QUEEN & CO.'S MANUAL OF ENGINEERS' AND SURVEYORS' INSTRUMENTS

Queen and company, Philadelphia.

QUEEN & CO.'S

MANUAL

...OF...

Engineers and Surveyors INSTRUMENTS.

Construction, Manipulation, Care, Theory and Adjustments.

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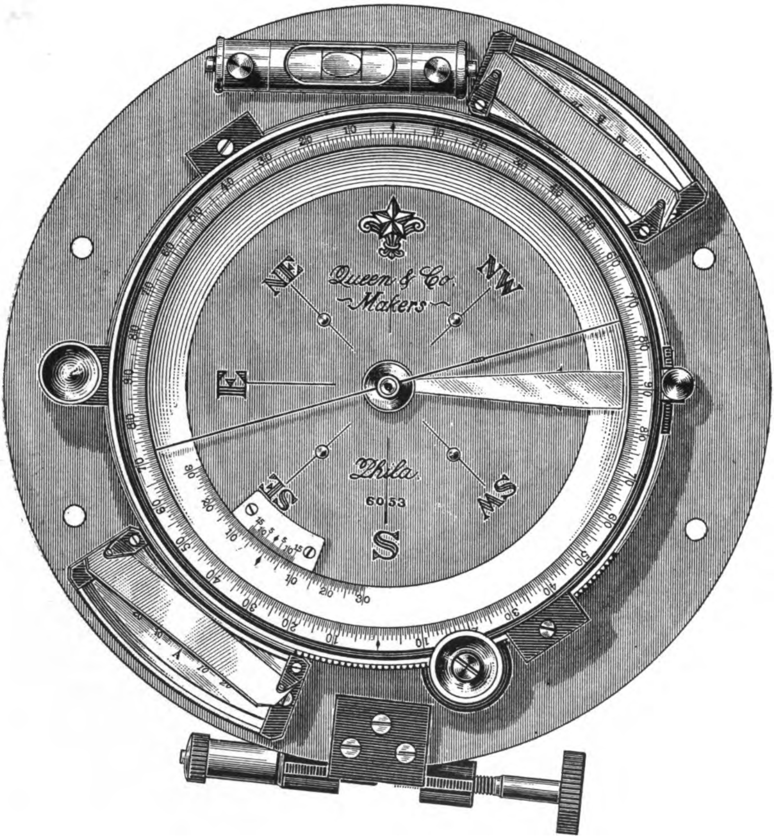


DESCRIPTION

OF THE

ENGINEER'S TRANSIT.

GENERAL INTRODUCTION.

THE **uses of the Engineer's Transit** are so varied and convenient as to command for it the eminent interest of all called upon to do field work. Properly designated the "universal instrument," the well-made transit is, above all others, the instrument suited to the general needs of the engineer. As combining portability with a high degree of accuracy, it is admirably adapted to the great majority of practical problems presented to the surveyor, the railroad engineer, the mining engineer, and the topographer. If of accurate, scientific construction, it may be relied on for good results in running straight lines, measuring horizontal or vertical angles, leveling, and in telescopically measuring distances.

The Quality of the Instrument being a most important factor in good field work, the purchaser should have clearly in mind the fact that the inferior instrument cannot always readily be distinguished from the superior, and that handsome finish, or even excellence in one particular, does not determine a good instrument. The general excellence of a transit instrument depends on scientific and practical knowledge, on the part of the maker, of every one of the many proper constructive features, and on a conscientious execution of the task in every detail. While a fine appearance and rich lacquering are by no means unbecoming a good instrument, there are in such an instrument hidden excellences of far greater importance. The kinds of metal used in the various parts of the instrument, the form of the "centres," their truth, the accurate centering of the graduated circles and verniers, the mechanical method of accomplishing this centering, the accuracy and style of the graduations of circles and verniers, the mathematical relation of the planes of the graduated circles to the axes, the sensitiveness and position of the level tubes, the form and position of the standards, the relation of the horizontal axis of the telescope to the axis of the instrument, the optical and mechanical construction of the telescope in general, the thorough testing and adjustment of every mathematical, mechanical, and optical characteristic of the instrument, and the numerous other details that cannot be enumerated, are all, though often out of sight, of essential importance to a first-class instrument. A fuller reference to details will be found in the following Description, and in the Special Articles of this Manual treating of the constructive features, and of the theory of the more important uses, of the engineer's transit and its accessories.

A Special Test of Excellence of a transit instrument is equality in the grade of accuracy possessed by each essential feature. It is not unusual for makers to become hobbyists on some special feature of construction. Now, it is high magnifying power; now, professed superiority of graduations; and now, sensitiveness of levels; and now, fine mechanical finish. But suppose, for example, a high magnification and inferior definition and coarse levels and inaccurate divisions, and is not the grade of work determined by the most inaccurate feature? The intelligent engineer well knows that the transit is a complex appliance for measurement, and that every feature of the instrument must be up to the standard of accuracy aimed at for the whole instrument, if it is to be, in any true sense, a measuring instrument. QUEEN & Co. suggest that the engineer will find no recreation more instructive than that of testing the various constructive features of transits, and then computing the errors which must result under the various conditions of use.

The Final Test of Excellence of an instrument is its performance in skilled hands. Unsatisfactory work and frequent and expensive repairs put a ban on any instrument. But aside from the test in the field, there are two points which determine the quality of the instrument: (1) the maker's reliability and (2) the maker's knowledge and skill. MESSRS. QUEEN & Co. wish it understood that they give conscientious attention to every detail of construction and adjustment, and that the best scientific talent co-operates with mechanical skill possessing years of experience. Their experts are not only generally familiar with the qualities that make the engineer's transit efficient, but, from a study of the mathematical theory of the most accurate uses of the instrument in geodetic work, and from a broad study of the mathematical theory and refined uses of all sorts of instruments of precision, have attained a clear comprehension of the errors most to be feared, and hence, of the course of construction best suited to secure the highest efficiency of the instrument in the field.

Description of the Instrument:—The following description is intended to convey some idea of the essential parts of the transits of QUEEN & Co., and of the purpose of these parts. It is also intended to direct attention to the Special Articles, presented in this Manual, on the theory, construction, and uses of various parts and accessories of the instrument.

The Telescope of the engineer's transit, as distinguished from the theodolite proper, is made to turn over or transit at one or both ends, so as to reverse without horizontal motion. In the two ordinary sizes the telescopes are, respectively, eight and eleven inches in length, with apertures from one to one and one-fourth inches clear, and powers from eighteen to twenty-five, according to the requirements of the instrument. So much depending on the character of the telescope for definition, light and power, and alignment, QUEEN & Co. use all the resources of science and mechanical art to bring it to the highest perfection. For further indications of their attention to details, and for detailed description of parts, the reader is referred to the special article on "*The Telescopes of Engineering Instruments.*"

The Object-Glass and Eye-Pieces require detailed description and explanation, and are referred to at length in the article just mentioned.

A Diagonal Prism, placed immediately in front of the eye-piece, so as to reflect the rays at right angles to the eye, is used when it is desired to take vertical angles greater than it is possible to observe with the ordinary eye-piece. It is found very convenient for observing the sun, on interposing dark glasses between it and the eye.

The Eye-hole Slide is a little slide placed just inside the eye-hole, and movable by means of a little projecting pin. It effectually excludes dust and rain from the instrument, and should always be used to close the eye-hole when instrument is not in use.

The Sun-Shade is an extra piece of brass tubing, fitted on the objective end of the telescope as an open cap. It excludes direct sunlight, dew, and dust. Its constant use in continuous work is insisted on by some supervising engineers, with great advantage to the quality of the work.

The Slide-Protector is a tube screwed to the objective end of the telescope, and covering completely the delicately fitted slide upon which the object-glass is moved in and out for shorter or longer sights. It excludes dust and moisture from the slide and the inside of telescope. It is attached to all of QUEEN & CO.'s telescopes having the object-glass slide.

The Cross-Hairs, placed in the common focus of the object-glass and eye-piece, are two fibres of the little black field spider. They are cemented in divisions of a metal ring accurately at 90° with respect to each other. Platinum wires are inserted only on special order.

The Cross-Hair Ring, as figured in the accompanying Fig. 1, can, upon release of its screws, be slightly turned for adjusting one hair to verticality. By removing the eye-piece and the screws of the ring, the ring itself may be taken out for the purpose of replacing broken wires. This is an operation, however, rarely necessary, and to be attempted only by one who can exercise the requisite care in replacing the spider-threads and the ring, and also in placing the eye-piece in its former centered position.

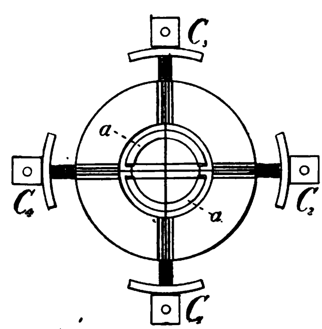


Fig. 1.

The Stadia Hairs, adjustable or fixed, are also attached to the cross-hair ring. The adjustable hairs are attached to movable pieces, *a a*, Fig. 1, held in position by a spring, and can each be brought to equal distances on each side of the fixed thread for every desired scale of stadia reading. A discussion of the important subject of stadia measurements is given in the special article entitled "*Gradienter and Stadia Measurements.*"

The Gradienter Screw is a specially cut screw, Fig. 2, with graduated head, acting upon an arm clamping to the horizontal axis, for turning off small vertical angles, and in the form furnished by QUEEN & Co. affords a ready means for running grades and measuring distances and differences of level. The screw-head reads directly to hundredths of a turn of the screw, and is so placed as to be easily read without change of position of the observer. One revolution of the screw moves the telescopic sight-line so as to intercept one foot on a vertical rod at a distance of one hundred feet when the telescope is horizontal. For a complete indication of the advantages, theory, and use of this attachment, the reader is referred to the article on "*Gradienter and Stadia Measurements.*"

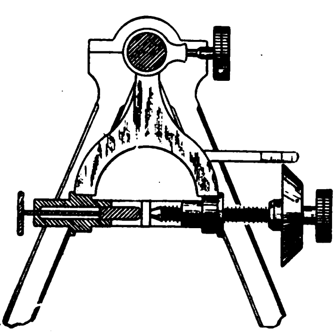


Fig. 2.

A Graduated Head for the Tangent Screw of the alidade is sometimes found a valuable addition, in the hands of the expert engineer, for measuring horizontal angles and determining distances. Further details, concerning its use, are given in the article mentioned in the preceding paragraph.

The Horizontal Axis of the telescope rests upon the carefully constructed V's of the standards, and is adjustable at one end, as described under the head of the standards. Plain cylindrical pivots are used where reversal of the telescope on the standards and the use of a striding level become necessary.

The Vertical Arc or Circle, attached to the horizontal axis for measuring angles of elevation or of depression, is graduated to read to minutes or less, according to requirement. The arc is sometimes made to clamp with respect to any position of the horizontal axis, so as to permit the measurement of an arc of greater extent than that of the instrument. The complete vertical circles are furnished either with one vernier or with two opposite verniers, according to the grade of work for which the instrument is intended.

The Standards of the Transit are made shapely, light, and strong, and firmly attached to the upper or alidade plate. The bearing of the horizontal axis, at the upper portion of one

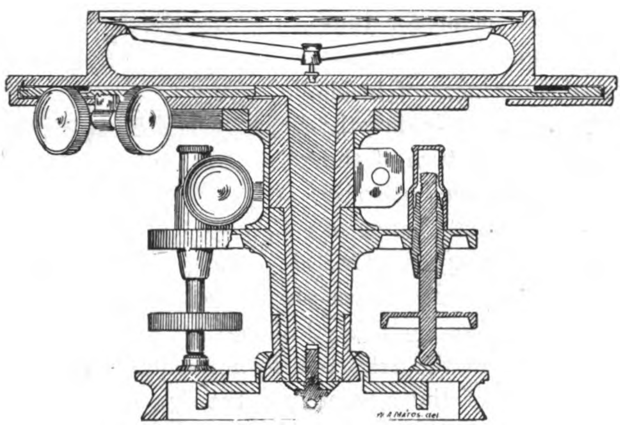


Fig. 3.

of the standards, is made vertically adjustable by means of a screw and jam nut. By moving this bearing up or down, as required, the horizontal axis of the telescope may be made accurately perpendicular to the vertical axis of the instrument, as fully explained in the articles on the adjustments and errors of the transit.

A Right-Angle Sight, formed by slits cut in the two clamping arms attached to the standards, and forming a means for quickly setting off lines at right angles to the telescopic sight-line, is found a desirable addition in some forms of the transit.

The Clamp-and-Tangent Movement attached to the vertical circle is a type of all clamp-and-tangent attachments used in the instrument, and may be readily understood from the figured instrument. The essentials are a clamp acting with certainty, a smoothly and easily moving tangent screw, and a stout and definitely acting spring. The spring adopted is a plain, stout strip of hammered German silver. QUEEN & Co. also furnish the usual enclosed spiral spring, if it is preferred. The clamp and tangent seen immediately above the upper plate of the leveling-head, when in use, enables the circle-plate to be slowly moved in its socket in the leveling-head. The clamp and tangent as seen near the edge of the alidade-plate, when in use, enables the whole alidade, with telescope, to be moved on its centre with respect to the graduated circle. The form preferred for this purpose clamps directly to the axis of the instrument, and not to the plate. The clamp-bar fits snugly on the axis, and the clamp acts with the least motion of the screw, and without strain upon the circle or the least disturbance of a pointing of the telescope.

The Alidade, upper plate, or vernier plate, carries not only the verniers but the magnetic compass, standards, and telescope as well. It is shown in the accompanying diagram and vertical section of the instrument, Fig. 3, as attached to the inner axis or "centre." It is made as light as possible, as is, indeed, every other portion of the instrument, consistent with the requisite strength and rigidity.

The Verniers are two in number, lettered *A* and *B*, and placed inside the graduated circle, and, for convenience in use, at angles of about 30° with the line of sight. This position of the verniers enables a broad and firm base to be secured for the standards. The verniers are always double, having the requisite divisions on each side of the zero, and are numbered so as to be counted in the same direction as the vernier is moved.

The two opposite verniers furnish the means of using the well-known principle of reversion in order to determine and eliminate any outstanding error of eccentricity, to determine errors of graduation, and generally to eliminate errors by reversion observations.

Reflectors, of celluloid or ground glass, are used to throw the requisite light on the divisions. The vernier glass covers are firmly cemented on the vernier openings, so as to exclude dust and moisture. For the theory of the vernier, and other points of interest relating to reading of circles, we refer the reader to the special article on "*The Graduated Circles of the Engineer's Transit.*"

Plain Reading Microscopes, for greater convenience and accuracy in reading the verniers, are attached to several of the larger special forms intended for city, tunnel, or triangulation work.

Micrometer Reading Microscopes, instead of verniers, are applied to QUEEN & Co.'s largest and finest geodetic instruments. For description of this form of microscope, see article entitled "*The Reading Microscope—its Forms, Theory, and Adjustments.*"

Estimation or Scale Microscopes are coming into use where rapidity and a fair degree of accuracy are required in the readings. Consult the article referred to in preceding paragraph.

The Compass-Box, though not an absolutely necessary feature of a transit, is for general work an important one. It is placed between the standards, directly on the upper plate. A glass cover protects the compass-circle, which is graduated to half degrees, and numbered both from the north point and the south point in each direction, from 0° to 90°.

The Magnetic Needle, four to five inches in length, according to the size of the transit, has at its centre a small brass cap, in which is inserted a little socket of hardened steel, or a highly polished jeweled centre, and by means of which the needle rests upon the hard, polished point of the centre-pin. It can thus move freely in a horizontal direction, and take the direction of the magnetic meridian. It is somewhat weighted on its south end by a small coil of fine brass wire, which can be easily moved along so as to adjust the needle to a truly horizontal position, or so as to prevent dipping. The north end is distinguished by a scallop. The needle is lifted from its pin, when not in use, by a lever actuated by a screw placed at the side of the compass-box. The same screw may be used in checking vibrations of the needle. The form of needle preferred is about six-hundredths of an inch deep and two-hundredths wide. The magnetization of the needle and other related matters, of interest to practical observers, are treated of in a special article of this Manual, entitled, "*Terrestial Magnetism in its Relation to Surveying Instruments.*"

The Centre-Pin is a sharp-angled cone of hardened steel, the point being made glass hard and carefully ground. When the point is dull, or the pin bent, the pin is easily removed, ground, and replaced. On eccentricity of centre-pin, see article of this Manual on "*The Adjustments of the Surveyor's Compass.*"

The Circle-Plate, lower plate, or limb, as it is sometimes called, is made of the finest quality sheet brass, and in such manner as to obviate unequal expansion and contraction through temperature changes. The circle itself is either graduated directly on the brass, and then silvered, or upon a rim of silver securely set into the plate. In the production of an accurate graduated circle, there are two points of especial importance: First, the character of the graduation, and, secondly, the centering of the circle with respect to the axis of the instrument. With the facilities possessed by QUEEN & Co. for producing finely graduated circles for astronomical and engineering instruments, no errors of graduation need be feared, but the graduation itself may be relied on with the utmost confidence. For a further description and discussion of the graduations, we refer the reader to a special article, entitled "*The Graduated Circles of the Engineer's Transit.*" The centering of the circle is provided for by special devices which not only allow it to be accomplished with certainty and accuracy, but also to be maintained after the adjustment has once been made. For a discussion of the subject of eccentricity, we refer the reader to a special article of this Manual, entitled: "*The Errors of Eccentricity of the Engineer's Transit.*"

The Graduations are made with fine, uniform, dark lines, so as at the same time to be read with ease and accuracy. The numbering is usually from 0° to 180°, in two directions, with a second numbering on half of the circle, round to 360°.

Thus angles may, with facility and certainty, be read in any manner desired. A very convenient set of inclined numbers has been adopted on the circle; the inclination always indicating in what direction from the zero the reading is being made. Hence, with the kind of numbering adopted, and with the inclined figures, the engineer always has a sure method of remembering the direction of the angle measured. The sizes of the circles vary, usually, from five and one-half inches to six and one-half inches diameter. They are graduated, ordinarily, to half degrees, and read to minutes, or, in order to give wider space on the vernier, to twenty minutes and read to degrees, or to twenty minutes and read to thirty seconds, or, in the higher grades, to any required fineness of reading.

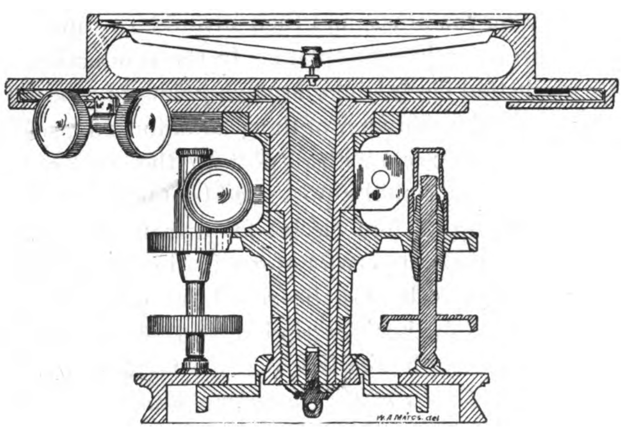


Fig. 4.

The Vertical Axis of the transit, as shown in section in the accompanying Fig. 4, is determined by two concentric conical "centres," as they are called. The vernier, or alidade-plate, is attached to the inner "centre," and the graduated circle is attached to the outer "centre," which, in turn, fits into the socket of the leveling-head. It is of the highest importance that these "centres" should be turned and fitted with mathematical accuracy, and to insure this Queen & Co. turn both "centres" finally on the lathe between dead centres.

The surfaces of the "centres" do not come in contact throughout their entire length, but are, for about one-third the distance, cut away, so as to insure a positive mathematical axis under all conditions of wear. Not only should the axis, when the instrument is sent out, be exactly concentric with the centre of the graduated circle, but it should have been so designed as not to introduce the error of eccentricity by wear. It has, however, been found that, in some patterns of "centres," wear not only produces the error of eccentricity, but introduces it in such form as to be irremediable without the construction of new centres.

In order to prevent unnecessary wear, and lessen friction, the three metals of the inner "centre," the outer "centre," and the leveling-head socket are selected, not only with a view to the requisite rigidity, but with a view to a small relative co-efficient of friction. Bell-metal, of the hardest quality, should be used for the inner "centre," a fine gun-metal for the outer "centre," and a superior quality of red metal for the socket of the leveling-head. MESSRS. QUEEN & Co. having in their own establishment superior facilities for making the necessary castings, are enabled to compound alloys of metals with a special view to the theoretical conditions in important pieces, such as the "centres" and their sockets.

The Levels of the Transit are usually three in number. Two are attached at right angles to each other on the upper plate or alidade, one being parallel to the line of sight, the other transverse to it. Various positions are given to these levels on the alidade by makers, according to the different constructive demands; and the positions assigned are, indeed, quite indifferent, if the levels are in proper relation to the line of sight and easily adjustable. For adjustment of these plate levels, with respect to the vertical axis of the instrument, proper screws are provided, and care should always be taken to unloosen the little clamping screws at the ends of the bubble-cases before, and to tighten them after, moving the vertical adjusting-screws.

The third level is the fine one attached to the telescope-tube, parallel to the line of sight. Sometimes a highly sensitive striding-level is furnished, for leveling the horizontal axis, in the higher grades of instruments. And sometimes, also, a coarse circular level is attached to the alidade for quick leveling. The solar and other attachments often have their own proper levels.

The transits of QUEEN & Co. are furnished with accurately designed, carefully made levels, true and suitably sensitive, and each level, including the plate-levels, provided with divisions throughout its entire length, so as to allow of accurate use under all conditions. The importance of the level as a constructive feature, and its general theory and use, are treated of in a special article of this Manual entitled: "*The Spirit Levels of Engineering Instruments.*"

The Leveling-Head is shown in the lower part of the accompanying Fig. 3, giving a vertical section through the plates and centres. It consists, essentially, of the two leveling-plates and leveling-screws. In these long-centre transits, the leveling-head is not, as in some inferior short-centre instruments, removable, but at all times forms an essential part of the instrument. It need scarcely be remarked that in all high-grade long-centre instruments it is not removable, for the reason that only thus can the most accurate adjustments be attained and kept, at the same time that the centres are protected from irretrievable injury. QUEEN & Co. have found that the short-centre instruments, with removable head, are those most frequently coming in for repairs. Leveling-heads with four leveling-screws are those usually preferred by American engineers; but, upon special order, heads with three leveling-screws are also supplied. The screws are all covered with neat dust-caps, and provided with milled heads of moderate diameter, those of very large diameter having been found to give too much mechanical advantage to inexperienced and thoughtless users, and also to impede quick leveling. The leveling-head is attached to the tripod-plate, either by means of a neat and effective clamp, or by means of screw, as preferred by the engineer. The clamping device saves a little time in setting up and dismounting the instrument.

The Shifting-Centre, as now supplied with each of the QUEEN

& Co. transits, allows the vertical axis, with its attached plumb-line and bob, to be accurately brought over a desired point, when once the instrument has been approximately set up over the point. With the leveling-screws somewhat loosened, the whole instrument may be freely moved on the lower level-plate to any required position. The great amount of time saved, and the accuracy attained in setting up by its means, makes the shifting-centre invaluable to the engineer.

The Quick-Leveling Attachment consists of wedge-like rings, which, as a separate piece, is clamped or screwed directly on the tripod-plate. The instrument is then clamped or screwed upon the attachment, and, by an easy revolution of the rings, quickly brought to an approximately level position. The fine leveling is then accomplished by the leveling-screws. It is furnished only upon special order.

The Tripod, furnished with QUEEN & Co.'s instruments, is designed to be rigid, of moderate weight, and adjustable to position with ease and certainty. Fine white ash-wood is used for the legs, as supplying the requisites of strength and lightness. The legs are furnished with a sharp steel shoe, well fitted to the wood. Winged clamping-screws are used to fasten the legs to the plate. The forms supplied are (1) the ordinary round leg of elegant pattern, (2) an improved "split-leg" tripod, and (3) an excellent extension tripod.

