultaneously represent the numbers from 10 to 100. The pair of scales on the slide (though movable as a pair) stand permanently with their extreme ends directly over and under one another; so also stand permanently fixed opposite one another the ends of scales *A* and *D*.

Now, while the double scales *C* and *D*, on account of their lateral motion along their common line of contact, answer the same purposes exactly that the lower pair do (that is, perform multiplication and division also), a little reflection and study of the figure will show how, regarding *A* and *D* or *B* and *C* as pairs, the following must always hold good, on account of the peculiarities of the mode of graduation: any number on the upper scale stands directly over its root on the *corresponding* lower scale; and conversely, any number on a lower scale may be raised to the second power by taking the corresponding number exactly above it in its companion scale. Thus a simple transfer made in a suitable manner, from either scale to the other, at right angles to the axis of the rule, effects an involution or a radication to the second degree; and either of these operations may be combined, at will, with multiplication and division, by a suitable movement of the slide.* Involution and evolution to higher powers may also be executed by the slide-rule, though we merely note the fact here.

The "slide," however, can be completely run out of the rule and re-inserted, when so desired, reverse side up. The reverse side of the slide bears two scales, *E* and *F*, these being respectively logarithmic scales of natural sines and natural tangents. The reverse side of the slide also carries a third scale, *G*, bearing equal divisions (1-1000ths of the scale length) and answering the purpose of a table of ordinary printed logarithms, in which the numerical value of any logarithm may be directly read off the scale.†

* To accurately effect this transfer, a small brass part, called the "runner," is provided. See Fig. 2, *A*. This slides freely along the rule in grooves on its outer sides, and carries two indices, *a*, *a*, which accurately transfer points from one scale to another.



With the slide in the reversed position, the slide-rule presents the appearance shown in Fig. 2. When used in combination with each other, scales *A*, *D*, *E* and *F* enable us to perform any calculation into which enter the trigonometrical functions of angles, combined in any way, by multiplication, division, involution or evolution, with quantities expressed in simple numbers.

Our slide-rule, now fully equipped, is an instrument only a few inches long,‡ suitable for being carried in one's breast pocket, and of but trifling cost. To enumerate its various uses, it at once serves as a table of numbers and their squares and cubes, their square and cube roots; it is at the same time a table of common logarithms of natural sines, cosines, tangents and cotangents. It is moreover capable of mechanically combining any of the above functions in any desired arithmetical combination, constantly showing up to better and better advantage the more complex the nature of the combination is. It serves also as a convenient pocket rule and straight edge, for it is both of these. It furthermore contains printed on its reverse side a valuable list of useful pocket data of many, frequently used, practical coefficients. Yet while being all these things combined, alas, absolute perfection is unattainable! It must be admitted it has its shortcomings also. Owing to the mechanical difficulty of graduation, and the uncertainty of reading results closer than to the third (at times the fourth) numeral place, it remains, notwithstanding all its theoretical perfection, practically an instrument only applicable where no greater accuracy than the third or fourth figure is required.

Its use must always be a judicious one. The banker, computing interest or exchange upon extended rows of figures, will find the slide-rule falls short of his requirements. Its accuracy is inadequate in many calculations of the engineer, and many have undoubtedly cast the slide-rule scornfully aside, only half examined, on account of the only approximate accuracy of its determinations.*

These shortcomings freely admitted, it still remains an invaluable assistant, and serves to good purpose wherever a limited degree of accuracy is required—and this, after all, holds good in the vast majority of cases in engineering practice. In construction; wherever we have to deal with practical coefficients (generally themselves but approximations); where, moreover, wide factors of safety are generally introduced, and where, after all, practical considerations usually dictate a selection of the nearest marketable standard size—here, always, the slide-rule gives us results quite as reliable as the most elaborate calculation carried out to the fifth or sixth decimal place. In estimates of earthwork, where our surveys are at best but close approximations to the true condition of the ground; for proportionately distributing minor errors; for interpolating intermediate grades; for at once transforming quantities expressed in one standard unit to equivalents in another standard—for all these purposes, on account of its great rapidity and freedom from liability to "mistakes," the slide-rule cannot be too highly estimated.