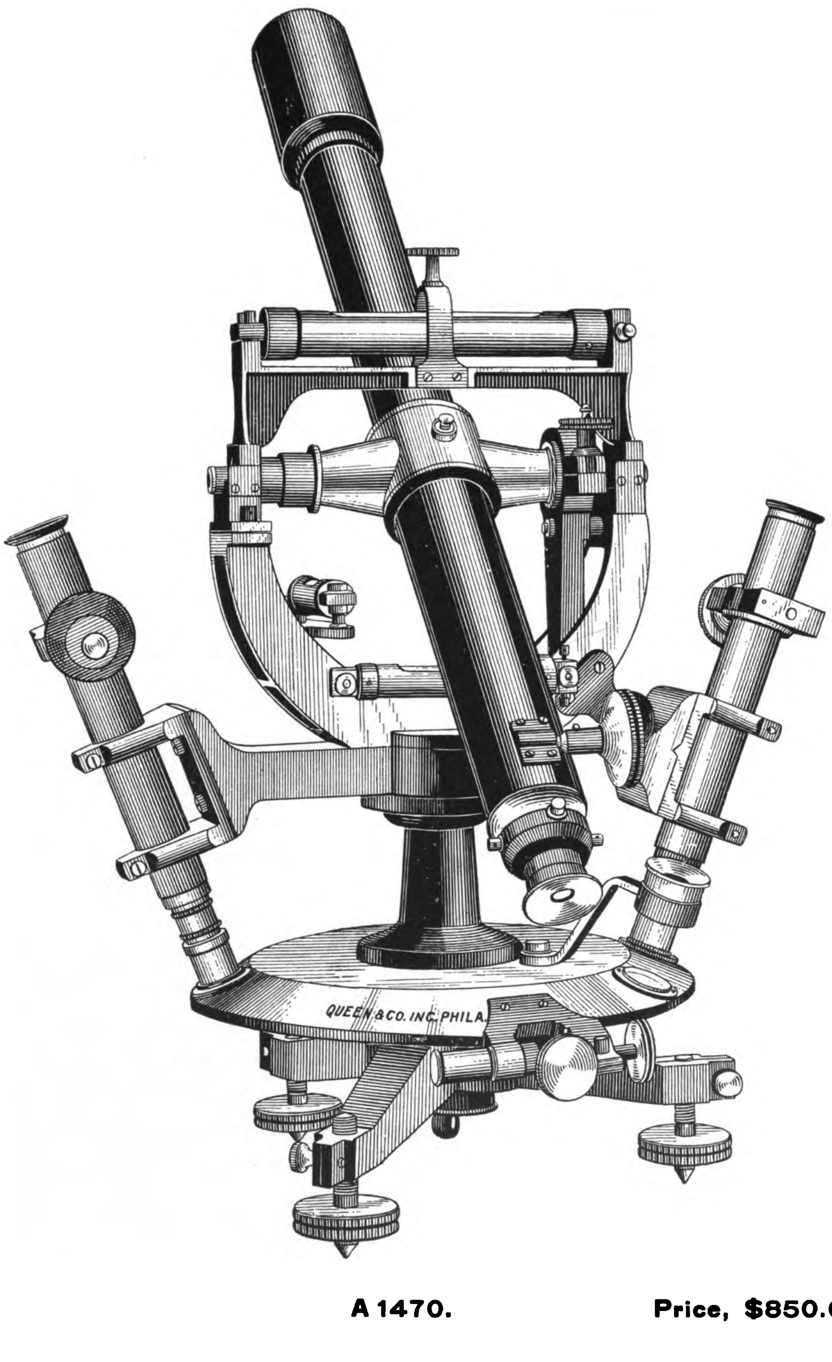
The Plumb-Bob is accurately attached to the central axis of the instrument by means of a small hook and chain, and is in all cases made adjustable. It is supplied in any desired weight, from eight ounces up to the heavy ones of two and three pounds required for plumbing down deep shafts. They are usually made of brass, and steel pointed.

The Plummet-Lamp, supplied for mining and other purposes, is so arranged that either the oil light or a small incandescent electric lamp can be used. The small incandescent lamp is attached centrally on the cap which covers the wick of the oil lamp when the latter is not in use. A small storage battery, or several cells of some suitable battery, will furnish the electrical energy required. The wires running to the incandescent lamp are perfectly flexible, and a key is inserted in the circuit, so as to enable the lamp to be lit and extinguished rapidly for purposes of signaling. The entire steadiness, certainty, and safety of the electric lamp under all conditions in mining have induced QUEEN & Co. to fit the lamp also to targets of the leveling-rod, so as to permit the ready use of the gradienter-screw and stadia wires in underground or night work.

The Solar Attachment, for determining the true meridian, is readily fitted to any form of transit, but for the most trustworthy results requires to be fitted only to transits capable of meeting the mathematical requirements. For a full description of the attachment, its theory, and use, the reader is referred to the article of this Manual on "*The Solar Transit, and Methods of Determining the Astronomical Meridian.*"

The Forms of the Transit made by QUEEN & Co. range from the plain transit, without telescope, level, or vertical arc, to the large altazimuths of refined construction, intended for geodetic triangulation and astronomical field work. Some of these forms are more particularly described and figured in their *Catalogue of Engineers' and Surveyors' Instruments,* and the reader is also referred to their *Catalogue of Astronomical Instruments* for information relative to instruments made by them for astronomical observations. Popular forms of the transit are the complete engineer's transit, with either six and a half-inch circle and five-inch needle, or with six-inch circle and four and a half-inch needle; the light mountain transit, with five and a half-inch circle and four-inch needle; and a cheaper grade of engineer's transit, with four and a half-inch circle and five-inch needle. In addition to instruments of the usual weight, QUEEN & Co. also make transits in which the metal used is, for the most part, aluminum, and the weight reduced to a minimum.

"QUEEN" TRANSIT THEODOLITE.



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THE MANIPULATION AND CARE

OF THE

ENGINEER'S TRANSIT.

TO Set Up the Transit on nearly level ground, stretch out one leg of the instrument and set it loosely at a convenient distance from the point over which the instrument is to be placed. This distance should be so taken that the legs of the transit will make angles of between 50° and 60° with the ground. Now spread out the other two legs and plant them in the ground so that the distances of each leg from the point will be nearly equal. Next, press on each of the three legs successively so as to drive them firmly into the ground. If the ground be hard very slight pressure will suffice. The distance to which each leg is driven into the ground should be so regulated as to bring the bob approximately over the required point. The bob may now be brought accurately over the point by unloosening the plate-screws and sliding the shifting centre. Then level both ways, taking care to tighten fairly but not to strain the leveling screws, and the instrument is ready for work.

A good surveyor will always endeavor to arrange his instrument in setting up so that the height of the eye-piece will nearly coincide with the height of his eye when standing erect. This will avoid a cramped position in taking sights. Judgment must be used in the case of a tall person, to prevent an insecure position of the instrument, such as would be caused by having the legs too close together.

When setting up the instrument on ground of any slope whatever, one leg of the instrument should be placed on the slope above the point, the other two remaining below. A rough estimate should be made so that the upper leg may be brought further distant from the point than the other two, whose distances from the point should be nearly equal. The excess of distance of the upper leg over that of the other two must be greater as the slope is more inclined. It is advisable first to push the upper leg into the embankment as far as possible, and then to press in the other legs until a secure position is obtained. This method will bring the screw-plate more nearly level.

In the case of setting up over a point on the edge of a perpendicular cut, one leg should be driven into the side of the cut, the others being spread out over the top.

Shouldering, carrying, and setting up an instrument requires practice and artistic method to avoid accidents and inconvenience. In taking the instrument up, first see that the lower clamp is loosened, and always leave it moderately loosened when the instrument is not in actual active use. Next bring one shoulder squarely against one leg near the tripod head, and rest the instrument against the shoulder while the instrument is turned upon this tripod leg as a pivot, and the other two are successively folded in toward it. Now take up the instrument and balance on the shoulder. In setting up, reverse the process by first resting the instrument on one leg and turning the instrument upon its toe as a pivot, successively bring the other two legs into position, as indicated in the preceding paragraph.

Grasp the Instrument, in mounting and dismounting from tripod, always by the leveling head only. When the instrument is not in use, or not being carried, leave the leveling screws and the lower clamp only slightly clamped.

The Tripod Legs should always have their shoes sharp and tightly screwed to the wood. The legs should also be snugly clamped to the tripod head.

The Leveling Screws should all be fairly seated before at any time removing the instrument. If leveling screws or tangent screws work hard, clean the threads well by means of a small, stiff brush and a little oil, taking care finally to remove all oil. Overstraining of any and all screws should be avoided.

The Magnetic Needle should always be very gently set free upon the centre pin, so as not to dull the pivot; *and the needle* *should also always be arrested and screwed fairly against the glass cover before moving, carrying, or dismounting the instrument.* Wide vibrations of the needle may be gently checked by means of the needle-lifter. The glass cover of the compass-box should be wiped off only with linen, and then gently breathed on to relieve all electrification produced by rubbing. Iron, as disturbing the needle, should be carefully excluded from hat rims, buttons, watch chains, reading-glasses, spectacles, and the like. On placing the instrument away after use, first release the needle, and then, after it has taken up the direction of the magnetic meridian, raise it against the glass. No false deflection, due to magnetization of the metals used in the instrument need be feared, since QUEEN & Co. take special precautions to carefully test all metals entering into the construction of the instrument, and reject any piece giving the slightest indication of magnetic properties.

The Spirit Levels, in proportion to their sensitiveness, are liable to error from differences of temperature in their parts. They should not be touched, or exposed to any sudden changes of temperature. The bubble will invariably move toward the end having the higher temperature. Accuracy requires a carefully preserved, even temperature. For faults of levels, consult the article of this Manual on "*The Spirit Levels of Engineering Instruments.*"

The Focusing upon the hairs is accomplished by carefully turning the eye-piece like the nut of a screw, until the hairs appear most sharply defined. The focusing upon the object is accomplished by gently turning the milled head near the objective end, until the object appears most clearly defined in the telescope. Consult the paragraph under the same heading, in the article of this Manual on "*The Telescopes of Engineering Instruments.*"

The Sun Shade should be used as much as possible, as it is nearly always an advantage to good work, as well as to the protection of the instrument.

The Cross-Hairs may be relieved of any annoying dust particles that cling to them by removing the eye-piece and very gently blowing into the tube. Broken cross-wires may be replaced by an engineer accustomed to nice manipulation and patience, as follows: Provide a little shellac, dissolved in the best alcohol, a small, fine camel's-hair brush, and a U-shaped frame upon which has been previously spun off a continuous thread from a little black field spider, the thread best adapted to varying hygrometric conditions. Removing the cross-hair ring and carefully cleaning it with alcohol, place it on a table, with the graduated lines, intended to receive the threads, uppermost. Then carefully lay the U-frame on it, in such a manner as to bring one fibre approximately in coincidence with a division. Brush it gently into the division, and fasten at one end with a drop of shellac. Wait a minute for this to harden, and then stretch the fibre across and secure it in the division at the other end by means of a little shellac. After waiting, as before, for it to harden, remove all extraneous fibres, and proceed in like manner to insert the other thread at right angles to the thread already fastened.

The Cleaning of the Lenses of a telescope should always be undertaken with caution. The fine polish of the lenses of first-class instruments, so necessary to the transmission of a high percentage of the light, is attained only by the use of the most delicate processes of the optician's art. And it would be most unfortunate if, from ignorance or carelessness, the highly transparent glasses should be dulled forever by a clumsy wiping. Therefore, as a precaution, do not *unnecessarily* attempt to clean them. Particularly do not add the insult of grease to the injury of dirt, by dabbing your fingers against the surfaces of the glasses.

If dust is found upon the lenses, gently brush it off with a fine camel's-hair brush. If dirt still clings, slightly moisten the lens by breathing upon it; then, take a piece of very old and very fine linen, and so wipe off the dirt as continually to push the dirt in front of the linen. Do not roll the dirt particles under the linen, and then scratch the glass by pressure and rubbing. Silk and buckskin are objectionable; the former scratches, and the latter often contains gritty particles. Keep a piece of fine old linen in your box, and use that only. Moistening the lens with a little alcohol will sometimes be desirable, in order to restore the original brilliancy of the surfaces. Keep the outer surfaces of eye-piece and object-glass always free from dust, moisture, and grease by careful cleaning, as here indicated.

Moisture penetrating between the crown and flint lenses of the objective, after exposure of the instrument in rain, will become visible there as a mist obscuring the view. Since the lenses of the objective should never be separated, it is in such cases necessary to place the instrument in a warm room until the moisture has been thoroughly evaporated, or, if this does not prove successful, carefully unscrew the objective and expose it to a gentle heat; but do not, in any case, remove the lenses from their cell. If at any time it becomes necessary to dry out the interior of the tube, the eye-piece may be removed and the eye-end carefully covered with a fine clean piece of linen to exclude dust.

The Object Slide, notwithstanding the nicely fitted slide-protector, may in time grind or work hard. The slide is exposed by unscrewing the protector, and, if necessary, also the pinion head which moves the objective. Careful cleaning is usually all that should be attempted. Oil gathers and holds dust. If the object-slide begins to fret, examine it instantly.

The Centres and Graduation are exposed, and the main body of the instrument taken apart by unscrewing in turn the upper clamp, the dust-cover ring which embraces the lower plate, and, finally, the centre screw from which the plummet hangs. The graduations are first to be brushed with extreme care with a camel's-hair brush, and then, if necessary, wiped, but only at right angles to the divisions, and never rubbed, especially not on the edge. The centres, when clean, may be slightly lubricated with pure watch oil. It is to be clearly understood that only after years of use should it be necessary, and therefore desirable, to separate the centres for inspection and cleaning of the interior parts. QUEEN & Co. use every artifice and precaution which good design and fine workmanship can provide for excluding dust and moisture from the instrument, and therefore only after long continued rough usage should an examination of the centres be necessary. If the centres fail to revolve with the usual freedom after exposure in extremely cold or hot weather, take an early opportunity to inspect them. If the centres begin to fret, examine them instantly.

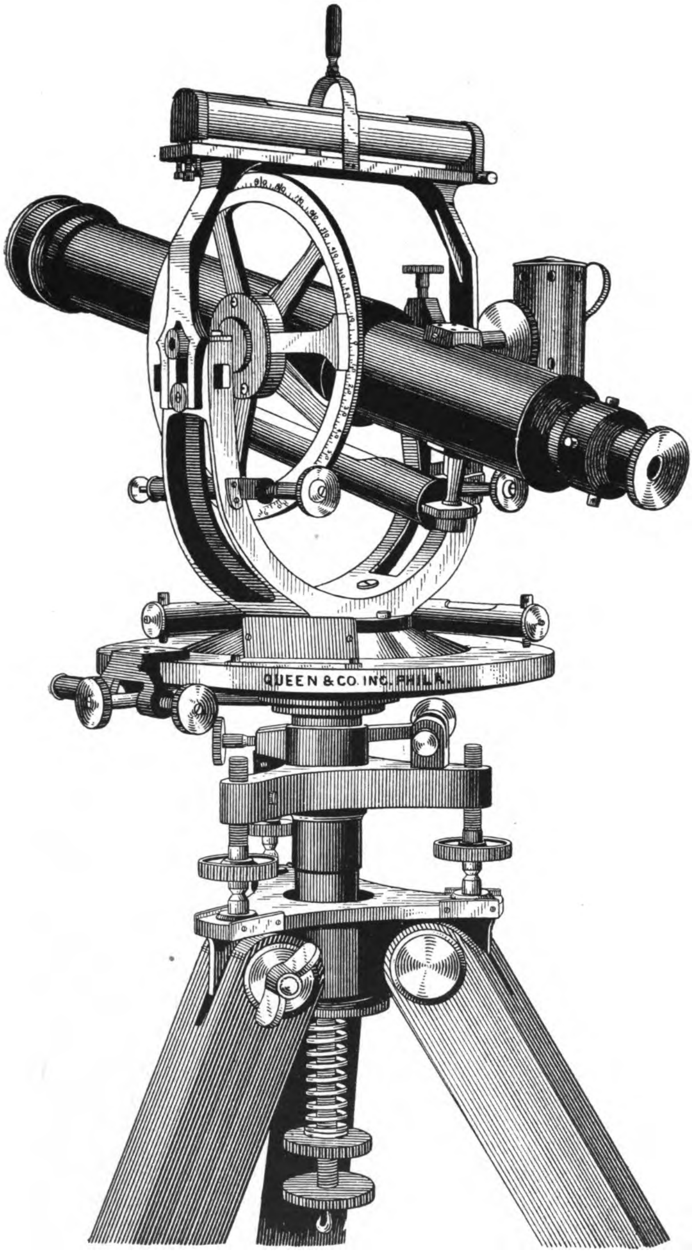
The protection of the instrument from rain, dust, and continued exposure to the direct rays of the sun are a constant duty and difficulty. The white, cashmere-lined gossamer rubber cover furnished by QUEEN & Co. with their transits, and always to be carried with the instrument, is, as a rain-proof, dust-proof, and heat-proof protector, of great practical advantage. Carelessness in exposing the instrument to the curiosity of cattle, or to other unnecessary risk, and in general, an uncouthness of usage, indicate such lack of respect for skilled and conscientious workmanship as to be quite unpardonable.

The Instrument Box should always be used in transporting the instrument. QUEEN & Co.'s boxes are all provided with flexible rubber cushions for taking up the sudden jars or violent vibrations incident to travel.

The Manipulation in general should possess "an ease and smoothness" that makes it next to impossible on the one hand to give a good instrument a disposition to fret in any of its parts, or, on the other hand, to bring about serious injury in an instrument whose parts need careful cleaning or have been bent and strained by a fall.

Repairs become necessary to the best instrument in time, and should not, when really needed, be unduly postponed. QUEEN & Co., from a long and varied experience in repairing all sorts and makes of engineering instruments, make it a distinct aim so to construct their transits that (1) they may pass through a certain amount of rough usage without injury, and (2) may be repaired with success even after serious injury.

"QUEEN" ALT-AZIMUTH.



A 1480. **Price, $550.00**

THE ADJUSTMENTS

OF THE

ENGINEER'S TRANSIT.

THE adjustments of an engineer's transit are of two kinds: (1) The maker's adjustments, or those which reliable scientific makers give the instrument while it is in process of construction; and (2) The field adjustments, or those which occasionally have to be verified in the accurate field use of the instrument. The latter are, as a matter of course, included in the former, since scientific makers always find it necessary to verify all the adjustments, and deem it an essential requisite of a properly constructed and thoroughly tested instrument, to send it from their hands only when in every respect accurately adjusted for immediate use.

THE MAKER'S ADJUSTMENTS.

In order that the mathematical conditions of the practical problem of angular measurements in the field (see "*Mathematical Theory of the Errors of the Engineer's Transit*," this Manual) may be realized in the instrument itself, it is necessary that the following points of construction and adjustment be accurately attained.

1. The lenses of the objective and of the eye-piece of the telescope truly centered in their respective cells.

2. The optical axis of the system of lenses coinciding with the mechanical axis of the tube, in all the relative positions of the objective and eye-piece, the lenses remaining always at right angles to this axis.

3. The cross hairs, during each observation, in the common focus of the object-glass and eye-piece.

4. The vertical cross hair (all other adjustments made) at right angles to the horizontal axis of the instrument.

5. The line of sight at right angles to the horizontal axis, or coinciding with the axis of collimation.

6. The axis of the telescope level lying in the same plane as the line of collimation, or not "crossed" with respect to the collimation plane.

7. The axis of the telescope level parallel with the line of sight.

8. The horizontal axis of the instrument at right angles to the axis of the alidade or to the axis of the upper plate; and hence (all other adjustments made) the line of sight always lying in the plane which is at right angles to, and passes through the centre of, the horizontal graduated circle.

9. The form of the pivots of the horizontal axis the equivalent of true cylinders.

10. The V's or bearings for these pivots of equal form.

11. The vertical graduated circle at right angles to the horizontal axis of the instrument.

12. The vertical graduated circle and its verniers truly centered with respect to the horizontal axis.

13. The alidade, or upper, plate at right angles to its axis.

14. The axis of the alidade, or upper, plate coinciding with the axis of the lower, or circle, plate.

15. The lower, or circle plate at right angles to the common axis of both alidade and circle plates.

16. The graduations of the horizontal circle and of its verniers, true and concentric with the common axis of the alidade and circle plates.

17. The zeros of each set of verniers or reading microscopes accurately 180° apart, as measured at the respective centres of the graduated circles.

18. The axis of each of the alidade levels at right angles to the vertical axis of the instrument.

19. The pivot of the compass needle coincident with the vertical axis.

20. The zeros of the compass graduations in the same plane as the line of collimation.

21. The magnetic needle perfectly straight.

22. The magnetic axis of the needle coinciding with the axis of form.

23. The magnetic needle adjusted for the magnetic dip of the place of observation.

24. The axis of the suspended plumb-bob coinciding with the vertical axis of the instrument.

While it would be difficult and unnecessarily tedious to set down every adjustment attended to by the skillful maker, the foregoing may be taken as a list of the more prominent ones. Other adjustments peculiar to the accessories of the transit and to special forms of the transit will be referred to in treating of these elsewhere.

THE FIELD ADJUSTMENTS.

The following practical methods for detecting and correcting the errors of an Engineer's Transit are given for use in the field. A full explanation of the nature of each error is also made in order that the detection and correction may proceed intelligently.

It is not to be inferred that QUEEN & Co., as scientific makers of Transits, pursue their tests of these field adjustments exactly as the practical engineer is here advised to do. Special appliances in the form of collimating telescopes and other delicate optical and mechanical devices, enable their adjuster to test and rectify the errors of a Transit by refined methods and consequently to secure a grade of accuracy in these adjustments which can scarcely be equaled in the field, even by the accurate observer.

First Adjustment:—*To make the axes of the plate levels perpendicular to the vertical axis of the instrument.*

DETECTION OF ERROR:—Level the instrument carefully both ways, care being taken to make each bubble-tube parallel to a pair of plate-screws. Turn the telescope through 180° by measuring on the vernier plate. This measurement should be a direct angular measurement on the plate, and not a mere approximation. If the instrument is not in adjustment the bubbles, after this revolution, will no longer remain in the centres of the tubes. This displacement of the bubbles is twice the true error of the instrument. For if *aa'* (Fig. 21)

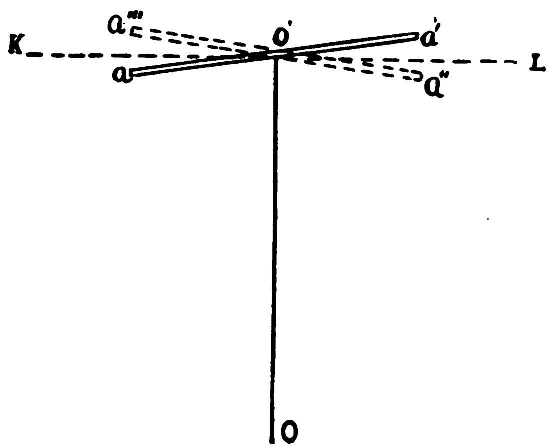


Fig. 21.

represent the trace of the plane of the bubble-tubes, *oo'* the vertical axis of the instrument, the turning through 180° would bring *a* to *a''* and *a'* to *a'''*, the angles *a''o'o* and *a'''o'o* being respectively equal to *ao'o* and *a'o'o*. The line *KL* representing the proper position of the bubble-tube plane, the angle *a'o'a''* will therefore be the double error, and cause twice the displacement of the bubbles due to the true error.

CORRECTION OF THE ERROR :—To correct, bring the bubbles half-way back to the centres of the tubes by raising or lowering either end of the tubes, screws being placed there for that purpose. Then level accurately by means of the plate-screws.

This process should be repeated several times, as without extreme accuracy in this adjustment, any attempt to perform the other adjustments is valueless.

Second Adjustment:—*To make the line of sight coincide with* *the line of collimation, or to make the line of sight perpendicular to the horizontal axis of the telescope.*

DETECTION OF THE ERROR:—The direction of the line of sight is determined by two points, the optical centre of the object-glass, and the intersection of the cross-hairs. Of these the latter is movable and is the part whose position is to be corrected.

Set up the instrument, level carefully, and sight, Fig. 22, to some well-defined point, *A*. Reverse the telescope (*i. e.*, turn

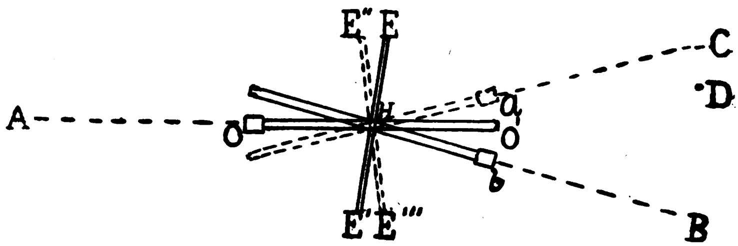


Fig. 22.

it over) and sight to *B*. *A* and *B* should be as far distant as possible from the instrument, since the apparent deviation and consequently the accuracy of the subsequent correction increases as the distance. *B H* should be taken equal to *A H*. If the line of sight *oo'* be not perpendicular to the horizontal axis of the instrument *EE'*, *A* and *B* will not be on the same straight line with *H*. To determine whether this is so or not turn the telescope around on its vertical axis and sight to *A*. The horizontal axis of the instrument now occupies the position *E''E'''*, the angle *OHE'* of the old position corresponding to *OHE''* in the new, and the angle *OHE* to *OHE'''*. Now reverse the telescope (turn over on horizontal axis); its line of sight will strike this time as far to the left of the line *Aoo'* as it did before to the right, that is at *C*. The angle *aHO'* represents the doubled error, so also does *E''HE*, since these angles are equal. But the total angular movement from *B* to *C* represents the sum of these angles, and is consequently four times the true error.

CORRECTION OF THE ERROR:—To correct, with the telescope these readings will be the true difference of height between the points, no matter what the error of the instrument may be. For if *eo*, Fig. 25, represent the position of the telescope, the line of sight will cut the rod at *A*. Turning the telescope around horizontally while the spirit level *l l'* still indicates the same horizontal reading, the new position of the line of sight will be *e'o'* and will intersect the rod set over *D* at *C*. *CD*—*AB*=true difference of height of points *D* and *B*. For, since *EF* represents the proper position of the telescope, then *FD*—*EB*=true difference of height of points, and since *S* is midway between *B* and *D*, the angles which *eo* and *e'o'*, the two positions of the telescope, make with *EF*, being equal, must be subtended by equal distances on the rod, or *EA*=*FC*, hence adding to *FD* and *EB*, we have (*FD*+*FC*)—(*EB*+*EA*)= true difference of height of points (since this addition does not affect the balance of the equation), or true difference= *CD*—*AB*, as we stated at first.

Now, clearly, having determined the true difference of height of the points, the instrument must be corrected so as to measure this accurately.

Correction of the Error:—Now set up the instrument over one of the *stakes*, measure the height of the cross hair above the top of the stake, either by direct reference to the horizontal set of screws of the cross-hair ring, or by looking through the objective toward a graduated rod held at a distance of about a quarter of an inch from the eye-end, and with a neat lead-pencil point marking on the rod the centre of the small field of view. Set the target on the rod to this reading plus or minus the difference of height between the points, according as the point set up over is higher or lower than the second. Now sight to the rod thus adjusted and held on the second stake, and note if the cross hairs cut the target in the centre, when the long bubble is in the centre of its tube. If not, correct by lowering or raising one end of the level tube by means of nuts placed there for that purpose, until the desired intersection is obtained, the bubble still remaining in the centre of the tube. Here the height of the cross hairs above the point over which the instrument is set up is very approximately independent of any accuracy of adjustment. The entire error of the instrument is therefore shown by its deviation from the true reading as indicated on the rod, by the distance of the cross-hair intersection from the centre of the target.

This adjustment will be further discussed in the article of this Manual on " *The Adjustments of the Engineer's Level.*"

Fifth Adjustment:—*To make the vertical circle read zero when the bubble of the telescope level is in the centre of its tube.*

DETECTION OF THE ERROR :—This may be done in two ways.
1st. By simple inspection.
2d. By reversion.

BY REVERSION :—Sight to some distinct point, note the reading on the vertical circle. Turn the instrument around horizontally half-way, reverse the telescope, and sight again to the same point. One-half the difference of the readings is the error, it having been doubled by reversion.

CORRECTION OF THE ERROR :—The correction is made by moving either the vernier or circle by loosening screws designed for the purpose of permitting circular motion. " The index error" may, however, be simply noted, and each observation corrected by the required amount. Inspection is the readiest method by which to perform the above adjustment, but when the index error is small and difficult of detection, doubling it increases the accuracy of the correction.

This error if it be small and the vertical circle have but one vernier, may also be corrected by first setting the circle so as to read zero altitude and bringing the bubble of the telescope level to a zero reading; and then, by the method of the fourth adjustment, moving the cross-hair ring up or down so as to bring the line of sight parallel to the axis of the telescope level.

Sixth Adjustment:—*To make the vertical cross hair truly vertical when the instrument is leveled.*

DETECTION OF THE ERROR :—Set up the instrument and level carefully. Suspend a plumb line from some convenient point. Bring the vertical cross hair into coincidence with it, and note whether the line and hair correspond throughout their entire length. If they do not, the hair is out of adjustment, because, if the instrument be properly leveled the plumb line will be perpendicular to the plane of the bubble tubes.

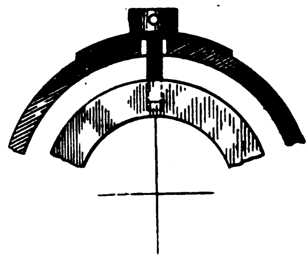


Fig. 26.

The same error may be detected by plunging the telescope and noting if the vertical hair passes over some point sighted to, throughout its entire length.

Correction of the Error:—To correct the error the cross-hair ring must be moved circularly. This is accomplished by loosening the four screws of the cross-hair ring. These screws penetrate the ring a short distance, as shown in Fig. 26, and are allowed a certain amount of play sidewise by reason of the enlargement of the space through which the screw is inserted. When the screw is tightened the piece just below the head of the screw is clamped fast to the telescope tube. When all four screws are loosened, however, it permits the ring to be turned through a distance limited by the edges of the hole through which the screw is inserted. The vertical hair alters its direction with the turning of the ring.

Relative Value of the Adjustments:—For pure transit work, by which we mean the running of straight lines, the measuring of horizontal angles, and the like, the first three adjustments are the most important. The fourth and fifth refer to the instrument when used as an engineer's level, while the sixth, though classed with the first three, is by no means essential. Indeed, this adjustment should be seldom made, inasmuch as its performance is liable, by moving the cross-hair intersection eccentrically, to displace the second and third, which have already been performed. Should an adjustment of the vertical hair, however, become necessary, the second and third must be tested again so as to insure their non-disturbance. The verticality of the hair, though not absolutely necessary for accurate work, is exceptionally convenient for determining the true perpendicular, when only a small portion of a rod sighted to can be seen. Frequent tests of the vertical hair are useful, but its adjustment is unwise unless followed by a readjustment of the instrument in regard to the line of collimation.

General Remarks on the Adjustments:—It is well to note that all of these adjustments, except the fourth, can be performed while the instrument still remains in one position. The fourth being entirely independent of the rest may be left until the last, and indeed is sometimes entirely omitted, as the use of the transit as a level is comparatively rare.

The great fault of young surveyors is to blame inaccuracies in their work upon a faulty construction of the instrument. For this there is no excuse. Errors may arise from three causes: (1) Errors in or damages to the parts of the instrument; (2) insufficient adjustment, and (3) carelessness in setting up or in sighting. The last are by far the most probable causes of inaccuracies in work, and, if the adjustment be unsatisfactory, the surveyor has no one to blame but himself, while errors in the instrument can always be detected by the refusal of the instrument to respond to repeated tests while being adjusted. In the latter case, the only remedy beyond obtaining a new instrument is to note carefully what species of errors are likely to occur, and so to handle the instrument as to avoid them as far as possible.

A wide and nearly level stretch of country is by all means preferable for the performance of the adjustments. The sights taken, except those in the fifth and sixth adjustments, should be as long as possible, so that the ensuing apparent error may be greater.

After the surveyor has used his instrument for some time he may be sufficiently competent to judge of its accuracy. Until then the instrument should be tested at least once a week, if not more frequently. If he should find the instrument one of accuracy and great permanency of parts, less frequent adjustments may be made. Adjustments should always be made if the instrument suffers a fall or if the surveyor has reason to believe that a severe jar has happened.

The field adjustments of the compass as attached to the ordinary form of the Engineer's Transit are essentially the same as those of the Surveyor's Compass. They will be found fully treated in the article of this Manual on "*The Adjustments of the Engineer's Compass.*"

THE FOREGOING METHODS, we would again remind engineers, while essential to the proper testing and use of a Transit, are intended only as instruction in practical field adjustments, and these do not take the place of the permanent adjustments given by scientific makers, although they are to some extent a test of the latter.

THE ATTENTION OF ENGINEERS is particularly called to the methods of elimination of error and the methods of instrumental manipulation suggested by the article of this Manual, entitled "*The Mathematical Theory of the errors of the Engineer's Transit.*" A summarized statement of the means for avoiding and eliminating the various forms of error is given at the close of the same article.

QUEEN & Co. pay great attention to the theoretical accuracy and practical permanency of all the adjustments in order that the engineer receiving a perfectly adjusted and durable instrument may with reasonable use of it, for years secure a high degree of accuracy in his work with the minimum expenditure of time and trouble.

A SPECIAL CERTIFICATE, indicating all the instrumental constants and data required to be known by the engineer in the more scientific methods of manipulation, is furnished by QUEEN & Co. with each instrument. This certificate recites

(1) The magnifying power of the telescope.

(2) The angular value of the field of view of the telescope.

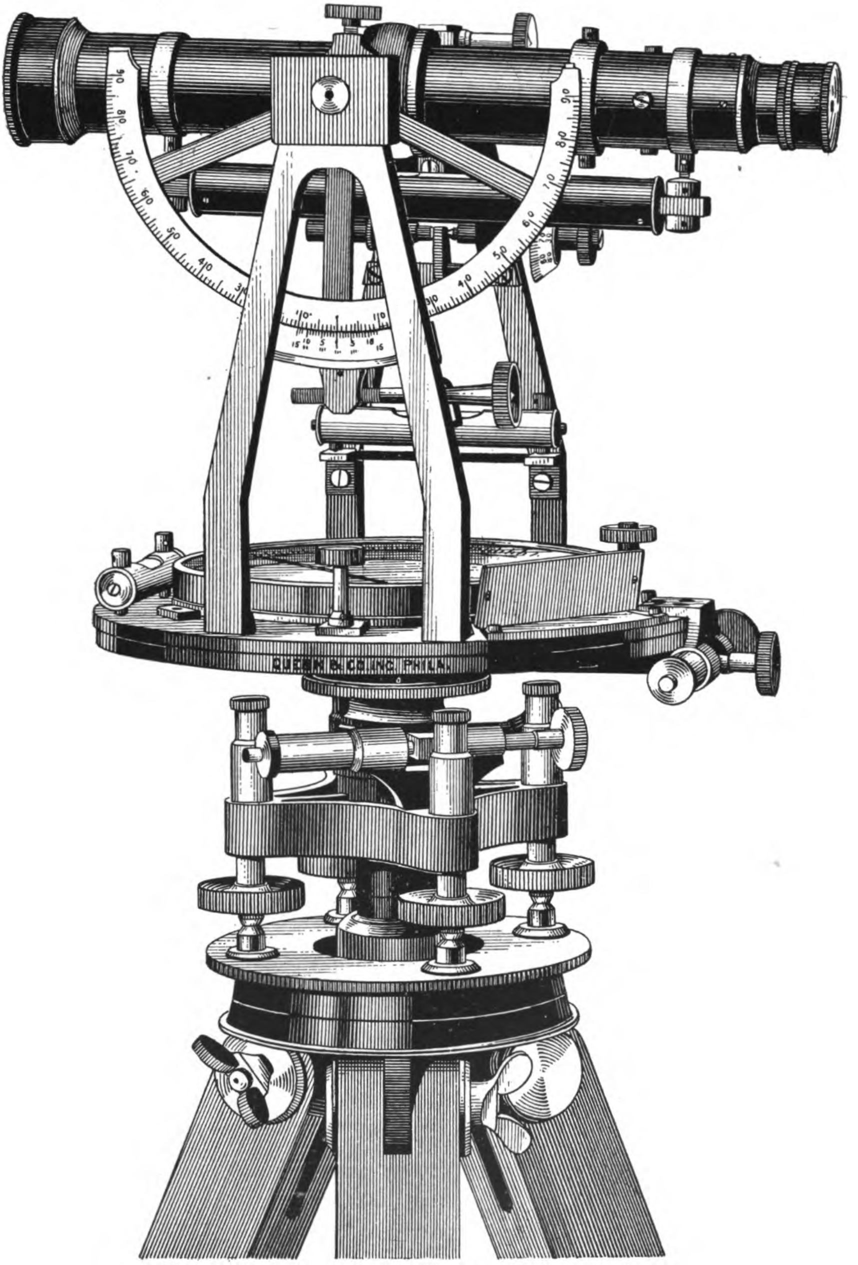
(3) The angular value of one division of each of the plate levels.

(4) The angular value of one division of the telescope level.

(5) The "least count" of each of the verniers, or the constants of each of the reading microscopes.

(6) The constants peculiar to the accessory parts of the Transit, as, for example, the stadia hairs, the gradienter screw, the filar micrometer, and the solar attachment.

"QUEEN" CITY AND BRIDGE TRANSIT.



A 1490. **Price, $275.00**

THE MATHEMATICAL THEORY

OF THE

ERRORS OF THE ENGINEER'S TRANSIT.

ALTHOUGH the practical treatment of the field adjustments has required some explanation of the nature of the errors to which the transit is liable, it is important that this matter be presented in a more mathematical and complete form. Alike the scientific construction and the intelligent use of a theodolite require as basis of such construction and use a thorough discussion of the errors. For the maker, such a discussion determines the elements to which special attention must be given in order to attain the highest constructive result. For the user it suggests the methods of manipulation and schemes of observation necessary in order to eliminate the small outstanding errors of adjustment.

It is found convenient to treat the subject under two general heads:

I. *The Axial Errors*, or errors due to the incorrect direction of the three principal axes of the instrument. II. *The Errors of Eccentricity and of Graduation*, or those pertaining to the reading of angles by means of the graduated circle.

I. THE AXIAL ERRORS.

In discussing the axial errors of an altitude-azimuth instrument we limit ourselves to a form of treatment best suited to an estimate of the *effect* of the given errors on the angular measurements. For the methods of determining by means of refined observation, the *amount* of the errors of an altazimuth we refer the reader to Chauvenet's *Spherical and Practical Astronomy*, Vol. II, Chapter VII; to Brünnow's *Traité d'astronomie spherique et d'astronomie pratique, Edition Française, par C. André*, Vol. II, Chapter III, or other standard works on practical astronomy and geodesy. The following discussion is largely due to Dr. W. Jordan's *Handbuch der Vermessungs-*

kunde, dritte verbesserte und erweiterte Auflage, and to this work as well as to Bauernfeind's *Vermessungskunde* we refer the reader for a treatment in some particulars more extended and detailed.

There are three principal axes of the transit, and there is also one accessory axis, namely, the level axis. Let us designate:

I. The Sight axis, S.
II. The Horizontal axis, H.
III. The Vertical axis, V, and
IV. The Level axis, L.

The following theoretical conditions are then to be fulfilled in the perfectly adjusted and accurately set-up instrument:

(1) $S \perp H$, or sight axis of telescope at right angles to horizontal axis of telescope.

(2) $H \perp V$, or horizontal axis of telescope at right angles to vertical axis of instrument.

(3) $L \perp V$, or level axis of (each) plate level, or of the striding level, at right angles to vertical axis of instrument.

The construction, final adjustment, and setting-up of the instrument should permit these conditions to be accurately attained. Yet, since all adjustments depending upon delicacy of manipulation are in the last analysis only approximations, it is highly important to know what the effect of any small outstanding errors of (1), (2), and (3) will be on the angular measurements made. The question plainly put is: Admitting a given error, what will be its effect on any proposed angular measurement; and which of the three given conditions, $S \perp H$, $H \perp V$, $L \perp V$, for a given error, produces the most serious effect on the angular measures? Since there are two kinds of angles measured by the transit, namely, horizontal and vertical, or angles of azimuth and angles of altitude, it becomes necessary to consider the effect of these errors, with respect to these classes of angles, separately. Investigation having, however, shown that the axial errors, though bearing important relations to the measurement of horizontal angles, have but a slight influence on vertical angles, the major discussion will naturally concern the former.

I. EFFECT OF THE AXIAL ERRORS ON THE MEASUREMENT OF ANGLES OF AZIMUTH.

(A.) ERROR IN THE CONDITION $S \perp H$.

If the line of sight is not at right angles to the horizontal axis but makes any angle, say $90° - c$, the quantity, c, is the error of the line of sight or the collimation error. The effect of such an error, c, on measurement of horizontal angles is best seen from Fig. 27.

In this figure *MN* is the horizontal axis, *OZ* is the vertical axis, while *OZ'*, *OP*, and *OS'* are three positions of the inaccurately adjusted sight axis or line of sight, which makes respectively the equal angles *Z'OZ*, *POR*, *S'OT*, or c, with the plane *ZRT*, so that *Z'PS'* is a parallel to the great circle *ZRT*.

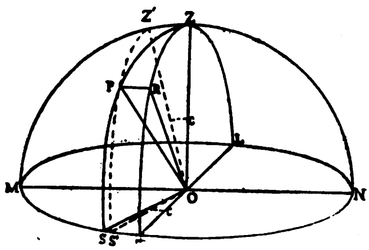


Fig. 27.

Let the sight axis be directed to a point *P* whose altitude is $PS = h$. Then, if the sight axis were accurately collimated, *P* would be projected on the horizon at *S*. But with the error c in collimation it is projected at *S'*. *PR*, as the arc of a parallel to *MTN*, very approximately equals c. For any altitude h, the error c, or *PR*, projected on the horizon, is *ST*, or *SS'* in excess of the effect of the same error on a horizontal pointing. For varying altitudes, therefore, the given error consists of a constant part *S'T* and a variable part *SS'*. Denoting *ST* by *Z*, *S'T* by c, and *SS'* by (c), we evidently have from the figure

$$(c) = Z - c$$

and because *PR* may be assumed as approximately equal to c and is the arc of a parallel to *ST*.

$$Z = c \text{ sec. } h \qquad (1)$$

and inserting this value in the previous equation, we have

$$(c) = c \text{ sec. } h - c \qquad (2)$$

which allows the variable collimation error to be computed as a simple function of the assumed constant error c and the altitude h.

The following table, for various assumed altitudes and various assumed values of c, will give a practical idea of the effect of collimation error upon measurements of horizontal angles with the line of sight directed to the given altitude.

TABLE SHOWING EFFECT OF AN ERROR c OF COLLIMATION ON MEASUREMENT OF HORIZONTAL ANGLES.

c	ALTITUDE h.								
	1°	2°	3°	4°	5°	10°	20°	45°	60°
10″	0.00″	0.01″	0.01″	0.02″	0.04″	0.15″	0.6″	0′ 4″	10″
1′	0.01	0.04	0.08	0.15	0.23	0.93	3 9	0 25	1′
2′	0.02	0.07	0.16	0.29	0.46	1.85	7.7	0 50	2′
5′	0.05	0.18	0.41	0.73	1.15	4.63	19.3	2 04	5′
10′	0.09	0.37	0.82	1.46	2.29	9.26	38 5	4 09	10′
15′	0.14	0.55	1.24	2.20	3.44	13.88	57.8	6 13	15′

THE PRACTICAL DEDUCTIONS from the preceding discussion are:

First. The constant part, $S'T$, of the projected collimation error is eliminated by taking the difference of the two readings for any two pointings, and hence is not ordinarily in question, in measurement of horizontal angles.

Secondly. The varying part, SS', of the projected collimation error, or *the* collimation error, is also eliminated by taking the difference of any two pointings of the same altitude.

For, representing the collimation error due to two pointings of different altitude, h_1 and h_2, by Δc, or, what comes to the same, letting $\Delta c = (c)_1 - (c)_2$, we have evidently from equation (2)

$$\Delta c = c\,(\sec. h_1 - \sec. h_2),$$

which, for $h_1 = h_2$, becomes zero.

Thirdly. The varying part, SS', of the projected collimation error is also for pointings of different altitudes eliminated, when the angle between the two points is determined by the principle of reversion, or when the angle is first measured in one position of telescope and then the telescope turned over on its horizontal axis and round a vertical axis, the measurement again made, and the mean of the two measures taken.

For, if Δc is considered positive in one position of the telescope it must be considered negative in the reverse position, and hence, entering with different signs, it is eliminated by taking the mean of the measures for the two positions of the telescope.

Fourthly. From the table it is evident that the collimation error likely to exist, is, for low altitudes, negligible even in high-class work. Even for $c = 10'$ and $h = 10°$ the table shows the error less than $10''$. The table also shows the necessity for painstaking collimation or for proper methods of elimination of the error, when the pointings of the telescope are of any considerable altitude.

(B.) Error in the Condition $H \perp V$.

If the horizontal axis of the telescope is not at right angles to the vertical axis of the instrument, but makes an angle $90° - i$, i is the error of the horizontal axis.

In Fig. (28), OZ represents the vertical axis, MN the horizontal axis at right angles to OZ, or in correct position, and $M'N'$ the horizontal axis making an angle i with the correct position. The line of sight will therefore move in the plane

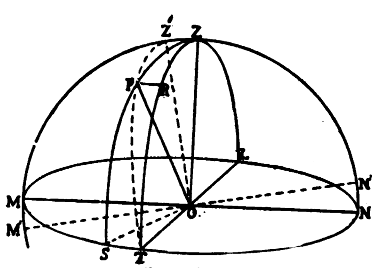


Fig. 28.

$Z'PT$ instead of the plane ZRT, and if directed to P, the deviation PR projected on the horizon will be ST. Let $ZZ' = i$, $ST = (i)$, $TR = h$, and $RZ = 90° - h$, then from the figure we have

$$PR = (i) \cos. h;$$

$$\text{also} \quad PR = i \cos. (90° - h),$$

$$\text{or,} \quad PR = i \sin. h,$$

and hence, $(i) \cos. h = i \sin. h$,

or finally, $(i) = i \tan. h$, (3)

from which formula the following table may be computed:

TABLE SHOWING EFFECT OF AN ERROR *i* OF HORIZONTAL AXIS ON MEASUREMENT OF HORIZONTAL ANGLES.

i	Altitude *h*.								
	1°	2°	3°	4°	5°	10°	20°	45°	60°
10″	0.17″	0.35″	0.52″	0.70″	0.87″	1.8″	3.6″	0′10″	0′17″
1′	1.05	2.10	3.14	4.20	5.25	10.6	21.8	1 00	1 44
2′	2.09	4.19	6.29	8.39	10.50	21.2	43.7	2 00	3 28
5′	5.24	10.48	15.72	20.98	26.25	52.9	1′49″	5 00	8 40
10′	10.47	20.95	31.44	41 96	52.49	1′46″	3 38	10 00	17 19
15′	15.71	31.43	47.17	1′ 3″	1′19″	2 39	5 28	15 00	25 59

THE PRACTICAL DEDUCTIONS from this discussion are:

First. The effect of the existence of an instrumental error *i*, or of the violation of the condition $H \perp V$, may be eliminated by the method of reversion observation, already explained in the practical deductions concerning the collimation error, *c*.

Secondly. The effect of the error *i* is also eliminated by taking the difference of the readings for any two pointings of the same altitude. For, if we represent the effective errors for the two altitudes h_1 and h_2 of an error *i*, by $(i)_1$ and $(i)_2$, and $\Delta i = (i)_1 - (i)_2$, we have evidently from equation (3),

$$\Delta i = i\,(\text{tang. } h_1 - \text{tang. } h_2),$$

which for $h_1 = h_2$ becomes zero.

Thirdly. This error, *i*, is of much more serious influence on horizontal angles than the collimation error.

Fourthly. In a thoroughly tested and carefully adjusted instrument, and with altitudes less than 5°, this error need not be feared, but with an instrument having any considerable error *i*, or with pointings of a considerable altitude, the resulting error (i) on the horizontal angle is serious.

Fifthly. It is to be borne in mind that in observations like those, for example, required in making the third adjustment, the effective error, (i), varies as the tangent of the angle of depression as well as of elevation.

(C.) Error of Deviation of the Vertical Axis of the Instrument from the Vertical.

This is due either (1) to error in the condition $L \perp V$, that is, inaccurate adjustment of the level axis with respect to vertical axis, or (2) to untruthfulness and lack of sensitiveness of the levels, or (3) to inaccuracy of use of the levels in setting up the instrument.