It may not be equal to figuring out traverses to the one hundredth, or the one thousandth parts of a foot (and how very seldom do our measurements really warrant such subsequent super-refinements in calculation); yet even here it may do good service as a check against "mistakes." There are hundreds of cases where its use in the field may obviate the many half hours and quarter hours consumed—with a party standing idle all the time—while one man alone is busy figuring out some field problem of location. We have, besides these cases, another frequently recurring set; namely, where the relations expressed in an equation are so complex as to make solution only practical by continued approximation;

† Scale *G* is really the scale of imaginary equal divisions first referred to as a preliminary step towards graduating our original sacle, *A*, *A'*.

‡ Generally 26 centimeters, or 10 inches.

* Notwithstanding the above remarks, those who really make a study of it, will be astonished at the accuracy it can be made to yield in the hands of an adept. The slide-rule, namely, often contains in itself the means of overcoming its own deficiencies. Thus used, the ordinary limit of the third of fourth numeral place falls away, and that of the sixth or seventh place appears as its limit in its stead. For instance, any rapidly converging series applied to the rule extends its range at once immensely. This study of the ultimate possibilities of the slide-rule and its special applications is a highly interesting one to any one with leisure to devote to it.

or where we have to assume coefficients, themselves functions of the element to be determined; where, *assuming* some probable value of the required quantity, we gradually, by successive trials, adjust all elements to conformity, as so frequently occurs in hydraulic work. Here we can always use the slide-rule advantageously for the first stages of the calculation, and when tolerably certain of being "near the mark," we can then resort to ordinary modes of calculation in the last and final stage.

From what has been said of the general accuracy of the slide-rule, one important corollary should be drawn: to use it successfully, that is, *rapidly*, we should never waste time in straining at the last hair, either in setting the scale or in reading a result; this will reap no adequate return for the extra labor spent.†

One of the chief difficulties to beginners in using the slide-rule lies in assigning to a result its correct local value; that is, to fix the position of the decimal point. Many do this by rule of thumb entirely, placing the decimal point by guess-work, whereby mistakes are liable always to creep in. The most satisfactory method is to preserve in one's head the logarithmic characteristic separate, and to execute mentally the operation implied by the calculation, regarded as a logarithmic problem. The result of this simple calculation always fixes the local value of the result correctly. For example, say 230 is to be multiplied by 0.0003, and the result divided by 2.7. Then we have 230 [characteristic + 2], 0.0003 [characteristic — 4], 2.7 [characteristic 0]; then + 2 + (— 4) — 0 = + 2 — 4 = — 2. The slide-rule gives the figures of the answer to four places, 2555 (the last place a little uncertain), and from the foregoing we know the correct value of 230 ÷ 2.7 × 0.0003 to be 0.02555. An additional unit must, however, always be added or subtracted every time we have to resort to a substitution of one index for another in attaining a result, or when we read a result by passing through an index (which corresponds entirely to carrying a unit or borrowing one where ordinary logarithms are used). A little practice, however, teaches us how this is to be applied. To illustrate: 56 × 7 = 392. If not modified, our rule would give us 1 + 0 = 1, or 39.2 as an answer. To obtain a reading at all, a substitution of the indices was required, for which a unit must be added, when we have 1 + 0 + 1 = 2, giving the correct result 392. Or, say we inquire how often 7 goes into 56. For the position of the decimal point, we would have 1 — 0 = 1, or the answer, 80 times. We had, however, to use the right-hand index to obtain a reading, where ordinarily the left-hand index would have given us the answer. This substitution implies our subtracting an additional unit, and we have 1 — 0 — 1 — 0, or 56 ÷ 7 = 8, the correct answer.