In Fig. 29, OZ is the vertical, OZ' the vertical axis deviating from OZ by an angle ZOZ', which we designate v. If the axis of sight is directed to P, this point will be projected to T instead of to S; and if we designate AS by u and $A'T$ by u', their difference will

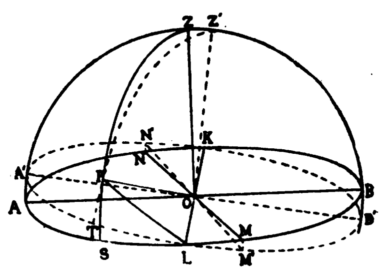


Fig. 29.

be equal to the desired projection error, which we designate (v), that is, $u - u' = (v)$. The plane of the circle at right angles to the vertical axis will therefore take the position $A'M'B'N'$ instead of $AMBN$, so that the angle BOB' between the planes is equal to v. The line of sight being directed to P, the horizontal axis must take the position of $M'N'$, at right angles to OT and approximately to OS, whence the inclination to the true horizontal plane is MOM', which we designate i'. We have now a triangle LMM' right angled at M, whose side $LM = AS$ because AL and SM each equal 90°. But the arc AS is the azimuth of the projected point P as measured from the point of greatest inclination A, and this arc, or its equal LM, we designate u. In the right spherical triangle LMM', $LM = u$, $L = v$, and $MM' = i'$, and hence

$$i' = v \text{ sin. } u.$$

But an inclination i' of the horizontal axis produced a projected error (i') in measurement of horizontal angles in which, according to the previous article, (B),

$$(i') = i' \text{ tang. } h,$$

and therefore $(i') = v \sin. u \text{ tang. } h$,

$$\text{or} \quad (v) = v \sin. u \text{ tang. } h, \qquad (4)$$

where (v) represents the effect of v, for any pointing, as projected on the horizon. For the maximum value of sin. u, or 1, the formula takes the form

$$(v) = v \text{ tang. } h,$$

and the table of the preceding section (B) gives the values of the effective error.

THE PRACTICAL DEDUCTIONS from consideration of this error are:

First. The error v made in adjusting and setting up the instrument cannot be eliminated by reversion observations.

Secondly. If we suppose an angle measured between two points of the same altitude we can find the expression for the maximum value of the error Δv. Let h_1 and u_1 be respectively the altitude and azimuth (as measured from point of greatest inclination of horizontal circle) of the first point, and h_2, u_2, the same of second point, and the difference between the effective errors (v_1) and (v_2) be Δv, that is, $\Delta v = (v_1) - (v_2)$; then from equation (4) we evidently have

$$\Delta v = v \left(\text{tang. } h_1 \sin. u_1 - \text{tang. } h_2 \sin. u_2\right). \qquad (5)$$

This value attains, for $h_1 = h_2$, its maximum in relation to u_1 and u_2 when $\sin. u_1 = -\sin. u_2$, or when $u_1 - u_2 = \pm 180°$. That is, the error becomes greatest for $h_1 = h_2$ when the angle measured $u_1 - u_2$ is 180°. Under these conditions the above formula (5) becomes

$$\text{Maximum } \Delta v = 2\, v \text{ tang. } h,$$

or the greatest error Δv arising from the error v in verticality of axis will, for a straight angle between two points of the same altitude, be just double the values set down in the table as given in section (B).

Thirdly. It is evident that for altitudes less than 5° and with good levels properly adjusted and care in setting up, no appreciable error need be feared, even in high-class work.

A FEW GENERAL INFERENCES to be drawn from the foregoing discussion of the axial errors c, i, and v, may be of practical use.

First. If we measure horizontal angles with an Engineer's Transit whose collimation error is c, error of horizontal axis i, and whose vertical axis has a deviation of v from the vertical, the three effective errors (c), (i), (v), may combine in a total (s), so that for a single pointing

$$(s) = (c) + (i) + (v),$$

and if Δs represent the total error made in measuring an angle, or for two pointings,

$$\Delta s = \Delta c + \Delta c + \Delta v,$$

or reproducing their values from sections (A), (B), and (C),

$$\Delta s = c \text{ (sec. } h_1 - \text{sec. } h_2) + i \text{ (tang. } h_1 - \text{tang. } h_2)$$
$$+ v \text{ (tang. } h_1 \text{ sin. } u_1 - \text{tang. } h_2 \text{ sin. } u_2). \qquad (6)$$

Secondly. From this equation (6) it becomes evident that it is of importance to choose points nearly of the same altitude if we would by reversion eliminate all instrumental errors eliminable.

Thirdly. Only the collimation error c and the error of the horizontal axis i can be eliminated by reversion.

Fourthly. Since the error of verticality of axis v can become larger than any other of the errors and can also have a more serious result on the measurement of horizontal angles, it requires special attention. The error v, as already stated, depends not only on care in the use of the levels in setting up, but on their proper adjustment, and on their truthfulness and sensitiveness as well. And hence the careful attention (see the article on "*The Spirit Levels of Engineering Instruments*,") bestowed by QUEEN & Co. on the plate levels, as well as on the telescope and striding levels, of the Engineer's Transit is fully justified.

THE EFFECT OF THE AXIAL ERRORS ON THE MEASUREMENT OF ANGLES OF ALTITUDE.

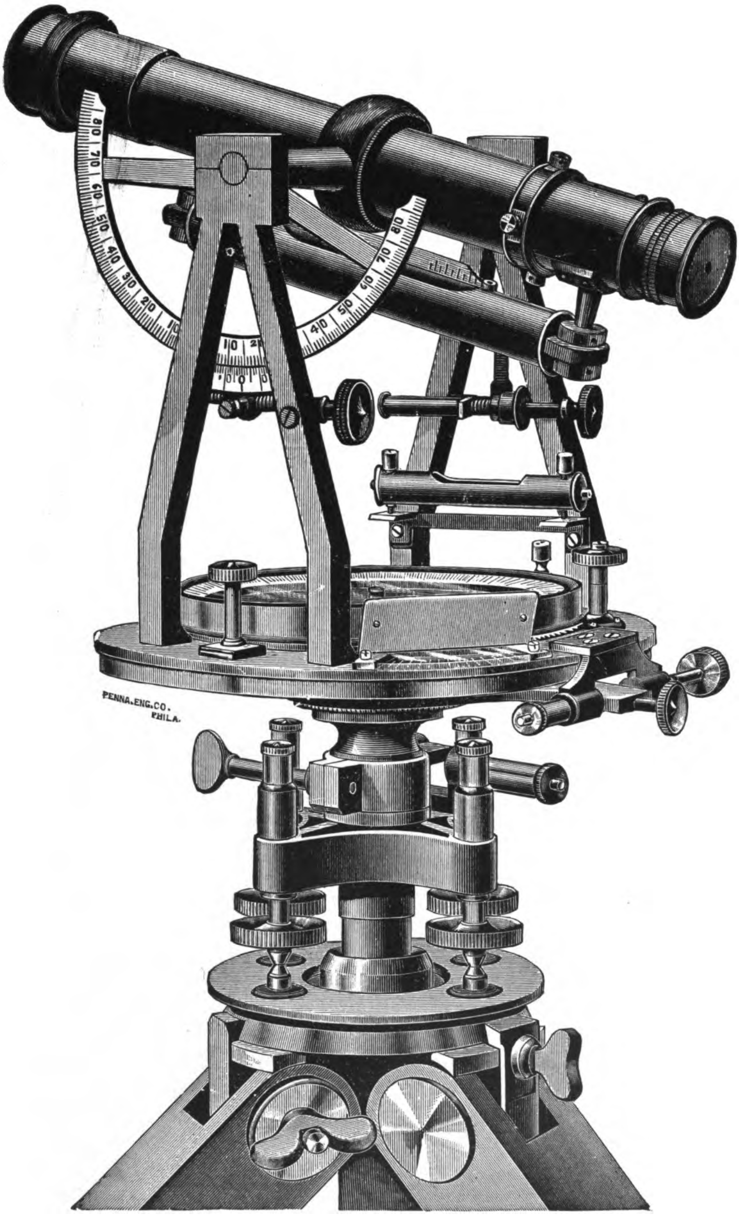
Having devoted considerable space to the consideration of the effect of small errors of direction of the three principal axes upon the measurement of horizontal angles, we have now briefly to speak of their effect on measurement of angles of altitude. This subject has been rather carefully investigated by Dr. W. Jordan in his inimitable *Handbuch der Vermessungskunde*, Vol. II, and we give here as a matter of considerable interest the general result of a cumbrous mathematical discussion.

For a fairly adjusted altazimuth instrument and for vertical angles not exceeding 45°, the effect of the usual small errors is altogether inappreciable. For angles of greater altitude than 45° and when extreme accuracy is required, greater care than usual must be taken with the adjustments. It is to be noted, however, that now we speak only of extreme accuracy and of instruments reading vertical angles to seconds of arc. For a total error of the axes of 10′ the sum total of effective error on a vertical angle of 45° is only 0.87″, of 60° only 1.51″, and for a total error of 30′ for vertical angle of 40° it is only 7.86″, and for 60° only 13.60″.

Therefore, even in the use of a fine geodetic instrument, the three axial errors do not, with reasonable precautions, produce any error in measuring angles of altitude less than 60°. Of course, in the use of the Engineer's Transit, these axial errors produce an entirely inappreciable effect on measures of moderate angles of altitude and are not in question.

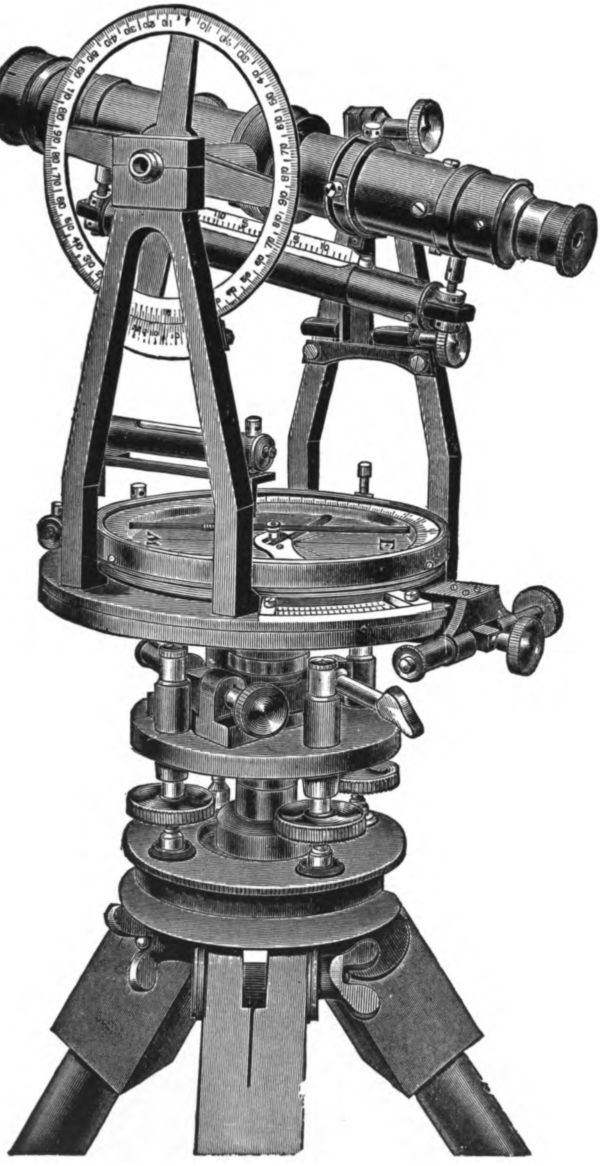
It would, however, be an entire misconception to suppose that, since the axial errors do not have an appreciable influence in the measurement of vertical angles, no errors are therefore to be feared in such measurement. The *constant* errors, such as the errors of graduation and of eccentricity of the circle, and particularly the index error and the error of the level lying in the same plane as the circle, are the ones requiring closest attention. Their elimination can be accomplished only by special methods of work and proper instrumental adjustment and design.

"QUEEN" FULL ENGINEERS' TRANSIT.



A 1494. Price, $185.00

"QUEEN" FULL SURVEYORS' TRANSIT.



A 1502. Price, $135.00

II. THE ERRORS OF ECCENTRICITY AND OF GRADUATION.

Having treated the axial errors, we still have to consider those errors which are due to (1), the eccentricity of the telescope; (2), the eccentricity of the circle; (3), the eccentricity of the verniers, and (4) the inaccuracies of graduation.

THE ECCENTRICITY OF THE TELESCOPE.

Assuming, in the first place, that there is no eccentricity of the circle or of the vernier, there may still be an eccentricity of the telescope, on account of the line of sight not being mounted directly over the centre. In Fig. 29 the eccentricity of the line of sight of the telescope is represented by the ra-

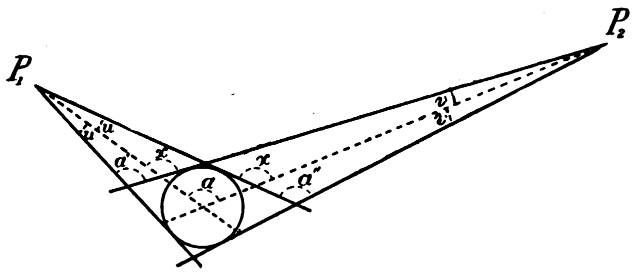


Fig. 29.

dius of a circle conceived as described about the centre, C, of the circle. All lines of sighting will be tangent to this circle. P_1 and P_2 are two points to which the eccentrically placed telescope is in turn directed, and between which it is intended to measure the angle. The angle a represents the true angle, while a' and a'' represent the angles measured with two positions of the eccentric telescope. A simple inspection of the figure gives us the following relations:

$$a+v=x=a'+u \qquad\qquad a+u=y=a''+v$$

$$a-a'=u-v \quad (1) \qquad a-a''=v-u \quad (2)$$

$$a''-a'=2\,(u-v) \quad (3) \qquad a=\frac{a'+a''}{2} \quad (4)$$

If the respective distances of P_1 and P_2, from the centre, are d_1 and d_2, and the eccentricity or radius of the small circle of the figure is represented by e, the angles of u and v may be expressed in seconds as follows:

$$u = 206265 \frac{e}{d_1} \qquad v = 206265 \frac{e}{d_2} \qquad (5)$$

Inserting these values in equation (1) we have:

$$a - a' = 206265\, e \left(\frac{1}{d_1} - \frac{1}{d_2}\right). \qquad (6)$$

Inspecting this equation we see that when d_1 and d_2 are equal to each other, $a - a' = 0$, or there is in this case no correction to be applied for eccentricity of telescope. We also note that $a - a'$ increases with e and with the difference between d_1 and d_2.

Assuming numerical values for e, d_1, and d_2, we may compute the value of $a - a'$. Let, for example, $e = 0.005$ inch, $d_1 = 20$ ft., and $d_2 = 120$ ft; then inserting these values in (6) we find $a - a' = 3.5''$. It is thus seen that when an important angle is to be measured the error of eccentricity of the telescope may become sensible, and the observations should be conducted so as to eliminate the error.

It is, however, also seen from equation (4) that a mean of two observations with telescope in different positions, direct and transited, gives the angle free from this error.

Therefore, to eliminate error of eccentricity of telescope, read the angle in one position of the telescope; then transit the telescope and read the angle again and take the mean of the two readings. This rule applies to all engineers' transits, no matter how distant from the centre of circle the telescope may be, and hence also suggests how the eccentrically placed telescopes of mining transits may be used for accurately measuring horizontal angles.

THE ERRORS OF ECCENTRICITY OF THE CIRCLE.

THE ERRORS PERTAINING TO THE GRADUATED CIRCLE are of four kinds: (1.) The error arising from the non-coincidence of the centre of the graduated circle with the centre of rotation, or the error of eccentricity of the circle. (2) The error arising from the non-intersection of the centre of rotation by the straight line joining the zeros of the verniers or microscopes, or the error of eccentricity of the verniers or microscopes, due to their zeros not being exactly 180° apart, as measured at the centre of the circle. (3) Errors due to faulty graduation; and (4) Errors due to inaccurate estimate in reading the verniers or microscopes.

THE ERROR OF ECCENTRICITY OF THE CIRCLE may be investigated as follows: In the accompanying Fig. 30 let C be the

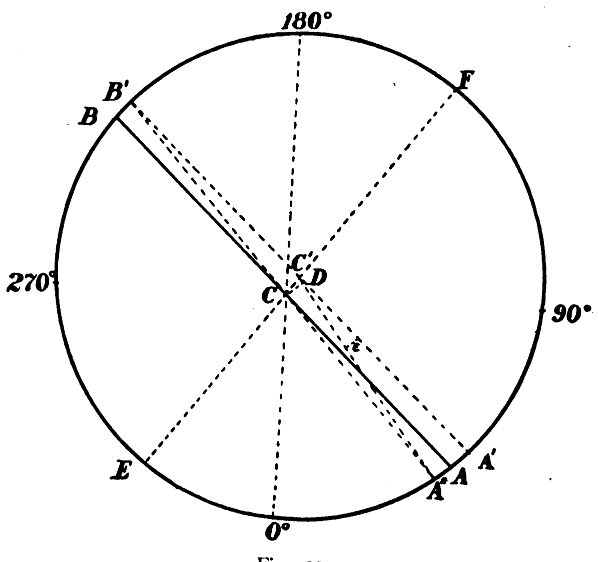


Fig. 30.

centre of the alidade, C' that of the circle, CC' the eccentricity, e, and $A'A''$ or $2AA'$ the effective error, ε, of the eccentricity. Let AB be a straight line joining the zeros of the verniers or microscopes; A the reading of vernier A, B of B, A' the true reading of vernier A, B' the true reading of vernier B. Then assuming that by careful centering of the instrument e has been made very small, the arc AA' may be regarded as equal to the perpendicular CD; and, therefore, representing the arc

$EO°$ by E and $O°A'$, as already stated, by A', or the angle $EC'A'$ by $(E+A')$, and representing the radius $C'A'$ by r and 206265″ by s we have, from the triangle $CC'D$, the following expression,

$$AA' = \frac{e\,s}{r} \sin.\,(E+A')$$

But since sin. $(E+A')$ and sin. $(E+A)$ are sensibly the same we may write

$$AA' = \frac{e\,s}{r} \sin.\,(E+A) \qquad (1)$$

If we now allow B to coincide with B', the vernier line of the alidade will lie in the direction $B'A''$, and the effective error due to the eccentricity of the circle will be the arc $A''A' = 2\,AA' =$ the central angle ε. We have, therefore, finally the following expression for the error due to eccentricity of the circle:

$$\varepsilon = \frac{2\,e\,s}{r} \sin.\,(E+A). \qquad (2)$$

This equation shows that for the direction EF, when sin. $(E+A) = 0$, the error ε becomes zero, and that for $(E+A) = \pm 90°$, $\varepsilon = \pm \frac{2\,e\,s}{r}$, which is the maximum value for the error due to the eccentricity of the circle.

It is also evident that from $(E+A) = 0°$ to $(E+A) = +180°$ a positive series of ε results, and from 0° to $-180°$ a negative series of ε. Hence, if but *one* vernier is read in a given position of the telescope, the telescope then transited and directed to the same object, and the *same* vernier read, the mean of the two readings will eliminate the eccentricity. For it is clear that the line of the verniers will in each case make equal angles with the line of zero eccentricity EF, and hence ε have the same value with opposite sign. In other words, since in equation (1) sin. $(E+A)$ will be positive, and sin. $(E+A+180°)$ negative, ε will have equal values of opposite signs, and, therefore, in a mean of values will disappear.

We may also apply equation (1) to the readings A' and B' and write:

$$A' = A + \frac{e\ s}{r} \sin.\ (E + A) \qquad (3)$$

$$B' = B + \frac{e\ s}{r} \sin.\ (E + B) \qquad (4)$$

By taking the mean of these two readings as thus expressed, we get:

$$\tfrac{1}{2}(A' + B') - \tfrac{1}{2}(A + B)$$
$$= \frac{e\ s}{r} \sin.(\tfrac{1}{2}(A + B) + E) \cos.\ \tfrac{1}{2}(A - B),$$

whence we see that the difference between the mean of the true readings and the mean of the vernier readings decreases as $(A - B)$ approaches 180°, and when $(A - B)$ exactly equals 180°, or when the verniers are rigorously 180° apart, this difference is nil. The mean of the readings of two verniers or microscopes which are 180° apart, therefore, completely eliminates the error of the eccentricity of the circle.

In order to comprehend the effect of even a small displacement of the centre, let us from equation (2) take the maximum value of ε or

$$\text{Maximum } \varepsilon = \frac{2\ e\ s}{r}$$

and assume $e = 0.0003$ in. and $r = 3.0$ in. Then we have:

$$\text{Maximum } \varepsilon = \frac{2 \times 0.0003 \times 206265''}{3} = 41.25''$$

If e had been as great as 0.003 in. the maximum error of eccentricity would have been 6′ 52.5.″

This fully illustrates the importance of three things: (1) Correct designs of the axes or "centres" of the instrument; (2) care in adjusting circle for eccentricity; (3) the reading of both verniers or microscopes in the higher classes of work.

The error of eccentricity of circles as here treated, is really made up of two mechanical errors, viz.: (1) Inaccurate centering of the circle on its axis or "centre" and (2) ellipticity of the "centres" themselves. Moreover there arises in some designs of "centres," as elsewhere in this Manual already intimated, a wear of "centres" which produces a serious eccentricity, and which cannot be remedied mechanically except by furnishing the instrument with new "centres."

QUEEN & Co. have selected a design of "centres" in which wear is not likely to introduce an appreciable error of eccentricity. The design is such also as to allow the nicest adjustment for eccentricity to be accomplished with mechanical certainty. It is therefore only incumbent on the engineer to read both verniers or microscopes in the finer classes of work.

THE ERROR OF ECCENTRICITY OF THE VERNIERS.

We have hitherto assumed that the zeros of the verniers or microscopes are exactly 180° apart. This may not be the case, and if it is not, we have what may be termed eccentricity of the verniers. The eccentricity of the verniers is the perpendicular distance between the centre of the alidade and the straight line joining the zero of the verniers, and is in Fig. 31 represented by *C V*. The effective error it produces is a *constant*

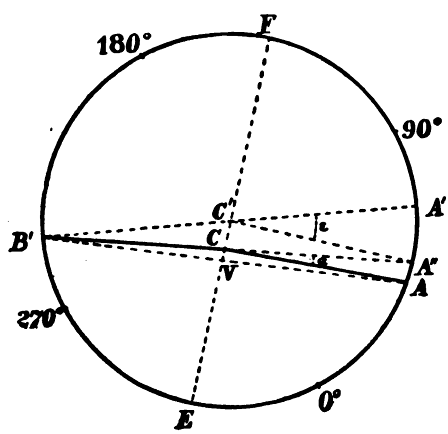


Fig. 31.

one, represented by the angle α. The effective error of eccentricity ϵ, is, on the other hand, as already shown, a *variable* one. If then, the zero of the verniers or microscopes are not accurately 180° apart, but make an angle of $180°+a$, so that, the eccentricity of the circle for the moment out of question, $B' = A' + 180° + a$, and we may then find from equations (3) and (4) for the entire difference of reading between the two verniers, or $B - A - 180° = \delta$.

$$\delta = a + \frac{2\,e\,s}{r}\,(\sin. E + A). \tag{5}$$

Considering the alidade turned from its 0° position respectively through the angles 90°, 180°, and 270°, we would have for these four respective values of A the following values of δ:

$$\delta_0 = a + \frac{2\,e\,s}{r} \sin. E. \tag{6}$$

$$\delta_1 = a + \frac{2\,e\,s}{r} \cos. E. \tag{7}$$

$$\delta_2 = a - \frac{2\,e\,s}{r} \sin. E. \tag{8}$$

$$\delta_3 = a - \frac{2\,e\,s}{r} \cos. E. \tag{9}$$

whence we find

$$a = \frac{\delta_0 + \delta_1 + \delta_2 + \delta_3}{4} = \text{the mean of all the } \delta\text{'s}. \tag{10}$$

$$\frac{4\,e\,s}{r} \sin. E. = \delta_0 - \delta_2 \tag{11}$$

$$\frac{4\,e\,s}{r} \cos. E. = \delta_1 - \delta_3 \tag{12}$$

which determine a and both e and E.

We also see from equations (6) and (8) that

$$\delta_0 = a + \varepsilon, \text{ and } \delta_2 = a - \varepsilon$$

whence $a = \frac{\delta_0 + \delta_2}{2}$ and $\varepsilon = \frac{\delta_0 - \delta_2}{2}$.

The objection to the use of the last two formulæ for determining a and ε are that but two differences are employed, and hence errors of observation and of graduation may make the result uncertain. The only complete method for determining a and ε, free from complication with errors of graduation and observation, is to determine a large number of δ's for different direct and reversed positions of the alidade, and then treat the results of the observations according to the well-known method of Least Squares. For such treatment of the subject our readers are referred to standard treatises on Practical Astronomy and Geodesy. Equations (10), (11), and (12), however, enable us for many practical purposes to derive fairly reliable values of a and ϵ by simply making four sets of observations at intervals of 90° of the differences of the vernier or microscope readings.