This calculation is never too difficult to be kept in one's head, save where the operation is a lengthy one, when it is well to keep the characteristic, as was done above in the process of illustration, on a separate scrap of paper, or to provide the slide-rule with some distinct recording device for keeping the characteristic. A simple device for this purpose is that of Mr. Deering, of the Southern Pacific R. R. A small annular disc, free to revolve around a center, upon which a radial scratch used as an index is marked, is provided with several radial divisions to either side of a central initial mark or zero. The disc is turned a suitable number of places to the right or left to record the characteristic, when the slide is set to the number and its position shifted appropriately at each stage of the operation; the index on the fixed center finally indicating the correct position of the decimal point. This little device is mounted on the runner of the slide-rule, and can be easily turned with the finger while one manipulates the runner.

We will now close our observations on the ordinary slide-rule, remarking that figures 1 and 2 are only illustrative representations of the rule, and only show the main subdivisions. An idea of the fineness of the graduation actually used may be derived from figures 3 and 4, which show the same rule with the runner removed, reduced to about four-fifths the usual size.

Besides that of Dennert and Pape the slide-rule of Le Noir has been widely introduced into this country, which, although apparently differing but slightly from the former, falls much short of it in practical efficiency. The most essential difference consists in its having three of the "double scales," and only one single

† In using the scale this is essential, as also that the slide should move with perfect freedom, though not so freely as to slip by an inadvertent touch. To effect this, keep the grooves clean, and, if necessary, lubricate with a drop of fine oil.



scale, instead of two of each kind—and there is no runner. Slight variations in the arrangements of the slide make great differences in the degree of serviceability.

The slide-rules already described are applicable generally to all calculations, and there is no calculation which cannot be executed by carrying out with the rule, step by step, each successive intermediate operation necessary to attain the result. This, however, often necessitates several settings of the scale, in order to obtain a single result. To avoid this extended manipulation, special slide-rules may be constructed, capable of solving almost any such case by one single, or at least by a greatly reduced number of settings of the rule.

Speaking generally, any function of two variables combined with constants, may be solved by one movement of a specially constructed rule, the peculiarity of the special construction being that the constants are embodied in a suitable manner with the variables directly. With each additional independent variable above *two*, one more movement is required, generally necessitating the introduction, however, of an additional scale.

Figure 5 gives an illustration of this kind, showing a scale very widely used in Germany in topographical work. With stadia measurements for direct readings of a vertical rod, we have the formulæ:

$$d = K\ a\ \cos^2 n\,,$$
$$e = K\ a\ \tfrac{1}{2}\sin 2\,n\,,$$

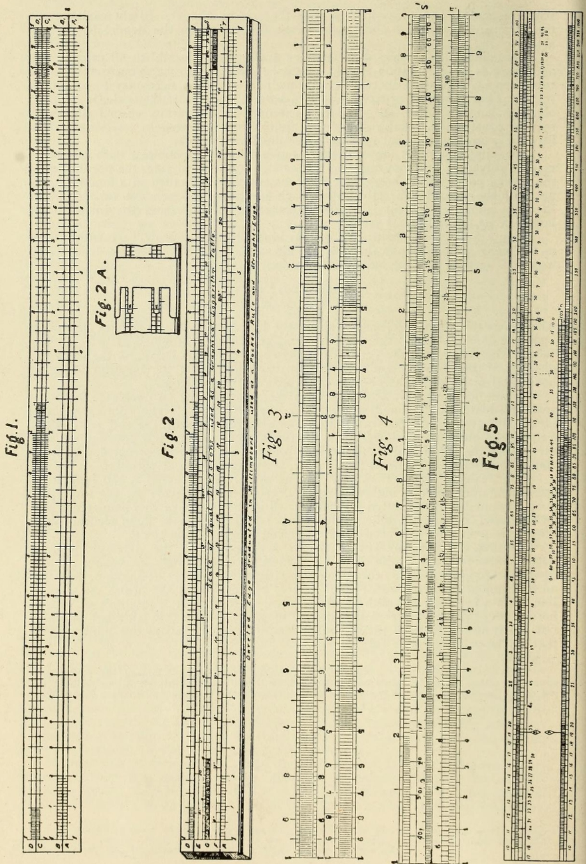
where $n$ is the angle of elevation above the horizontal; $K$, a constant dependent upon the construction of the telescope, and generally so adjusted as to be exactly 100; $a$, the reading on the vertical rod between the stadia hairs; $d$, the corrected distance of the observed point from the instrument; and $e$, its elevation above the horizontal plane through the horizontal axis of the telescope.