THE ERRORS OF GRADUATION.

The errors of graduation, unless of the coarsest sort, cannot be investigated until the effect of eccentricity of the circle and of the vernier has been ascertained. After determining the value of the eccentricity of the circle and computing its effect on the division whose graduation error is to be found, the outstanding differences, allowing for the constant deviation of the verniers from the required 180°, are to be attributed to graduation and observation errors. The errors of graduation are divided into two classes: (1) Those which are of a periodic character, and (2) those which are of an accidental character. The former depend upon slow changes during graduation in the temperature of the engine, or in the condition of the cutting tool. The latter are not dependent on known conditions, and being as likely negative as positive, are classed as accidental. It is usually found in well-graduated circles that the major errors of graduation are of the first class and may be expressed as a periodic function of the varying angle.

Instead of using the distance apart of the two vernier zeros as the standard angle, the length of the vernier may be used as a test when successively applied round the circle, and read by means of the excess graduations of the vernier. The effect of the eccentricity of the circle on the length of the vernier, must, in this case, be computed and duly allowed for before errors of graduation as such can be noted. For a complete discussion of this subject we refer the reader to the *Vermessungskunde* of Jordan, and to the treatises on Practical Astronomy of Chauvenet, Brünnow, and Sawitsch.

The errors of graduation, whether periodic or accidental, when not known, are best eliminated by combining a number of readings at different parts of the circle by Bessel's method of *Reiteration*. This method is to be carefully distinguished from Borda's method of *Repetition*, which is no longer in favor among the most scientific observers, and therefore not here described. The method of reiteration consists in systematically and by equal arcs displacing the zero of the circle with respect to the verniers or microscopes, so as to pass through an entire circumference, or, in the case of two verniers, simply through a semi-circumference. By thus giving the circle a number of equi-distant positions and taking the mean of all the observed readings, the periodic errors of graduation will be completely eliminated by compensation, and the accidental errors will, according to the method of Least Squares, be diminished in the inverse ratio of the square root of the number of reiterations.

THE ERRORS IN PRACTICAL WORK.

The foregoing discussion of the axial and circle errors, aside from its value in suggesting points of construction and adjustments of special importance to accuracy of work, should also afford many a hint to the practical engineer. The limited space does not permit us to state either the special features of instruments or the special programmes of work which are in the different cases required to avoid and eliminate all the errors. And yet we may not better close this review of the errors than by drawing attention to several points of caution to be exercised in the three most usual forms of work with the transit, viz.: the measurement of vertical angles, the laying out of straight lines, and the measurement of horizontal angles.

VERTICAL ANGLES have their zero in the horizon, and this zero must be physically determined by a level lying in a plane parallel to the graduated circle on which the measurements are to be made. This level, whether it be a plate level, the telescope level, or a special level attached to the vernier arm, should not only (*1*) lie in a plane *parallel* to the measuring circle, but (*2*) have a sensitiveness comparable to the fineness of the reading on the circle, and (*3*) always in an observation be adjusted to zero position of bubble or else be read for the small deviation of the bubble. If the telescope level is used the vertical angle is simply the difference of readings on the circle for the zero position of the bubble and for the pointing.

The error of vertical axis, or the deviation of this axis from the vertical, may affect the measurement to the whole amount. Both the error of adjustment of the plate level and the index error (see sixth adjustment in article on "*Adjustments*") can be eliminated by striking the mean of the measures of the angle taken with the telescope both in the direct and in the reverse or transited position, provided the alidade is carefully releveled after being revolved 180°. The errors of eccentricity are eliminated by reading both verniers or microscopes, if there be two. Transiting and two verniers, however, require a complete circle. For an arc of a circle with one vernier, the adjustments must be relied on. The eccentricity may, for small angles, be considered *constant*, and, if the "fourth adjustment" has been accurately made, it is eliminated by taking the difference of the readings for bubble at zero and for the pointing. The graduation errors can only be eliminated by using an entire circle, capable of being shifted on its axis. The method of reiteration of the angle may then be employed.

QUEEN & Co. desire engineers, when special accuracy is required in vertical angles, to indicate the grade of accuracy to be attained. They will then be able to recommend a design of instrument in every particular suitable to the kind of work.

STRAIGHT LINES can be prolonged accurately only with good instruments and the most careful attention.. Here the secret of the elimination of errors is so to arrange the programme of work as to distribute the errors symmetrically with respect to the proposed line. If a circumpolar star is observed for the direction of the meridian it is therefore important that the observations both as to number and character, be arranged symmetrically with regard to the time of transit, or the time of elongation, as the case may be.

If the pointings for a line are all horizontal, and the line is to be prolonged by transiting the telescope, or turning it over on its horizontal axis, the constant collimation error will enter with double its value. If, secondly, one of the pointings is at an angle as in the case of determining the direction of a circumpolar star, the errors of collimation, of the horizontal axis, and of verticality of the vertical axis, may all enter the result. Particularly would the error of verticality, due to the level at right angles to the line, be serious and necessitate attention to the sensitiveness, adjustment, and reading of the level lying in that direction.

A line may be prolonged so as to eliminate all these errors by setting up over the forward point, leveling cross-level, bisecting rear point, transiting telescope, and locating the required point; and then revolving the alidade 180° and repeating the operation and taking the mean position between the two located points as the true required point.

QUEEN & Co. make instruments especially adapted for running straight lines, including tunnel work. These are provided with powerful telescopes, delicate striding levels, and are reversible on their horizontal axes.

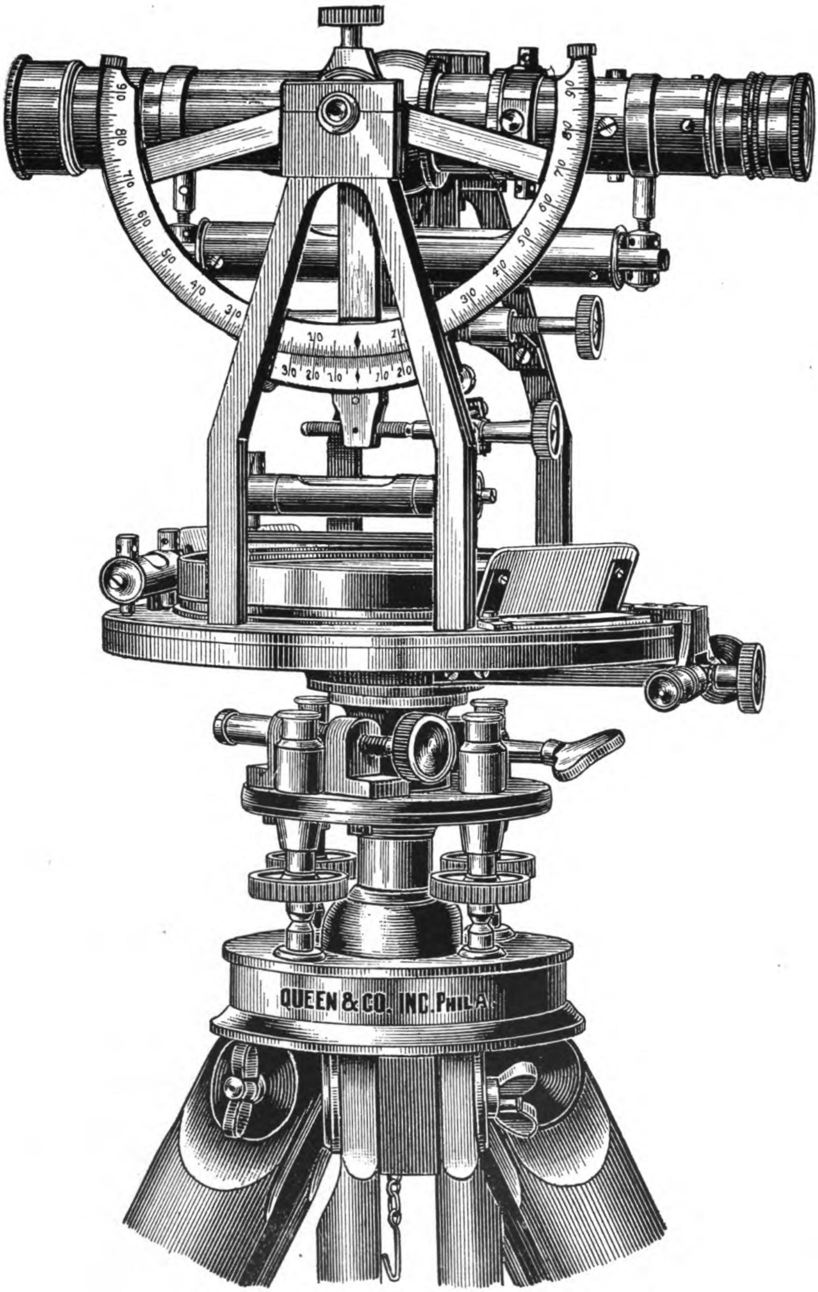
HORIZONTAL ANGLES, including the horizontal straight angles just referred to, are those most frequently measured in practical work, and the errors to which they are liable have, therefore, been fully discussed.

The accurate measurement of a horizontal angle may proceed as follows: Test the adjustments, particularly that of the levels. Level carefully. Set vernier *A* accurately to zero, and with clamped alidade turn the telescope upon the left-hand object. Clamp the circle and bisect by means of lower, or circle, tangent screw. Vernier A still being at zero, read vernier B. Now unclamp alidade and turn telescope upon right-hand object. Clamp alidade and bisect by means of upper, or alidade, tangent screw. Read both verniers accurately. The difference between the means of the vernier readings is the measurement of the angle for the telescope in direct position. Now transiting the telescope, direct the telescope to left-hand object and shift the circle a fraction of 360° from its initial position and repeat the foregoing programme for this reversed position of the telescope. The mean of the results for direct and reversed telescope is the angle freed from the errors of collimation, horizontal axis, from error of verticality (as far as possible), and from eccentricities of telescope, verniers, and circle. Reiteration of this process by shifting $\frac{1}{n}$th of 360° if the angle is to be measured n times with each position of telescope, will give a mean result measurably free from graduation errors.

A PRACTICAL INFERENCE of great importance alike to those who use, and to those who make engineering and geodetic instruments follows from the foregoing Theory of the Errors of the Universal Altazimuth. It is that since in each of the three main classes of work adverted to, the errors to be feared and if possible, avoided or eliminated, are of a peculiar type, therefore a peculiar type of instrument ought to be designed to meet the highest demands in each class of work. An instrument may be designed mainly for measuring horizontal angles or for prolonging straight lines, or for measuring vertical angles and the particular purpose, together with the degree of accuracy to be met in the special class of work, will, with the expert maker, determine every detail of the instrument.

QUEEN & Co., accordingly, stand ready not only to meet the demands for good universal transits suited to all ordinary practical requirements, but also to furnish those special instruments required in the more difficult engineering and geodetic operations.

"QUEEN" LIGHT MOUNTAIN TRANSIT.



A 1508. **Price, $185.00**

THE GRADUATED CIRCLES

OF THE

ENGINEER'S TRANSIT.

THE GRADUATIONS.

THE accurate graduation of circles is one of the most delicate operations in the mechanical arts. It requires not only machinery of unquestioned certainty of condition and of movement, but constancy of temperature during the entire process, and, even with purely automatic machines, the most alert and skillful attention. QUEEN & Co. have in their works two large dividing engines adapted to the graduation of the different classes of circles required for the astronomical and engineering instruments they make. Every attention is given not only to accurate centering, correct spacing, and to an even performance of the graduating engine, but to the final finish and numbering of the graduated circle, so as to secure ease and certainty, as well as accuracy, in the reading.

Errors of graduation, though never so small, are to be found in every circle yet graduated by human skill. The problem is, then, one of degree of error. With QUEEN & Co. the aim is to furnish graduated circles whose errors may safely be regarded as infinitesimal, except in astronomical and geodetic work of the highest class. In this most refined class of work there is, as the most noted observers have again and again demonstrated, absolutely no recourse excepting a complete examination of the graduation, and the preparation of a table of corrections. For a further reference to this subject consult "*Errors of Graduation*" in the article of this Manual entitled "*The Mathematical Theory of the Errors of the Engineer's Transit.*"

MEANS FOR READING SUBDIVISIONS OF CIRCLES.

The devices chiefly employed for reading the subdivisions of circles are the Vernier and the Micrometer Reading Microscope. Of these the former, on account of its simplicity, cheapness, and sufficient accuracy, is almost exclusively used in engineering instruments. It is only in high-class geodetic instruments that the use of the Micrometer Reading Microscope is at all warranted. The Estimation Microscope, referred to further on, is, however, coming into favor for the finer readings where rapidity of work is desirable.

THE VERNIER—ITS THEORY AND FORMS.

The Vernier was first described in a work entitled *La Construction, L'usage et les Proprietes du Quadrant Nouveau de Mathematiques, etc., du Pierre Vernier, Bruxelles, 1631.* The same appliance is by the Germans called a "*Nonius*," although the instrument described by the Portuguese "Nunnes," or "Nonius," in 1542, was in principle essentially different.

The Vernier is an accessory divided scale placed alongside the main divided scale, and permits the subdivisions of the main scale to be read by noting the *difference* in length of the Vernier and the Scale divisions. In Circular Instruments the Vernier is, of course, an arc concentric with the main divided circle, and so graduated that the ratio of the divisions of the Vernier to those of the Circle may be the one required to give the reading to the subdivision intended. An easy mathematical discussion will make this clear in every detail.

The general theory of the Vernier, forming the basis for the construction of all verniers may be stated, as follows:

Let s = The value of a division of the main Scale or Circle.

v = The value of a division of the Vernier.

$\left.\begin{array}{c} s - v \\ \text{or} \\ v - s \end{array}\right\}$ = The "least count," or smallest subdivision of the Scale or Circle to be read by the Vernier.

n = The number of divisions of the Vernier corresponding to $(n - 1)$, or $(n + 1)$ divisions of the Scale or Circle.

The Vernier is then always so graduated as to make

$$nv = (n \pm 1)s. \qquad (1)$$

If the upper sign is used, then any single vernier division is smaller than a single scale or circle division, and the vernier is a direct reading vernier with divisions numbered in the same direction as the circle is read. If the lower sign is used a vernier division is larger than a scale or circle division, and the vernier is a retrograde vernier, reading and numbered in the direction opposite to the reading on the circle. From equation (1) we easily derive the following sets of equations for the two classes of verniers:

FOR DIRECT VERNIERS.		FOR RETROGRADE VERNIERS.	
$n = \frac{s}{s - v}$.	(2)	$n = \frac{s}{v - s}$.	(5)
$v = \frac{n - 1}{n} s$.	(3)	$v = \frac{n + 1}{n} s$.	(6)
$s - v = \frac{1}{n} s$.	(4)	$v - s = \frac{1}{n} s$.	(7)

The direct Reading Vernier, being the one almost exclusively in use, we need illustrate only the first set of formulæ by means of a few examples. Suppose a circle divided to 20′, and that it is desired to read it to 30″, then from equation (2) we see that $n = \frac{1200}{30} = 40$, or 40 vernier divisions must be made equal to (40 — 1), or 39, scale divisions, in order to make 30″ the least count. Also from (3), $v = \frac{39}{40} \times 1200'' = 19'\ 30''$ = value of one vernier division; or, in other words, each vernier division will be 30″ smaller than the scale division, and hence if a given vernier division coincides, or forms the same straight line with a scale division, it shows how many times 30″ the *zero* of the vernier has passed the scale division immediately preceding it. Also from (4), $s - v = \frac{1}{40}\ 1200'' = 30''$ = the least count. The accompanying Fig. 33, represents a double direct reading vernier, applied to a circle with 20′ divisions, and reading to 30″.

The reading of a circle by means of a vernier consists of two operations. First, to find beyond what graduation the zero of the vernier has passed; second, to read the vernier itself for coincidence. We always read the vernier in the direction the numbering is inclined. If we read in the direction of the upper numbering, we use the right-hand vernier, as follows: First, the zero of the vernier has passed 1° and 20′ beyond the 110° mark, and the first reading would therefore be 111° 20′. Second, we find that the 25th division of the vernier is in coincidence with a division of the limb, and as the least count is 30″, this would mean 12′ 30″; adding this to 111° 20′, we have 111° 32′ 30″ for the reading.

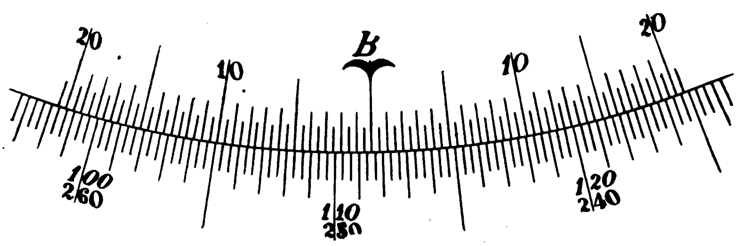


Fig. 33.

Similarly, if we are reading in the direction of the lower numbering, first the rough reading is 248° 20′; second, the reading on the vernier is 7′ 30″; the sum of the two, 248° 27′ 30″.

Practically the reading of a vernier like the one here figured is made very quickly by first taking up the degrees, and while keeping in mind the minutes of the circle, adding to these the minutes and seconds of the vernier, the whole minutes being indicated by the alternate long lines of the vernier. Thus, reading to the right, the excess of 20′ on the circle is mentally added to the reading of 12′ 30″ on the vernier, and the whole reading 111° 32′ 30″ at once set down.

A table illustrating the properties of the verniers employed with the usual graduations of Queen & Co.'s instruments is here appended. A study of it may prove useful to beginners, as familiarizing them with various kinds of graduations and verniers:

Vernier.	s	n	$n-1$	v	$s-v$
(1)	30′	30	29	29′ 00″	1′
(2)	20′	40	39	19′ 30″	30″
(3)	15′	30	29	14′ 30″	30″
(4)	20′	60	59	19′ 40″	20″
(5)	15′	45	44	14′ 40″	20″
(6)	10′	60	50	9′ 50″	10″

The Retrograde Vernier is sometimes used on the arc or circle of the Engineer's Compass. It is also used in connection with barometer scales.

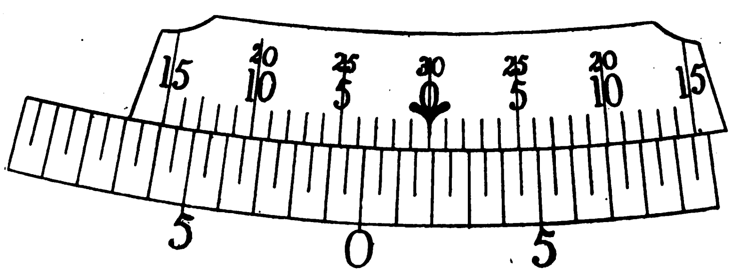


Fig. 34.

A retrograde double vernier of a compass is shown in Fig. 34, where 30 vernier divisions equal 31 of the limb and the limb is divided to half degrees. Consequently, according to formula (7), $v - s = \frac{1}{n} s$, or the least reading $= \frac{1}{30} \times 30' = 1'$. This form of vernier is here only one-half as long as a double direct vernier. It extends to 15′, and the upper figures on one-half are in a manner a continuation of the lower ones on the other half. Thus in the figure the zero of the vernier having been moved to the right, the *lower* figures of the *left-hand* vernier are read when the angle passed over is less than 15′; but as more have here been passed, the *upper* figures of the right hand are taken as a continuation, and the reading evidently is, 1° 30′ (limb) + 23′ (vernier), = 1° 53′.

THE READING MICROSCOPE—ITS FORMS, THEORY, AND ADJUSTMENTS.

The Micrometer Reading Microscope is esteemed an essential requisite for the highest class of circle readings. The accompanying Fig. 35 shows a vertical section of the microscope as placed over the graduation. In the common focus of the objective and eye-piece at *F* is formed an image of the division of the limb. The narrow lane formed by two parallel micrometer threads, as shown in Fig. 36, is then, by means of the micrometer screw, moved until it centrally includes the given division. The number of whole revolutions of the screw are counted by means of the notches seen in the field of view Fig. 36, and the fraction of a revolution is read off on the graduated head *H*. The notches used as counters are each a complete revolution distant from each other, and each fifth one is cut deeper and specially marked. The graduated head *H* of the screw is usually divided into sixty divisions and reads directly to seconds, and by estimation to tenths of seconds.

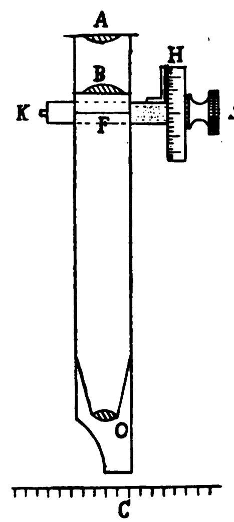


Fig. 35.

Figures 35 and 36 will, without much further assistance, indicate the construction of the micrometer microscope in sufficient detail. The eye-piece *A B* is a positive one, and (except in determining the requisite magnification and definition) does not enter into the optical theory of the reading microscope. The micrometer screw is opposed by springs, *b b*, which hold the slide *a a*, carrying the parallel threads, so that it always bears against one side of the screw threads *c c*, and there is no lost or dead motion. It is conducive to accuracy, nevertheless, always to turn the screw in only one predetermined direction before each bisection of a division of the limb.

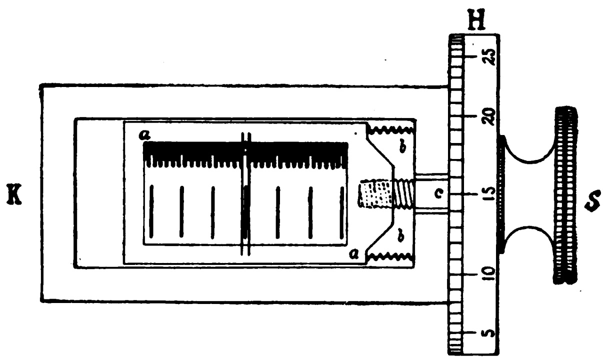


Fig. 36.

The optical theory of the Micrometer Microscope is put in simple form as follows: Assuming that one revolution of the micrometer screw carries the set of parallel threads from one central position over a division to another, and letting:

s_1=Linear movement of these threads due to one revolution of screw.

s_2=Length of one division of circle.

d_1=Distance of threads from the microscope objective.

d_2=Distance of circle from the microscope objective.

We have, according to Fig. 37:

$$\frac{1}{d_1}+\frac{1}{d_2}=\frac{1}{f_1}, \quad (1), \text{ and } \frac{s_1}{s_2}=\frac{d_1}{d_2}, \quad (2),$$

whence by respectively eliminating d_2 and d_1 by combining (1) and (2) we have:

$$d_1=f+\frac{s_1}{s_2}f, \quad (3), \quad d_2=f+\frac{s_2}{s_1}f, \quad (4).$$

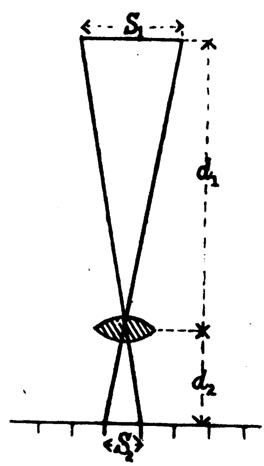


Fig. 37.

The equations (3) and (4) give the distances respectively at which the threads and the limb must be placed from the microscope objective, provided the eye-piece be a positive one, as shown in Fig. 35. An eye-piece of the Huygenian sort, with its collective lens, would introduce other considerations.

The adjustments of the Micrometer Microscope may be stated as follows:

1. The threads of the microscope should be parallel to the circle divisions. This is accomplished by turning the entire microscope in its support.

2. The optical axis of the microscope should be at right angles to the graduated limb. This condition may be tested with sufficient accuracy by direct measurements. A good optical test is the precise equality of definition of a division of the limb as it passes across the field.

3. The distances d_1 and d_2 are to be so adjusted that a whole number of revolutions of the screw is equal to the distance between two consecutive graduations of the limb. If the head of the screw indicates more than a whole number of revolutions for one division of the limb, d_1 and d_2 must be lessened, *i. e.*, the objective brought nearer the threads, and the whole microscope nearer the limb. If the head of the screw indicate less than a whole number of revolutions for one division of the circle, d_1 and d_2 must be increased. In each case d_1 is first lessened or increased, and then the microscope moved until the circle graduations again appear well defined. The changes in d_1 and d_2 for any given excess or deficit of the screw reading, are, however, most certainly and accurately made by first computing their value by formulæ easily derived from equations (3) and (4).

4. The micrometer screw should be as nearly as possible a perfect one, without inequalities or irregularities.

The errors of the Reading Microscope are readily investigated. As in other features, so here, although a high grade of accuracy of adjustment is to be expected from competent and conscientious makers, there will still be small errors of adjustment as well as other errors arising from changes of temperature and the like, which have to be determined and allowed for in the most refined classes of measurement. It is usually sufficient, even in the best work, to investigate the following errors:

1. **The error of runs**, or the excess of a circle division above a whole number of revolutions of the screw may be determined

by measuring a number of divisions in different parts of the circle and taking the mean so as to eliminate graduation errors. A proportional part of this error must be allowed for in all readings. If one division, for example, measures $5\frac{1.8}{60}$ revolutions, or equals $5' + 1''.8$, each minute read off must be corrected by $= -\frac{1''.8}{5}$ or $-0''.36$. Only for the highest accuracy need the error of runs be determined at different temperatures and corrected for inequalities of the screw.

2. **The errors of inequality** of the screw may be determined by measuring some small distance, as that between a circle graduation and a special graduation, or as that of the distance apart of the two micrometer hairs, if this is an aliquot part of a division. The mean of many such measures is then taken as the standard value for the preparation of a table of corrections for the inequality of the screw. These corrections should be allowed for before the error of runs is determined. But in well-made screws the errors of inequality are small enough to be entirely neglected.

The Estimation Microscope, as recently applied to the reading of the circles of the theodolites, dispenses with the micrometer screw, and in its place has a fixed scale divided on glass. It is on this account sometimes called the Scale Microscope. The accompanying figure shows a circle divided to 10′, as appearing under an estimation microscope. The ten divisions marked 0, 5, 10 belong to the microscope, and are together equal in length to 10′. The zero is 3′, and, we estimate, 0′.7 more, beyond the 40° 10′ mark, and hence the reading is 40° 13′.7 = 40° 13′ 42″. This method lacks the accuracy of the micrometer microscope, but has the advantage of rapidity. Single readings can be made by this means with a probable error of about ± 5″. The ordinary graduation intended for vernier reading

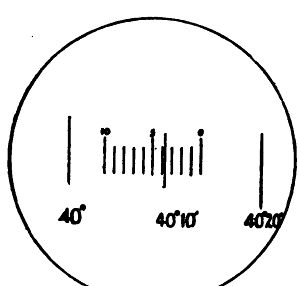


Fig. 38.

appears too heavy under the microscope for the most accurate reading by estimation, and hence, when desired, QUEEN & Co. make a specially delicate graduation, suited to the demands of the estimation method.

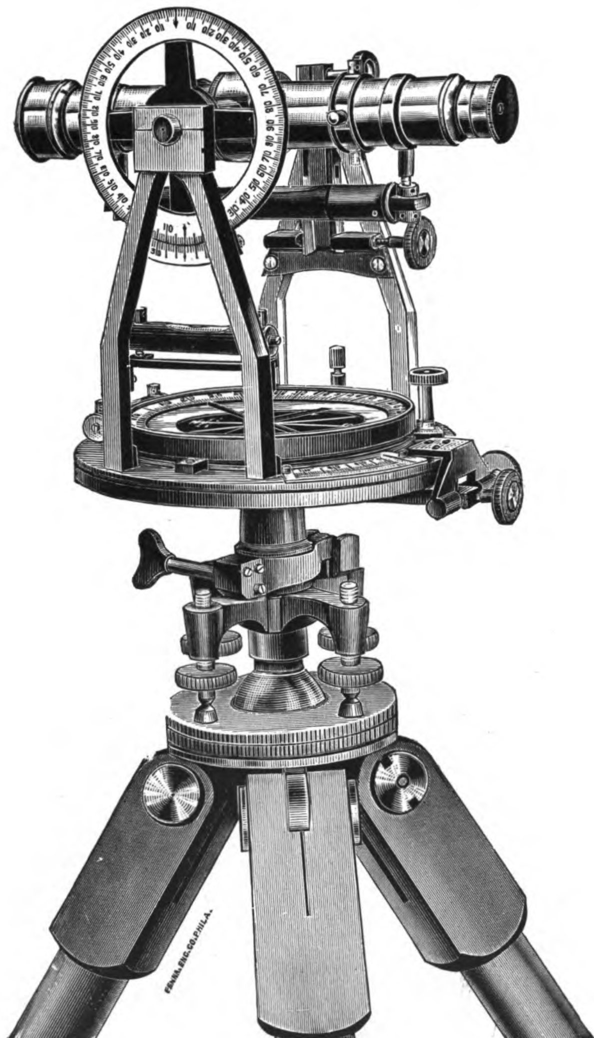
THE ADJUSTMENTS of the Estimation Microscope are similar to those of the Micrometer Microscope. The scale and the image of the graduation must both appear with good definition. The divisions of the scale must be parallel to the divisions of the graduation circle, and the whole microscope must have its axis at right angles to the plane of the circle. The interval of the scale must also correspond with that of the graduations, and there may hence also, from lack of accurate correspondence, be an error similar to the error of runs of the micrometer microscope.

THE RELATIVE ACCURACY of verniers and micrometer reading microscopes has been investigated by Bauernfeind, who concludes that for circles of five inches and over the microscope is the more accurate, but that the time expended in adjusting and reading the microscope is very much greater than for the vernier. Well-made verniers, read with good illumination and with the axis of the eye in the same plane as the coinciding divisions, may produce results of a high order. But the highest accuracy with large circles can only be attained by means of the micrometer microscope. It is probable, however, that taking both time and accuracy into consideration, the estimation or scale microscope is often to be preferred to either the vernier or micrometer microscope.

A RECENT PLAN adopted to obviate the necessity for adjusting the microscope to correspondence with the graduations is, to carry the direct graduation of the circle down to such a degree of fineness that it is only necessary to use a single thread in the microscope as a means of estimating further subdivisions.

QUEEN & Co. believing that there is room for materially extending the accuracy of graduation and the convenience of circle reading as applied to engineering and geodetic instruments, make it their constant aim to be abreast of the highest modern science and skill in this work.

"QUEEN" RECONNOISSANCE TRANSIT.



A 1518. **Price, $125.00**

THE SPIRIT LEVELS

OF

ENGINEERING INSTRUMENTS.

AS an essential part of nearly every important engineering instrument, the spirit level deserves special consideration in respect of its theory, construction, and use. This the more on account of the apparent indifference among the engineering fraternity, and consequently among makers themselves, regarding the performance of the levels of instruments. Neglect of the subject is also shared by the standard American treatises on surveying. It is therefore deemed important to draw the special attention of the engineer to this essential part, in the hope that scientific makers may be fairly encouraged to furnish instruments suited, as well in this, as in other respects, to reliable work.

Spirit Levels are the most sensitive, and therefore the most important, appliances for practically determining horizontal or vertical planes and for measuring small angles. They replace and far excel the plumb line as formerly used for the same purpose. They are of two kinds, cylindrical levels, and circular or box levels.

The Cylindrical Level consists of a cylindrical glass tube, with the inner surface ground to circular curvature, and, being nearly filled with a very mobile liquid like alcohol or ether, sealed at both ends. The part of the tube not filled by the liquid is occupied by its vapor. A scale of equal divisions is usually either engraved on the outside of the glass tube or on a metallic strip placed near the level, and in the plane in which the level is to be used.

The geometric features of the cylindrical level will be understood from Fig. 39.

The curve in any plane, as that represented by this sectional view, is the arc of a circle whose chord is either AB, or CD. The "axis of the level" is a line parallel to the chord AB, as the medial axis MM, or it is the tangent, TT, to the arc at the point O. While the axis of the level may indeed be a line parallel to any tangent of the curve, the axis is by common consent taken as that line which is, or is parallel to, the tangent of the curve at the marked zero. The "plane of the level" is the horizontal plane containing this axis. The central point, O, of the arc which is occupied by the centre of the bubble when the axis is horizontal is called "the zero point" of the level. The graduated scale should read both ways from this zero. The practice in vogue among some makers of leaving the central portions of the level without graduations is as unscientific and inconvenient as it is antiquated.

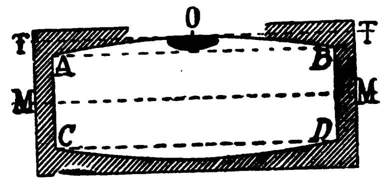


Fig. 39.

The theory of the Spirit Level may be briefly stated as follows:

Let, l = Amount of any given bubble displacement expressed in linear units.

r = Radius of curvature of inner surface of the bubble tube, measured in the same linear unit.

πr = Semi-circumference of this circle.

n = Number of scale divisions the bubble is displaced.

d = Value in seconds of arc of each scale division.

nd = The total displacement, expressed in seconds of arc.

Then evidently we have the following relation:

$$\frac{l}{\pi r} = \frac{nd}{180^\circ} \qquad (1)$$

That is, the linear displacement of the bubble is to the whole length of the semi-circumference, as the number of seconds of arc of bubble displacement is to the total number of seconds in the semi-circumference. From equation (1) we derive:

$$l = \frac{rnd}{206\,265}, \ (2); \quad r = \frac{l\,206\,265}{nd}, \ (3); \quad d = \frac{l\,206\,265}{nr}, \ (4)$$

Formula (2) gives the linear bubble displacement in terms of the radius of curvature, the seconds of arc this displacement is to represent, and the number of seconds in a radian. Formula (3) enables one to derive the radius of curvature from the linear displacement of bubble, its value in seconds, and the number of seconds in a radian; and equation (4) expresses the arc value of a division in terms of the radius, the number of seconds in a radian, and the linear value of a division.

The sensitiveness of a level, or the given bubble displacement corresponding to a given angle, varies directly as the radius of curvature. Hence levels ground to a short radius give scarcely any displacement of bubble for a small variation of angle, while those of sufficiently long radius may be made to show an appreciable displacement of bubble for an angular value of but a fraction of a second of arc. The sensitiveness of levels is usually stated as so much deviation of bubble per single division of one French line of 2.26 mm. in length. It varies from 5′ per division for circular levels applied to leveling rods, to 5″ per division or less, in levels applied to the finer leveling instruments, and to 2″ or less in those applied to astronomical instruments.

The reading of the bubble requires the position of both ends to be noted with respect to the scale. Only the roughest work allows the position of the centre of the bubble to be estimated. The estimations of the positions of the ends of the bubble are usually expressed in divisions and tenths of divisions, counting from the zero of the scale in the middle of the tube. Readings of the bubble for the left-end, 13.8, and for the right-end, 16.2, mean that the half-length of the bubble is 15 divisions, and its middle displaced 1.2 divisions to the right.

In the use of very delicate levels it is not always convenient to read from the marked zero, and an assumed zero determined by observation of the error of adjustment may then be used.

The Adjustments of the Cylindrical Level are two in number. The first requirement is that the axis of the level and the axis of the instrument shall lie in the same plane. Any other position of the level-axis is said to be a crosswise position. The second requirement is that the physical line or plane formed by the supporting base of the level shall be parallel to the level-axis, or parallel to the tangent of the level-curve at the zero of its graduation. Both these adjustments will be fully described in the subsequent explanation of the use of a striding or other fine level.

The making of a fine level requires much skill and patience. It includes principally the grinding of the curve and the sealing of the tube.

The grinding of the inner surface to the requisite curvature would seem an easy operation, but practically it is found that the grinding does not always bear the test of the level-trier. Irregularities of curvature are a fatal blemish and can only be obviated by costly skill.

The sealing of the tube is also not a simple matter. Leakage follows upon nearly all methods except the hermetic. The plan of electrolytically depositing copper on the stoppered ends has, however, also proved a success.

The brass case usually supporting and largely inclosing the level tube should be separated from it by some good non-conductor of heat. Sometimes, to protect the delicate level from rapid temperature changes, the case is a double one, inclosing air. Another requisite is that the level be so fastened in its case as not to suffer stress from changes in temperature.

The Chambered Level is one provided at one end with a partition, which allows part of the bubble, if too long, to be removed and confined apart. This device is only required in very large levels, where the highest sensitiveness and quickness of action are required.

The Double Level is a cylindrical level ground to curve above and below, and provided with two corresponding scales. When attached to a telescope it consequently enables leveling to be done in two positions. The complicated errors to which it is liable, together with its costliness, make it, however, of doubtful value. It seems better always to use two levels instead of the double level, when it is necessary to keep the telescope level, both in a direct and in a reverse position.

The Circular Level, or box level, consists of a small metallic vessel nearly filled with mobile liquid and sealed with a glass covering whose inner surface has been ground to a spherical surface. This level is usually of but a small sensitiveness, the angular value of a deviation of the bubble, for a French line, being one minute or even more. The plane of the circular level is that horizontal plane containing the centre of the circle engraved on the glass disc.

The Adjustment of the Circular Level is accomplished as follows: Place it upon an instrument provided with leveling screws, and, by means of the latter bring the bubbles to the centre of the circle engraved on the glass. Then turn the level about its vertical axis and note in what position it attains its maximum deviation of bubble. Correct half of this maximum deviation by means of the proper screws attached to the level, or, if there are no screws, by a proper grinding of the base. The adjustment may be verified by now leveling the instrument and again testing whether the bubble remains in the centre on turning the level about its vertical axis. The principle involved is the familiar one of reversion, fully illustrated in the subsequent explanation of the use of the cylindrical level.

The usefulness of the Circular Level arises from the fact that it is at once a test of level in every azimuthal direction, and therefore requires the minimum turning of the instrument to which it is applied. This characteristic, combined with its low sensitiveness, make it often indispensable for the economy of time. It is attached to leveling rods, to all the ordinary surveying instruments, and even to the finer instruments as an important accessory conducive to rapidity of work.

THE ADJUSTMENT AND USE OF A STRIDING OR OTHER FINE LEVEL.

In order fully to explain the operations and precautions necessary to determine the inclination of a line by means of the spirit level, or to render a line horizontal, we will describe in detail the use of a delicate level in testing the inclination to the horizon of any line, as for example, the horizontal axis of a theodolite. Every such level, and, in fact, every level capable of correct use possesses at least two means of adjusting the direction of the level tube with respect to its support, viz., First, means for laterally moving one end, so as to render the level parallel to the line intended to be leveled. The screws for accomplishing this are called "the lateral adjusting

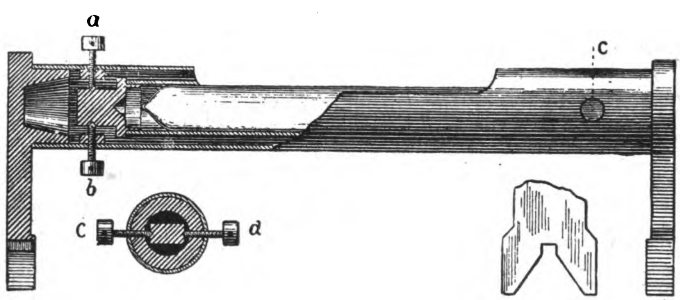


Fig. 40.

screws." Secondly, it possesses means for vertically moving one end of the tube with respect to the support, so as to enable the bubble to be brought to zero when the line of the supports is horizontal. This line of the supports, of an accurately adjusted level, brought in physical contact with any other line, and the bubble brought to zero, the other line is also horizontal. The screws used for accomplishing the vertical movement are called "the vertical adjusting screws."

Both these required conditions may be summed up in the statement that the axis of the level must lie in the same plane as the line whose inclination is to be determined, and also parallel to the physical line used as an intermediary for applying the level. The accompanying Fig. 40 will fully illustrate the mechanical means used for securing these adjustments. The vertical adjusting screws are *ab*, and the lateral adjusting ones, *cd*.

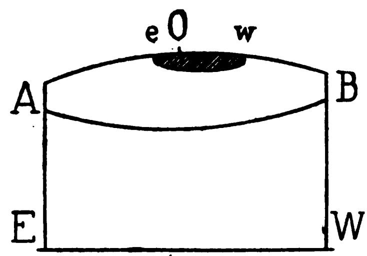
The cross-wise position of the level with respect to the axis of the instrument may, in the case of this striding level, be readily tested. Suppose, for example, that in Fig. 40 the end on the left projects forward, and the end on the right to the rear of the instrumental axis. Rotating the level on the instrumental axis toward the rear, the bubble will move toward the left, because that end is thus raised. Moving the level forward, the bubble will be displaced toward the right. If, however, the level axis is parallel to the instrumental axis, there will be no movement whatever of the bubble upon rotating the striding level upon the instrumental axis. This is the first adjustment to be made. It should also be tested after the second adjustment.

The case of the cross-wise position of the level with respect to a line sight, as occurring in leveling instruments, is also of considerable importance and is fully discussed in the article of this Manual entitled "*The Adjustments of the Engineer's Level.*"

The parallel position of the level axis with the physical line or physical plane forming the base of the level can be secured only after making a complete test, as now to be explained. The physical plane mentioned is here the plane joining the points of contact of the inverted V's of the striding level. The accurate use of a level always requires such a manipulation as shall eliminate any error due to lack of parallelism of its axis with the plane forming its base. It is not always necessary nor even desirable that the error shall be removed by adjustment, but it is essential that its value be known, and allowed for. Moreover, it ought to be distinctly understood that there is no form of level whatever not subject to this error. The following method of observation will be found to lead both to the desired accuracy in observation and to the neatest means of determining the error and of accomplishing this adjustment of the level:

Let AB in Fig. 41 represent a level tube applied in an east-west direction to a truly horizontal line E.W.; e and w the end readings of the bubble. Let l equal the half-length of the bubble. The bubble readings, e and w, will be exactly the same, and each equal to l, provided, First, the legs AE and BW are equal and, Secondly, the zero point O is in the middle of AB. If BW is the longer leg, the bubble will stand nearer B by, say, y divisions; also, if the zero O stands nearer A by, say, z divisions, the reading of w will be increased by that amount.

Fig. 41.



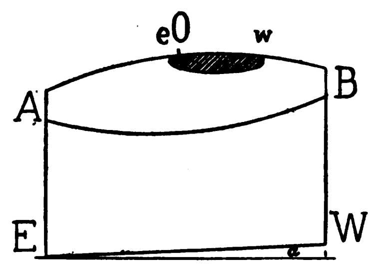


Fig. 42.

Letting $\varepsilon = y + z$. The readings for the ends are then:

$$w = l + \varepsilon$$

$$e = l - \varepsilon$$

But if the end B be now raised, as shown in Fig. 42, through an angle α which would of itself give, say, x divisions of displacement, the readings in this position of the level will then be

$$\begin{aligned} w_1 &= l + \varepsilon + x \\ e_1 &= l - \varepsilon - x \end{aligned} \qquad (1)$$

And, if we now, in Fig. 42, reverse the position of the level, so that B stands over E and A over W, the errors $y + z = \varepsilon$, will change sign, and the readings of the bubble ends toward W and E will be respectively,

$$\begin{aligned} w_2 &= l - \varepsilon + x \\ e_2 &= l + \varepsilon - x \end{aligned} \qquad (2)$$

From these sets of equations, (1) and (2), we have

$$\begin{aligned} \tfrac{1}{2}(w_1 - e_1) &= x + \varepsilon \\ \tfrac{1}{2}(w_2 - e_2) &= x - \varepsilon \end{aligned} \qquad (3)$$

Hence $x = \tfrac{1}{2}\left[\tfrac{1}{2}(w_1 - e_1) + \tfrac{1}{2}(w_2 - e_2)\right]$

or finally
$$x = \frac{(w_1 + w_2) - (e_1 + e_2)}{4} \qquad (4)$$

The practical rule given by the last equation is: Place the level on the given inclined line. Read the divisions at the bubble-ends. Reverse and read again. Add together the two bubble-end readings of the one end, also the two bubble-end readings of the other end, and divide the difference of these sums by four. This result measures, in divisions of the level, the elevation of the end with the greater sum of readings.

In order to find the angular elevation we must multiply the number of divisions, n, of bubble displacement, by the value of a division in arc, d, to obtain the angle a, or, $a = nd$.

The errors y and z cannot be found separately, but their sum, ε, is readily found from equations (3).

$$\varepsilon = \frac{(w_1 - e_1) - (w_2 - e_2)}{4} \qquad (5)$$

If the level always remained in a constant condition, the errors y and z could be found and corrected, and their sum being then zero, either of the equations, (3), would give x without reversal of the level. In refined leveling this constancy should never be assumed. It is, however, always convenient to render ε as nearly as possible equal to zero.

A practical example is furnished by the following readings of a level placed on the horizontal axis of an instrument:

	W.	*E.*	$w - e$
First position,	24.1	26.3	$-2.2 = (w_1 - e_1)$
Second position,	29.2	21.2	$+8.0 = (w_2 - e_2)$
Sums,	53.3	47.5	4)-10.2
	47.5		$-2.55 = \varepsilon$
	4)5.8		
	$1.45 = x$		

Assuming the value of a division, d, of this level as 1.8″, the west end of the axis of the instrument inclines upward by 1.45 times this amount, or 2.6″.

The negative sign of s shows that in the first position of the level, the west end bubble reading is too small, or the west end of the tube is too low by that amount. The vertical adjusting screws must therefore be so turned that for this position the bubble is brought west 2.55 divisions. This being done, the reading for each position of the level, direct and reversed, will be 26.65 and 23.75 for the west and east end respectively; and in either position of the level, one-half the difference of the bubble-end readings will give the number, 1.45, of bubble-divisions of inclination of the axis of the instrument.

Change of bubble length due to change of temperature during the reading of the level may introduce an error. It is eliminated by arranging the several readings in the two positions of the level symmetrically with respect to the time. For reasons to be stated under the head of errors of the level, each set of readings should be made an independent one by lifting the level after each observation of both ends of the bubble. The rule would then be: Read the bubble-ends once in the first position of level, twice in the second position (taking care to lift level between these observations), and once again in the first position. The difference of the sums of readings on the same side, divided by the whole number of end readings, is, in bubble-divisions, the inclination upward of the side having the greater sum of readings.

METHODS OF FINDING THE VALUE OF A DIVISION OF A SPIRIT LEVEL.

Taking great care to place the level tube while it is being tested under precisely the same conditions as when it is in use in connection with the instrument, a spirit level may have the value of a division determined by one or other of the following methods:

1. **By the use of a Vertical Circle.**—If a finely divided verti-

cal circle is at hand, the value of a division may be determined by suitably attaching the level in the plane of the circle and simultaneously taking the readings of the circle and of the level with the bubble near one end, and then by a slight rotation bringing the bubble near the other end and taking the simultaneous readings. The value of one division of the level will evidently result from a division of the number of seconds of angle measured on the circle, by the number of divisions of bubble displacement. By taking simultaneous readings with bubble in various positions of the tube, the equality of value of the divisions of the level may be tested.

2. By Means of Instrument and Rod.—A convenient, practical method of finding the value of a division of the level of an engineer's transit, or of an engineer's level, consists in sighting the telescope to a leveling-rod set at a known distance from the instrument, and causing the bubble to run first toward the eye-end and then toward the object-end of the level tube, at the same time that the rod readings are taken for these different positions of the bubble. If D represents the distance of the rod from the instrument; r, the difference of the rod-readings for the two positions of the bubble; n, the number of divisions traversed by the centre of the bubble; d_r, the value of one division of the level in units of the rod for the unit distance, and d_s the value of one division of the level in seconds of arc, we have

$$d_r = \frac{r}{Dn}, \quad (1), \qquad \text{and } d_s = 206\,265\,\frac{r}{Dn}, \qquad (2).$$

If we let E_e equal the eye-end reading, and O_e the object-end reading of bubble for the bubble run toward the eye-end of the tube; E_o the eye-end reading, and O_o the object-end reading of the bubble for bubble-run toward object-end of the tube; R_e the rod reading for bubble run toward eye-end, and R_o the rod reading for bubble-run toward object-end, the bubble deviation being counted from the middle of the tube, and reckoned positive if toward the object-end, we may write equations (1) and (2) in the following suggestive forms:

$$d_r = \frac{R_o - R_e}{D\left(\frac{O_o - E_o}{2} - \frac{O_e - E_e}{2}\right)} \qquad (3)$$

And

$$d_s = \frac{(R_o - R_e)\,206\,265}{D\left(\frac{O_o - E_o}{2} - \frac{O_e - E_e}{2}\right)} \qquad (4)$$

It is advantageous in practice to let each one of the letters representing readings in equations (3) and (4) stand for the mean of a number of readings. Equation (3) will be found useful in computing a table of corrections to the rod-readings, corresponding to various distances and bubble deviations, incident to the use of an Engineers' Transit or Engineers' Level.