In this form of slide scale, we have the slide bearing two scales; the upper scale graduated to $\frac{1}{2}\sin 2\,n$, the lower one for $\cos^2 n$. The rule carries two identically graduated scales of simple numbers representing the rod readings, $a$. Setting the index of the lower scale to coincidence with the rod reading, we read directly on the lower scale opposite the observed angle $n$, the corrected, *i. e.*, horizontal distance $d$, also on the upper scale, the difference in elevation, $e$.

This scale is very serviceable,* but as usually constructed is too long to be convenient for anything but office use. There is another scale for the same purpose, executed in metal, fitted for being used in the field, a vernier being employed. In this case, the finer metallic graduation is relied on to make up in accuracy what otherwise would be sacrificed by the reduced length of the scale.

Another direction presents itself for development of the slide-rule by artificially extending the length of unit (without correspondingly increasing the size of the instrument). In his catalogue of instruments, Stanley of London, describes an instrument by Professor Fuller. Here, by developing the scales on a spiral line upon a cylinder, a length of unit equivalent to 83 feet is attained, of course, hereby very materially increasing the accuracy of the slide-rule, although probably not nearly in the ratio of the increased length (which is about one hundred-fold that of the ordinary slide-rule).

* This scale is also very convenient in running grade lines, enabling the transit-man always to select his grade points on the ground, and keep track of his elevations without the aid of the level, and judiciously used will often save much "backing up" in field location.



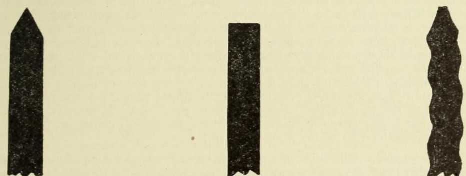

No. 3.

# SOME PRACTICAL HINTS ON HOW TO TELL A GOOD SURVEYING INSTRUMENT.*

By A. LIETZ, Member Tech. Soc.

There are, indeed, many improvements, which may yet be added, but if they are not made in a thorough workmanlike manner they are of little, if any, importance, and will in no case make an instrument of fine quality.

*Graduation.*—In a transit, the graduation is the most important part. Solid silver is the best metal known, upon which a perfect graduation can be made, and it is therefore almost exclusively used by makers. It has the advantage of keeping its surface better than the silver wash, which is found on most of the older instruments.



A B C

To examine the graduation, the first thing should be to see whether each line is perfectly sharp and clearly cut; for this purpose it is well to use a compound microscope, as only a very keen observer will be able to detect unevenness in the lines with a common magnifier. The starting point of a line, if closely examined, will show whether a perfectly-shaped and well-set tool was used in cutting it.

The line shown in figure A, in which the upper or pointed end is the starting point, indicates by its true shape that it could only have been made with a perfect and properly set tool. It is a fact that this shape is found in all graduations of first-class instruments.

In Fig. B the line has no taper, but begins with its full width. In such an event the cut was either made from the inner rim of the circle outward, or, what is more likely, the engraving tool was set end for end and drawn from the start-

* Reprinted and revised, by permission, from the Transactions of the Technical Society of the Pacific Coast, Vol. VII, No. 5, December, 1890.