3. **By Means of a Level-Trier.**—The level-trier is an instrument specially designed for determining the value of a division of a level and investigating the uniformity of that

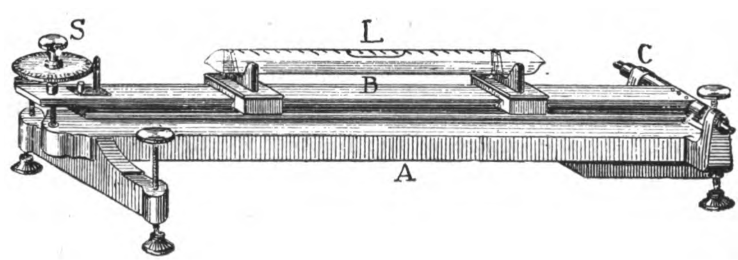


Fig. 42.

value in different parts of its scale, and under different conditions of temperature. Figure 42 gives a perspective view of a level-trier, or level-tester. This instrument consists of a main T-formed plate *A* mounted on three leveling-screws; a second plate *B* hinged to the former at one end, by means of accurate pivots, and hence capable of having the height of the other end varied by means of a fine micrometer screw *S* placed there. This screw is provided with a graduated head, from which the seconds of arc may be directly read off. Slides with suitable V's rest upon the movable plate, and serve to hold in place levels of various lengths.

The theory of the level-trier is very simple. If the length, *CS*, accurately measured from the centre of the axis *C* to the axis of the micrometer screw, *S*, be designated by λ, one thread interval of the micrometer by μ, the total number of divisions on the graduated micrometer-head, *N*, and *n* the number of these corresponding to *l* divisions of the level, then the angular value, *d*, of one division of the level will be given by the equation

$$d = \frac{\mu}{\lambda} \frac{n}{N} \frac{206\,265}{l}$$

Here $\frac{\mu}{\lambda}$ is evidently the tangent of the angle corresponding to a single turn of the micrometer screw, and since this angle is small, $\frac{\mu}{\lambda}\,206\,265$ represents the value of the angle itself. The relations of μ, λ, and *N* are so taken as to enable the micrometer-head to be read directly to seconds.

THE FAULTS OF LEVELS.

The faults to which levels are subject are the more worthy of remark, because so frequently overlooked, even by expert observers. Moreover, it sometimes happens that a whole series of very important measures is cast into doubt or altogether lost by a level which, from original faulty construction, suddenly shows seemingly inexplicable errors.

Irregularities in the curve to which the level is intended to be ground, will, of course, produce irregular values for the different divisions. These values may, indeed, be investigated, and a table of them used for the various deviations of bubble; but, practically, it is found best to reject all such levels or re-work their curves.

Improper length of bubble may be due to original fault in filling, to leakage, to variations in the diameter of the level-tube, or finally to excessive temperature changes. Low temperature lengthens and a high temperature shortens the bubble. It is found that extreme shortness or length of the bubble somewhat influences the value of a division of bubble-displacement. The bubble should not much vary from one-fourth to one-half the whole length of the tube. A length of one-third that of the tube is a good average.

Temperature variations not only affect the length of bubble, but may cause unequal stresses on the tube, owing to improper methods of securing it in its case. Particularly is unequal heating of the level to be carefully guarded against. The bubble always moves toward the point of higher temperature, and hence unequal temperature of tube may entirely destroy its value as a level. Levels should therefore be guarded from the direct rays of the sun, and from bodily heat.

Particles of dust and glass in the sealed tube have been found to produce very serious and often mysterious errors in the indications of levels. Astronomers and others called upon to do delicate work with levels, have frequently verified the curious behavior of levels without quite comprehending the nature of the defect. QUEEN & Co. employ a kind of glass and a method of preparing the tubes, and of filling them, which effectively obviate this serious and unexpected class of errors.

The elimination of errors, like those just mentioned, may perhaps best be accomplished by frequent disturbances and re-readings of the bubble during the progress of any work of special importance. Any tendency toward constancy of error may thus be translated into the province of accidental and compensating errors. A level containing free solid particles or crystals formed by deterioration of the glass is, however, prone to systematic error under all conditions of use.

The deterioration of levels, although much discussed in the past, has only recently received a scientific explanation, and an adequate remedy through the elegant investigations of Professor R. Weber, of Berlin. This noted chemist has put it beyond question that the ordinary soft qualities of glass are dissolved by water admitted with the ether, and that the quantity of crystalline matter developed inside of level tubes is proportional both to the impurity of the ether and the solubility of the glass.

This he has verified chemically in several scientifically selected test cases, as well as by reference to some fifty different levels.

The high importance of his investigations lies not only in having disclosed the true causes of the deterioration of levels but in having proposed and thoroughly tested a form of level whose permanence may be guaranteed.

Two points have to be attended to in making durable levels. First, the glass must be of a special chemical constitution, and secondly, the ether used for filling must be freshly rectified and freed from every trace of water. Deterioration is certain to follow the omission of either precaution. Levels filled for a long while should hence always be carefully examined for the characteristic clouding of the interior before being too confidently trusted in any delicate work. QUEEN & Co. now undertake to furnish fine levels with the special glass and filling.

NEW FORMS OF LEVELS.

Mr. H. H. Turner, of the Greenwich Observatory, suggests a form of level which is practically a combination of level and level-trier in one instrument. This is accomplished by the addition of a micrometer screw and system of levers for delicately moving the bubble and bringing it to the same mark in each position of the level. Inequalities of the scale do not affect the readings in this form.

Dr. A. A. Common, of the Royal Astronomical Society, goes a step further and proposes, in refined work, to discard the filled level altogether, and in its place substitute a horizontal telescopic line of sight, whose direction, beyond the object-glass of the device, is rendered vertical by means of a right-angled prism, and then verified by reflexion from mercury according to the familiar Bohnenberger method.

THE LEVELS AS APPLIED TO INSTRUMENTS.

The Engineer's Transit of the ordinary form usually has three levels, two applied to the alidade and one of considerable sensitiveness attached to the telescope and enabling the instrument to be used for leveling. If the instrument be designed to measure vertical angles with accuracy, it may have a level attached to the vernier arm of the vertical circle. If designed for straight line work or for geodetic use, it may have a sensitive striding level. The solar attachment as applied to the transit also requires a small level to set the solar telescope to the required inclination. Instead of two cylindrical levels, one circular may be applied to the alidade.

The axis of each plate-level is adjusted so as to be at right angles to the vertical axis of the instrument. The axis of the telescope level is adjusted parallel to the line of sight of the telescope. The bubble of the level of the vertical circle is adjusted to read zero when the line of sight is horizontal and the vernier of the vertical circle reads zero. The axis of the striding level is intended to be at right angles to the vertical axis of instrument, and its adjustment and use have already been fully explained. The axis of the level attached to the solar telescope is adjusted to be parallel to the line of sight of that telescope, when this line is parallel to the sight-axis of the main telescope.

The Engineer's Level has ordinarily but one level attached parallel to the telescope. Sometimes, however, it is considered advantageous to have small cylindrical levels or a circular level attached to the leveling head of the instrument for use in rough adjustment of the instrument. The axis of the telescope level is, by adjustment, brought parallel to the sight-axis of the telescope, and must be of a sensitiveness proportional to the accuracy of which the instrument as a whole is to be capable.

Other instruments, like the Engineer's Compass, and the Plane Table, as well as the usual Geodetic, and Astronomical instruments, have levels for similar purposes which will be readily understood from the discussions of this article.

Queen & Co. take no little pains to make the levels of their instruments of reliable construction and of a sensitiveness suited to the purpose of the particular level and instrument. They also specially aim to so graduate all the levels as to facilitate their convenient reading and proper use. The value, in angular measure, of a division of each level is furnished by them in the certificate accompanying each instrument.

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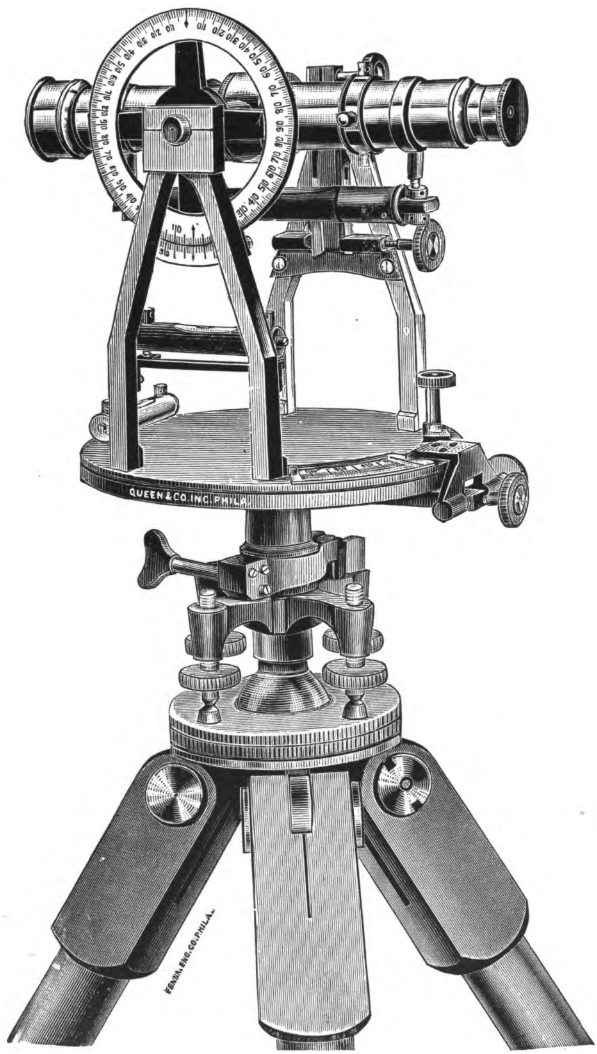

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THE TELESCOPES

OF

ENGINEERING INSTRUMENTS.

A GOOD telescope is generally admitted to be an essential feature of an engineer's transit or of an engineer's level, and yet it is very doubtful whether the points necessary to excellence in the optical parts of the instrument are always fairly understood, since even direct misstatements of the scientific facts, such as that the excellence of a telescope is determined by its high magnifying power, are used as a means for exploiting inferior instruments. A detailed discussion of the construction of the telescope will best show in what points excellence consists.

Every telescope consists of three essential parts: First, the image-forming apparatus; second, the image-examining apparatus; and third, the tube. If the telescope is to be used for measuring purposes a fourth essential is a set of cross wires in the common focus of the objective and eye-piece. In refracting telescopes, such as exclusively used in engineering instruments, the image is formed by an object-glass or objective through which the light is transmitted. By means of the object-glass, the rays are so bent as to unite in a certain plane behind the lens, called the focus, and there form a small image or picture of the objects toward which the telescope is directed. This image, which may be readily seen by the unaided eye by placing a dull white surface in the focal plane, is then examined by a set of lenses called the eye-piece or ocular, which acts like an ordinary hand magnifier or single short-focus lens, and causes the image to appear enlarged and clearly visible to the examining eye. The tube holds the object-glass and eye-piece in proper relation to one another.

The Simple Astronomical Telescope of Kepler, Fig. 10, consisting of two simple convex lenses, one of long focus, *O*, the objective, and the other of short focus, *E*, the ocular, is the best form to consider in a discussion of the general properties of the telescope. In the Kepler telescope the distance apart of the two lenses when a distant object is viewed is equal to the sum of the focal lengths of the lenses. The compound achromatic objectives and oculars of other telescopes may be regarded as single lenses whose equivalent focal lengths and positions are such as to produce a similar optical result.

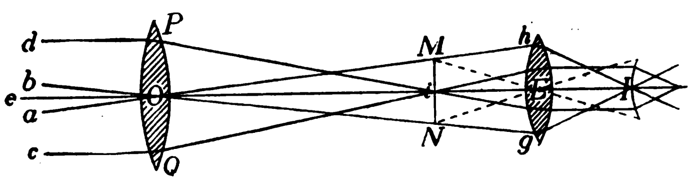


Fig. 10.

The magnifying power of any telescope is equal to the ratio of the angular size of the object as it appears in the telescope to that which it presents to the naked eye, or, in Fig. 10, the ratio of $hIg = MEN$ to $bOa = MON$, which, since the angles are small, is equal to the ratio of Oi, the focal length, F, of the objective to Ei, the focal length, f, of the eye-lens. If M designates the magnifying power,

$$M = \frac{F}{f}$$

It being difficult and inconvenient to measure the focal lengths of the lenses with accuracy, the magnifying power is practically measured by other methods presently to be mentioned.

The Field of View is the angular space that can be viewed with the telescope at one and the same time. The angle formed, Fig. 10, by the two principal rays, *a* and *b*, passing through the centre, *O*, of the objective and tangent to the diaphragm of the ocular, or the angle $aOb = gOh$, measures the field of view. The effective aperture of the ocular thus alone determines the size of the field.

The field decreases with the increase of magnifying power. If we let a equal the aperture of the eye-lens, M the magnifying power of telescope, F the focal length of objective, and f focal length of eye-lens, then in minutes of arc,

$$\text{Field} = \frac{3488'a}{F+f} = \frac{3488'a}{f\,(m+1)}$$

If, as is usual, $a = \frac{1}{2}f$, the following relations result:

Mag. power,	10	20	30	40	100
Field,	2°39′	1°26′	56′	43′	17′

The brightness of objects as seen through the telescope depends upon (1) the proportion of the light, L, transmitted through the lenses; (2) the clear aperture of the objective, A; (3) the aperture of the pupil of the observer's eye, e; and (4) the magnifying power, M. The proportion of light transmitted through the best achromatic telescopes, taking the brightness as seen with the unaided eye as 1, is eighty-five per cent., though this proportion may in inferior instruments descend to seventy per cent. If B represents this brightness, the expression for it will be:

$$B = \frac{LA^2}{e^2M^2}$$

which indicates that the brightness of objects as seen through the telescope increases in proportion to the square of the instrument's aperture and decreases as the square of its magnifying power. It is thus seen that increase of magnifying power very rapidly decreases brightness. A limit of decrease of brightness beyond one-half that presented to the unaided eye should never be allowed.

The maximum brightness of objects giving a sensible size of image is attained when the diameter of the cylinder of rays issuing from the telescope equals the aperture of the eye. The brightness is then equal to the natural one. Stars being, under all telescopic powers, mere *points*, increase in brightness beyond the natural brightness in the ratio of the squares of the apertures of the objective and of the eye.

The Simple Objective, formed of a single lens, has two serious defects. First, the image is fringed and rendered indistinct by the spectral colors, and, secondly, the image is so curved that when projected on a plane it appears for the most part indistinct and hazy.

The Achromatic Objective, formed by combining two lenses of different dispersive and refractive powers, usually of crown and flint glass respectively, may be so constructed as almost wholly to avoid these two defects of chromatic and spherical aberration. The achromatism or colorlessness of the image will then depend on the ratio of the focal lengths of the two lenses, while the freedom from spherical aberration or from a nebulous, milky appearance of the image will be determined by the ratio of the curvatures of the lenses.

The eye-pieces of a telescope may be of two kinds, astronomical and terrestrial, the former usually comprising two lenses, and showing the image in the same inverted condition in which it is formed by the objective, and the latter usually comprising four lenses and erecting the image. Although the terrestrial eye-piece is inferior in point of optical performance, it is still generally preferred by American engineers.

The Astronomical Eye-pieces are either of the Huyghenian or of the Ramsden form. The former, or negative eye-piece, is used only for its qualities as a good seeing ocular, but cannot so well be used with cross-hairs, both because the focus lies between the lenses and because the hairs can only be well defined in the centre of the field. It consists of two plano-convex lenses, with their convexities turned toward the object-glass.

The Ramsden, or positive, consists of two plano-convex lenses, with their convexities, turned toward each other. The focus of this ocular lies in front of the field-lens, and it is for this reason, as well as on account of defining the threads well over the whole field, adopted for use with micrometer threads. The purely optical defects of the positive for seeing purposes are greater than those of the negative eye-piece.

The terrestrial eye-pieces are usually composed of four lenses, the first two, counting from the objective, being called the erectors. The focus of this lens, as shown in Fig. 11, lies in front of the first lens, and it is at that point that the cross-hairs are placed. The theory of this eye-piece is too compli-

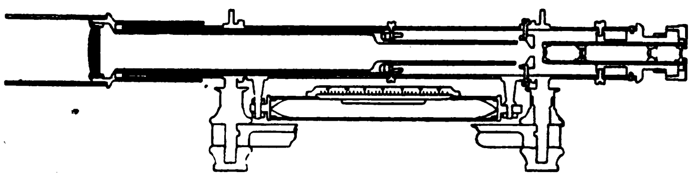


Fig. 11.

cated to be entered into here. Suffice it to say that, on account of the number of possible variables, the production of an excellent eye-piece involves science and art in combination that is the exclusive property of the expert optician. The various forms known as the Fraunhofer, Kellner, Airy, Steinheil, etc., are to be selected by the skilled optician with regard to the particular service to which the telescope is to be put.

The clear aperture of a telescope is determined by the size of the pencil of light which passes through the entire instrument. The pencil entering the object-glass may be partly cut off by diaphragms, and thus the apparent aperture may not be the real one. Inferior telescopes not infrequently have a considerably less clear aperture than apparent. The following method is an easy test of the true aperture: First, having focused the telescope for distant objects, direct it to a bright cloud, or the well illumined sky, and bring the eye to a position behind the eye-hole and at a distance from it equal to that of distinct vision, so as to permit the well-defined little "Ramsden's Circle," or image of the objective formed by the eye-piece, to be clearly seen. Then take a sharp pencil point and, placing it at the edge of the object-glass, move it across toward the centre and note the point where it first becomes visible in the little Ramsden disc. Subtract double this distance of the pencil point from the edge from the entire diameter of the object-glass, and the result is the clear aperture. A magnifier or low power microscope may be used for observing the little Ramsden circle and the appearance of the pencil point in it.

Diaphragms properly placed in the main tube are necessary for the exclusion of scattered and injurious rays. But through ignorance of the optical theory determining their use, they are often so inserted as to vitiate this purpose, and also reduce the effective aperture and the field of view.

The eye-hole is such a diaphragm, and is intended to be so placed that the eye can easily be brought to that position behind the eye-piece where the entire cone of rays may enter the eye. Its size and position can, as in the case of the other diaphragms, be computed only from the course of two principal rays through the system of lenses.

The line of sight of a telescope, if determined by two fixed points, namely, (1) the optical centre of the objective and (2) the centre of the cross-wires. The image of a point of an object is brought centrally upon the crossing-point of the threads, and, since the rays of each point of the object must have passed through the optical centre of the objective, these two points—"optical centre" and "crossing-point of the threads"—fix the direction of the "line of sight," or "sight axis," or "sight line." If we speak according to the modern Gaussian theory of lenses, the first point is known as "the second principal point" of the objective. It is also seen that since this "second principal point" is, for the objective and telescope, a fixed point, all adjustments of the line of sight are made by moving the cross-hair ring, and, moreover, that any point on any thread may be selected as the second point determining the line of sight, but that for convenience and definiteness the crossing-point of the two middle threads is used.

The line of collimation of a telescope is, strictly speaking, the mathematical line at right angles to a certain axis. In the

Engineers' Transit, and all other instruments of that class, the line of collimation is the line at right angles to the horizontal axis of the telescope. An instrument is said to be collimated when the line of sight is brought into coincidence with the line of collimation, or in the transit when the line of sight is at right angles to the horizontal axis. The term, "line of collimation," is often erroneously and loosely used by writers for "line of sight."

The centering of the telescope involves a number of delicate operations and adjustments implied in the processes (1) of centering each lens; (2) of centering each combination of lenses—(*a*) objective, (*b*) eye-piece; (3) of centering these combinations with respect to the tube; and (4) of centering the cross-hairs with respect to the optical and mechanical axis.

The centering of a lens must be performed in the grinding process. A lens is truly centered when the centre of the circle determining its size lies in the line joining the thickest or the thinnest part—that is, in the axis—of the lens.

The centering of the objective in its cell involves not only the primary centering of each of the two lenses, but their careful relative adjustment, so as to make the axis of each lie accurately in the same straight line. This common axis of the objective lenses is thenceforth regarded as the optical axis of the telescope to which all else must be centered. So important and delicate is this centering of the objective in its cell that no one except the skilled optician should attempt to disturb it by removal of the lenses. The centering of the objective may be tested by setting the cross-hairs upon some point, and noting whether, upon unscrewing the objective through a complete turn, the point remains bisected. All telescopes have this error, at least to some small extent, and the object-glass should therefore be screwed in securely, and always remain in the *same* position. This proper position is always marked in QUEEN & Co.'s instruments.

The centering of the lenses in the ocular tube is necessary to the proper optical performance of the eye-piece, and once accomplished by the maker, is not to be disturbed by unskilled hands.

The centering of the objective slide is readily tested in the telescope applied to leveling instruments. For after having centered the cross-hairs, with the telescope focused for very distant objects, the slide is tested by focusing on a very near object, and noting whether, upon rotating the telescope about its mechanical axis, a point remains bisected. If there is a deviation, one-half its apparent value must be corrected by means of the slide-centering screws.

In the telescope of the Engineers' Transit the following method is used: Sight to a distant point, note it, and, clamping the horizontal circle, focus upon a near point. Now turn the instrument half-way round horizontally and transiting the telescope sight to the near point. Clamp horizontal circle and focus for the distant point. If the cross-hairs accurately bisect it there is no error of the slide. Otherwise, one-half the apparent error is to be corrected by means of the slide-centering screws.

This centering is important where both long and short sights enter into the work. Any error due to it is, of course, eliminated by keeping the focus and distances constant.

The centering of the cross-hairs, assuming that the objective is correctly centered, may, in cases where the telescope can be rotated about its mechanical axis, as in the Engineers' Level, be accomplished as follows: Sight to a distant point, and note, upon rotating the telescope 180° in its wyes, whether the point remains bisected. One-half the apparent deviation is to be corrected by means of the cross-hair screws. In telescopes of the Engineers' Transit this centering is practically involved in bringing the line of sight into coincidence with the line of collimation as in the Second Adjustment of the Transit.

The centering of the ocular-head slide in the case of telescopes having a fixed objective, as in the higher grades of instruments, is accomplished in the same manner as in the case of the objective slide. The ocular-head slide carries both ocular and cross-wires.

The centering of the ocular in reference to the cross-wires is sometimes arranged for by means of a special set of screws. The ocular is then moved until the cross-hairs appear in the middle of the field of view.

Focusing with accuracy is necessary not only for clear definition, but also for the correct use of the telescope as a means of determining direction. In its completeness it involves two operations:

First, it requires the cross-wires to be brought into the focus of the eye-piece. To accomplish this, direct the telescope to the sky, and then move the ocular in or out very carefully until the most distinct vision of the wires results. A mean position between the points of equally fair vision of the wires for inward and for outward motion of the ocular will give the best focusing of the ocular.

Secondly, it requires the cross-wires to be brought into the focus of the objective.

To accomplish this, either move the objective with respect to the stationary ocular-head, which carries cross-threads and eye-piece, or move the whole ocular-head with respect to the stationary objective, until there is, with the same eye as employed in focusing the ocular, the most distinct vision of distant objects.

Parallax of the wires, or an apparent displacement of the wires with respect to any visible object upon moving the eye in front of the ocular up and down or to the right and left, is due to the wires not being in the common focus of objective and eye-piece. If care has been taken to focus the ocular accurately on the threads, the parallactic displacement of the wires must entirely disappear in focusing the objective. In fact, this disappearance of parallax of the wires is the best test of accurate focusing.

The measurement of the field of view is easily accomplished by either of the following methods: (1) Select two distant points which appear at diametrically opposite edges of the field of view. Measure the actual distance, *d*, of these points from each other, and also their distance, D, from the telescope; then the field is expressed in minutes of arc thus:

$$\text{Field} = 3438' \frac{d}{D}.$$

The points required in this method are most conveniently furnished by a leveling rod placed at some distance. (2) Either the horizontal or vertical circle of the instrument may be used for directly measuring the angular distance apart of two points appearing at the diametrically opposite edges of the field, or for measuring the motion of a point throughout a diameter of the field. A knowledge of the angular value of the field may be of assistance in roughly estimating angles and distances.

The measurement of the magnifying power of a telescope may be performed in several ways.

The ordinary two-eye method requires the telescope to be placed at a great distance, as compared with its length, before any object serving as a scale and distinctly visible to the naked eye. As object, a distinctly visible measuring-rod, or even the regular pattern of a wall may answer. Looking through the telescope with one eye and viewing the scale directly with the other, two superimposed images are seen. If, now, n divisions, as seen with the telescope, appear to correspond with N divisions as seen with the naked eye, the magnifying power, M, is

$$M = \frac{N}{n}.$$

The inaccuracy of this method arises from the impossibility of securing distinct vision with the naked eye of an object at a sufficiently great distance.

Jordan's method has the advantage over the usual two-eye methods, in that a horizontal axis of the telescope does not interfere, and that both eyes are adjusted for distinct vision. Look through the telescope at a divided rod, or at some bright object of known size projected on a dark background, and hold up before the other eye, at the distance of distinct vision, an open pair of compasses. Now bring the points of the compasses, as clearly seen with one eye, into apparent coincidence with the telescopic image of the rod as seen with the other eye, and measure off, as on a drawing, the apparent size of a portion, R, of the rod, and afterward find this distance apart, r, of the compass points by means of a divided scale. The distance of the rod from the eye being D, and the distance of the compass from the eye, d, the magnifying power, M, is evidently—

$$M = \frac{r}{d} \div \frac{R}{D} = \frac{rD}{Rd}$$

Valz's method is both neat and easily applied. It depends on the measurement of the angle which the rays, coming from an object of known angular diameter, form on issuing from the ocular of the telescope. The sun, on account of its brightness and well-known angular diameter, is for this purpose particularly suitable. Place a screen at a distance, D, from the "eye-point," and there receive the solar image, whose linear diameter we shall call d. Let also s be the true angular diameter of the sun, and S the angular diameter of the image on the screen, subtended at the eye-point, then—

$$M = \frac{tan.\ \frac{1}{2}\ S}{tan.\ \frac{1}{2}\ a} = \frac{d}{2D\ tan.\ \frac{1}{2}\ S} = \frac{d\ cot.\ \frac{1}{2}\ S}{2D}$$

And, finally, if we take $2\,D$ equal to $cot.\ \frac{1}{2}\ S$,

$$M = d.$$

That is, if the double distance, $2\,D$, of the image from the eye-point is taken equal to the cotangent of the semi-diameter of the sun, the number of parts of the scale comprised in the extent of the image will express the magnification. Thus, in January, the image should be received and measured at 105 scale parts from the eye-point, in April and October at 107, and in July at 109 parts.

The Gaussian method is, all considered, the most scientific, but requires for its use an additional instrument. The telescope whose magnifying power is to be determined is first carefully focused on a distant object, and its *eye-end* is then directed toward some well-illumined object of regular shape several hundred feet distant. A second instrument is now set up, with its objective turned toward the objective of the telescope whose magnifying power is desired. The object will be seen through both instruments, but in reduced size, and its apparent angular size, *a*, is measured by means of the second instrument. Afterward the angular size, *A*, of the object is measured without the interposition of the first telescope. The magnifying power, *M*, of this telescope is then given by the expression—

$$M = \frac{tan.\ \frac{1}{2} A}{tan.\ \frac{1}{2} a}$$

Example: A piece of white card-board, placed at a distance of several hundred feet, subtends an angle, *A*, of 1° 30′ 25″, and on interposing a Wye Level, with its eye-end directed toward the object, the apparent angular size, *a*, of card, is found to be 2′ 30″, hence,

$$M \text{ of the Wye Level} = \frac{tan.\ \frac{1}{2}\,(1^\circ\ 30'\ 40'')}{tan.\ \frac{1}{2}\,(2'\ 30'')} = 36.27 \text{ diameters.}$$

QUEEN & Co., possessing a wide experience in optical manufacture, keep pace with all the latest scientific improvements in optical glass making, and aim by combining the best optical theory and skill, to furnish their engineering instruments with telescopes of the highest excellence. They have no peculiarity of their telescopes to announce except it be the judiciously planned combination of aperture, focal length, power and qualities of glass best adapted to the uses of each kind of instrument. Good seeing capacity, and not the particularly high power with its concurrent disadvantages, is considered of the foremost consequence. It is greatly regretted that the necessary limits of the foregoing article have prevented a complete exposition of the theory of the telescope. A good-sized volume on the subject would, however, seem inadequate, and serve only to show more fully and clearly in how many essentials it is necessary to unite optical science with experienced skill in making telescopes that are adapted to satisfactory measurement in engineering.

DESCRIPTION

OF THE

ENGINEER'S COMPASS.

THE following description of the Engineer's Compass is intended to direct attention to its various parts and forms.

The Tripod furnished with the engineer's compass is either of the ordinary round leg or split leg form. If desired a head and shoe to be used with an improvised Jacob's staff is also furnished.

The Ball-spindle, on which the socket of the compass is fitted, is of conical shape, and at its lower end turned to a perfect sphere. This sphere is confined in a socket on the tripod head in such a manner as to enable the compass to be brought readily to an approximately level position.

The Spring Catch, which engages in a groove of the spindle of the compass the moment it is inserted in the socket, is attached at the side of the socket. It obviates the danger of the instrument slipping off the spindle when it is being carried.

The Clamp Screw, by means of which the spindle of the instrument may be clamped in any position, is placed at the side of the socket of the compass.

The Circle of the Compass is graduated to half degrees and the divisions so marked as to be read with the greatest ease. The figuring extends from 0° to 90°, from the north and the south points in both directions. The line of zeros passes through the vertical axis of the compass and is also in line with the sights.

The Tangent Screw attached to the circle enables the line of zeros to be set at an angle with the sight line equal to the variation of the magnetic needle. This angle is measured on an accessory arc or circle, placed just outside the clamp and tangent movement.

The Variation Arc or Circle is placed immediately on the main plate of the compass. Its centre is concentric with the vertical axis of the instrument. The vernier of the arc or circle is usually fastened to the main plate while the arc or circle plate forms one piece with the graduated compass circle. The arc or circle is used for setting off the magnetic declination of the place so as to enable the bearings to be taken with respect to the true astronomical meridian. When a complete circle is used, as in the railroad compass, horizontal angles may be measured with it for any purpose whatever.

The Spirit Levels are placed directly upon the plate at right angles to each other and made adjustable.

The Sights are vertical standards clamped to each end of the plate and at right angles to it. They have fine slits running through nearly their entire length. Large circular apertures are placed at intervals along the slits and allow a distant object to be the more readily seen.

The north sight has graduated upon its lateral edges a scale of tangents corresponding to a circle whose centre is a small eye-hole placed upon the south sight. The eye-hole at the lower end of the south sight is intended to be used in sighting for angles of elevation, the eye-hole at the top of the same sight being used for angles of depression.

The Needle Lifter is actuated by a screw placed below the main plate. The needle should always be raised from its centre pin by means of the lifter before carrying the instrument.

The Out Keeper is a small graduated dial turned by means of a milled head and used for the purpose of counting the number of chains measured.

The Brass Cover fitting on the compass-box is intended to shield the glass cover from accidental injury during transportation.

The Telescopic Sight is an appliance consisting substantially of a transit telescope with its fine level and a suitable clamp for attaching it at right angles to one of the sighting standards of the compass. It is supplied with any of the various forms of the compass.

The Forms of the Compass made by QUEEN & Co. may be best understood in all their variety by reference to their *Catalogue of Engineering Instruments.* The following are the chief forms:

The Plain Compass is furnished with needles of four, five, or six inches in length but has no variation plate. It is sometimes made with folding sights and may also be fitted with telescopic sights.

The Vernier Compass is furnished with variation arc and has the tangent scales necessary for reading angles of elevation or depression.

The Railroad Compass has the levels, sights, and needle of the ordinary Plain Compass, but has also underneath the main plate a graduated circle by means of which horizontal angles to single minutes may be taken independently of the needle.

The Pocket Compass exists in a great variety of forms and is often valuable in preliminary rapid work. The prismatic compass of Schmallcalder deserves to be particularly mentioned among hand instruments. The graduated card of this compass is attached to the needle, and the prism permits the reading of the needle to be made simultaneously with taking the sight.

The Solar Compass has, in addition to the features of a first-class surveyor's compass with full graduated circle and verniers, the characteristic devices whose chief use is to enable the surveyor to take bearings with respect to the true or astronomical, meridian. These devices consist essentially of two arcs, one called the latitude arc, with a movable arm, and set at right angles to the horizontal plate of the compass; and the other, a declination arc placed at right angles to an arm with an axis attached perpendicular to it and revolving in a socket carried by the latitude arm. This axis lying in, or parallel to, the planes of both arcs is called the polar axis, and also lies in or parallel to, the vertical plane containing the main line of sight of the compass. Its use and adjustment is referred to in the article of this Manual entitled, "*The Solar Transit and other Methods of determining the Astronomical Meridian.*"

THE ADJUSTMENTS

OF THE

ENGINEER'S COMPASS.

THE adjustments of an engineer's compass may be treated of as: (1) The maker's adjustment; and (2) The field adjustments. The latter are those which the surveyor finds it necessary and convenient to verify in practical work, and the former, in fact inclusive of the latter, are those to be accurately accomplished by the maker.

THE MAKER'S ADJUSTMENTS.

The following points of construction and adjustment of the Engineer's Compass must be accurately attained in order to realize the mathematical conditions of the problem.

1. The main plate accurately perpendicular to the spindle of the compass.

2. The variation arc or circle and its verniers truly graduated and concentric with the spindle.

3. The sights and sighting-slits truly at right angles to the main plate.

4. The line joining the centre of the sighting-slits passing through the mathematical axis of the instrument.

5. The zeros of the verniers of the variation arc or circle in the same straight line with the sights and axis of the instrument.

6. The compass circle truly graduated, its centre concentric with the axis of the instrument, and its line of zeros coincident with the truly adjusted line of sights.

7. The axis of each of the plate levels at right angles to the axis of the instrument.

8. The pivot of the compass needle coincident with the ver-

tical axis of the instrument, and sharp enough to obviate appreciable friction in the needle-cap.

9. The magnetic needle magnetically sensitive and perfectly straight.

10. The magnetic axis of the needle coincident with the axis of form.

11. The magnetic needle adjusted for the magnetic dip of the place of observation.

12. The axis of the suspended plumb bob coincident with the vertical axis of the instrument.

It is not intended that the foregoing shall represent an exhaustive statement of the details requiring the attention of the skilled maker, but it is hoped that this statement may direct attention to essential features of construction otherwise likely to be overlooked by purchasers and users of the instrument.

THE FIELD ADJUSTMENTS.

The following methods for practically detecting and correcting the errors of adjustment of an Engineer's Compass are given for field use:

First Adjustment:—*To make the axis of the plate levels perpendicular to the vertical axis of the instrument.*

Detection of the Error.—Carefully level the instrument in the two directions parallel with the levels. Note some point seen through the sights, and turn the sights exactly through 180°, or until the same point is again in line. Now examine each of the levels in turn, and see if there has been any displacement of the bubble. The amount of bubble displacement is in each case just double the error of the bubble-tubes, as already explained under "First Adjustment" of the Engineer's Transit.

Correction of the Error.—By means of the screws near the ends of the level-tubes, carefully bring back the bubble through half the displacement, taking care to have the screws fairly tightened when done. The remaining half of the bubble displacement, being due to lack of horizontality of the plate, may now be corrected by leveling up the instrument.

Second Adjustment:—*To bring the pivot of the magnetic needle into coincidence with the axis of the instrument.*

DETECTION OF THE ERROR.—Bring one end of the needle on a division of the circle, and note the deviation of the other end from the division making 180° with it. Then remember that this deviation from a true reading may be due to any one or all of the following defects:

(1.) Errors of graduation in the circle.

(2.) Eccentricity of the circle with respect to axis of instrument.

(3.) Bent needle.

(4.) Eccentricity of the pivot with respect to axis of instrument.

The first two errors, if they exist, cannot be adjusted by the engineer, and they are here assumed as negligible errors. This reduces the causes of the deviation mentioned to the two last named. But in order to determine the nature of the errors fully, readings must be made round the circle at intervals, say, of 15°, and the end deviations noted. Then,

(1.) Constant difference between end readings of needle means { Needle bent, and
Pivot centered.

(2.) Variable difference between end readings of needle means { Pivot eccentric, and
needle either { straight, if difference is zero for any one direction; or
bent, if difference is never zero.

This is made evident by (A), (B), and (C), of Fig. 49. Fig. (A) illustrates case (1) of pivot centered and needle bent, the differences *S a*, *E b*, etc., always remaining constant. Fig. (B) illustrates the case of straight needle and eccentric pivot, the difference of end readings becoming zero, say for the position *W E*, where the straight needle cuts both pivot, *D*, and centre of circle, *C*; and the difference being at its maximum, *S a*, at 90° from the position of zero difference. Fig. (C) illustrates the case of eccentric pivot and bent needle; *S a* being the maximum; and *E b* the minimum difference of the end readings.

CORRECTION OF THE ERROR.—Find the position of the maximum difference of end readings, *S a*, Fig. 49, (C), and also the minimum, *E b*. Take one-half the difference of these differences, and adjust the pivot through this amount at right angles to the position of maximum deviation.

Another method of correction proceeds as follows:

(1.) Temporarily adjust pivot so as to allow needle in some position to cut diametrically opposite graduations. Reverse and thus double the error due to bent needle. Straighten needle by bending through one-half this difference.

(2.) Adjust pivot till at all intervals, say, of 30°, the needle points to opposite divisions.

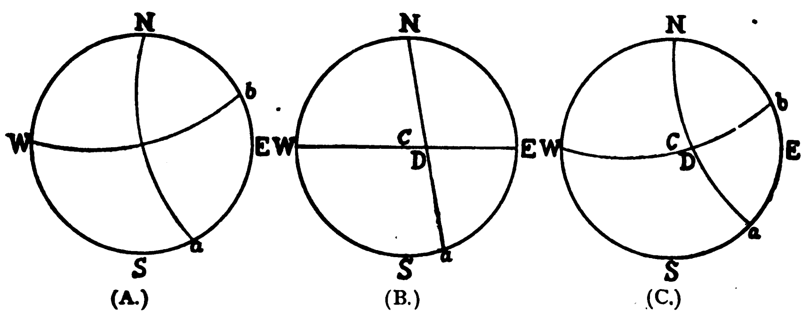


Fig. 49.

Third Adjustment:—*To straighten the magnetic needle.*

DETECTION OF THE ERROR.—This has already been for the most part explained under the head of the Second Adjustment. It is only necessary here to remark that the minimum deviation, *E b*, Fig. 49, (C), is altogether due to the bent needle.

CORRECTION OF THE ERROR.—Having found the position of the minimum deviation of end readings, *E b*, Fig. 49, (C), bend the needle carefully near the centre to an amount equal to *E b*.

Fourth Adjustment:—*To make the plane of the sights perpendicular to the plane of the levels.*

DETECTION OF THE ERROR.—Carefully level the instrument and bring the plane of sights upon a plumb-line suspended at some convenient distance. Sight by looking through lower part of one sight, and, running the eye along the other, note the latter's deviation from the vertical plumb-line. Similarly test the other sight.

CORRECTION OF THE ERROR.—Any error of this sort can be corrected satisfactorily only by the maker. Temporary relief may be had by clamping under the sides of the sighting standards thin bits of paper, so as to bring the sights truly vertical.

Several other important points in the maker's work may also be easily tested:

(1.) To test whether the diameter passing through the zero graduations, or the "line of zeros," lies in the plane of the sights. Set the declination arc carefully to zero, and stretch two fine hairs vertically in the centre of the slits, and note if the zeros are in line.

(2.) To test whether the line of sight passes through the centre, sight to a very near object, and read one end of needle. Reverse and read same end of needle. One-half the difference of the readings is the error due to the eccentricity of the line of sights. One-half the sum of the same readings is the true reading. Also, if both ends of needle are read, and one-half the sum taken, the eccentricity of the sight line is eliminated.

(3.) The magnetic sensitiveness of the needle may be tested by setting the needle in vibration by approaching and removing some iron piece, and then noting whether, upon repeated trials, the needle returns precisely to the same point. If not, the pivot is either dull or the needle lacks directive force, and must be remagnetized.

(4.) The absence of metal in the compass capable of affecting the needle, may be verified by slowly turning the instrument about its axis and noting whether or no the needle is in any position slightly carried along.

(5.) The horizontal swinging of the needle is affected by the Magnetic Dip, and is, with other matters pertaining to magnetism, explained in the article of this Manual, entitled, "*Terrestrial Magnetism in its Relation to Surveying Instruments.*"

QUEEN & CO. invariably test the mechanical perfection of their instruments by giving them, finally, a thoroughly complete adjustment.

TERRESTRIAL MAGNETISM

IN ITS RELATION TO

SURVEYING INSTRUMENTS.

THE earth acts on magnetic substances placed on its surface very much as though it were itself a great magnet. One pole of this huge magnet is near the earth's North Pole, the other near its South Pole. If the magnetic condition of the earth were of an entirely constant nature, the surveyor should need nothing better than a freely-suspended magnetic needle directed by terrestrial magnetism, to give him a zero line, namely, the magnetic meridian, from which to measure his angles. But terrestrial magnetism is a very variable thing, and moreover bears peculiar relations to the needle of the surveying instrument. It is, therefore, desirable to give a brief explanation of these fundamental relations.

Terrestrial magnetism may be studied by noting its action on a freely-suspended magnetic needle. The three factors usually measured are the Magnetic Intensity, the Dip of the needle, and the Declination of the needle. If a long steel knitting-needle of the old-fashioned type be suspended by a fine thread attached to its middle, it will when *unmagnetized*, direct itself in some position in a horizontal plane determined by the slight torsion of the thread. On being magnetized, it will direct itself differently. In the first place, instead of being horizontal its north end will now incline downwards. The angle made by the north end of the needle with the horizon, is called the angle of Dip or of Inclination. In the second place, it will be noticed that this magnetized needle also directs itself in a plane which is *nearly* north and south. The angle which the north-south plane of the magnetic needle makes with the true north-south plane is called the Declination of the needle. This angle is also sometimes called the Variation of the needle, although this designation is both antiquated and misleading. Finally, the force with which the needle will direct itself in the magnetic meridian when disturbed from it is, other things being equal, determined by the Strength of the Earth's magnetism, or by the Magnetic Intensity. We shall now take up each of these terrestrial magnetic elements and show their practical relation to the surveyor's needle.

I. **The magnetic intensity** or magnetic strength of any "field" is proportional to the square of the number of vibrations made in the unit of time, by any magnetic needle placed in that "field." Vibrating the *same* magnetic needle at different places or in different "fields," the intensity of the earth's magnetism will vary as square of the number of vibrations made at each place in the unit of time. The Intensity, spoken of without qualification, is considered as taken in the direction of the earth's magnetic force, or in the line of dip. The earth's action on a horizontal needle is of course the horizontal component of the intensity. If, I, denote the Magnetic Intensity, H, its horizontal component, V, its vertical component, and D, the angle of Dip or Inclination below the horizon, then evidently

$$H = I \cos D$$

and

$$V = I \sin D.$$

The magnetic moment of the needle combined with the strength of the earth's magnetic field determines the force with which the needle tends to direct itself in the magnetic meridian. The magnetic moment, M, of the needle is equal to the product of the "magnetic mass," m, of one of its poles by the length, l, of the needle, or, $M = ml$. A magnetized needle movable about a vertical axis, as in the case of the surveyor's compass, obeys the horizontal component, H, of the earth's magnetic force, and directs itself so that its axis of magnetization is in the magnetic meridian. If the needle is turned out of the meridian through an angle δ, the moment of the couple tending to bring it back is expressed by

$$m\ l\ H \sin \delta.$$

The sensitiveness of the needle is measured by the accuracy with which it returns to the same position after displacement from its natural direction in the meridian. From the foregoing expression it is seen that, so far as the needle is concerned, the amount of magnetization, *m*, and the length, *l*, combine to make its magnetic moment effective in any given magnetic field. Acting against the moment tending to direct the needle, is the friction on the centre-pin or pivot. And, hence, with a needle lacking sensitiveness, it is a question either of sharpening the centre-pin and thus reducing the friction, or of increasing the magnetization, *m*, by remagnetizing the needle. When the needle is deflected, as by bringing near it a bit of iron, it should always return to the original position within a few minutes of arc.

The magnetization of the needle, or the increase of the magnetic mass, *m*, is accomplished by stroking the needle with a good permanent magnet in the following manner: With the south pole of the magnet approach the middle of the needle in a direction at right angles to it, and then pass this south pole along the neeedle toward the north pole of the needle and beyond it, returning by circular sweep to the middle again. Repeat this, say, twenty times. Similarly stroke the south end of the needle with the north pole of the magnet. The needle may thus, in a few minutes, be magnetically saturated.

The conservation of the needle's magnetism depends on its original proper tempering, its freedom from subsequent jars, and its remaining when unused in the normal position in the magnetic meridian.

II. **The Magnetic Inclination or Dip** is, as already explained, the angle made with the horizon by the north end of the freely-suspended needle. The tendency of the north end of the needle to dip increases as we go north until the magnetic pole is reached, where the free needle occupies a vertical direction. It is on account of this variableness of the Dip that the surveyor's needles usually have wound round the south end a small bit of wire whose position may be varied so as to bring the needle into a horizontal position at the place the instrument is set up for use. It is for the same reason, therefore, to be borne in mind that however accurately the needle may be adjusted to a horizontal position by the maker in his locality, it will require careful adjustment by the surveyor for the Dip of the place of observation, if it be at any considerable distance from the place of original adjustment. The Dip may vary, also, at any given place, on account of the prevalence of some unusual magnetic disturbance.

The dipping needle is a magnetic needle suspended on a horizontal axis, and free to move only in a vertical plane. If the plane of this needle be brought into the magnetic meridian its north end will incline downwards, and the angle of Dip may be read off on the circle. If, as the dipping needle is kept in the plane of the magnetic meridian the angle of Dip changes as the observer moves along, it is an indication of attractive force due to beds of iron ore. It is evident that the unwonted dipping of a previously well-adjusted surveyor's needle may be due to the same cause.

III. **The Magnetic Declination or Variation** is the angle made by the free magnetic needle with the astronomical meridian, or true north-south plane. The term Variation, though almost out of use, still survives in the "variation plate" of the surveyor's compass. This magnetic element of the earth has by far the most important relation to the surveyor's work, and requires detailed explanation.

The determination of the declination of the magnetic needle for a given place and time, has often to be undertaken by the surveyor. Since this requires a knowledge of the direction of the astronomical or true meridian, the subject is referred to in the article of this Manual, entitled, "*The Solar Transit and Methods of Determining the Astronomical Meridian.*"

The variations of the Declination are numerous and of a very complicated nature. The direction of the needle changes from hour to hour through the day, from month to month through the year, and from year to year through the centuries. In addition, it is subject to extraordinary disturbances during magnetic storms. These special disturbances aside, the laws of the periodic changes in the declination have been fairly well established, and the surveyor is often obliged to have recourse to these observed laws. It is fortunate that in our own country the study of terrestrial magnetism has been an important part of the work of the Coast and Geodetic Survey. Professor Charles A. Schott, the able scientist in charge of the discussion of the magnetic observations, has, in the Survey Reports, during many years, published comprehensive papers of the highest value to the surveyor in the solution of problems involving changes in the declination of the needle.

Irregular variations accompanying so-called "electric storms," are undoubtedly in close relation with changes in the sun, and its spots. Auroras frequently occur at the same time. Since these extraordinary deflections of the needle from the normal positions may either be limited to a few minutes of arc, or amount to several degrees, the careful observer must be continually on the alert. The verification of a "magnetic storm" would be ample excuse to await its subsidence, before trusting the indications of the magnetic needle.

The small periodic variations which require no attention on the part of the surveyor, are the *annual variation* of the declination, its amplitude being at most one and a half minutes of arc; the *solar rotation variation* having a period of about 26 days, and of very small amplitude; and *the lunar variations*, the *diurnal* one exhibiting, like the tides, two maxima and minima each lunar day, and having a range at Philadelphia of about 27″, the other lunar inequalities being of still smaller order.

The Solar-diurnal variation is a systematic angular movement of the direction of the magnetic needle, having for its period the Solar day. The amount of this daily swing of the needle is on the average about 8′, the north end having its extreme easterly position about 8 A. M., its extreme westerly, about 1.30 P. M., and its *mean* position about 10.30 A. M. and 8 P. M. This daily variation of the needle is not exactly the same for different places and seasons, but the following table, correct to the nearest tenth of a minute of arc for Philadelphia, presents a good average for the United States. It is derived from Appendix 8, of the Report of the United States Coast and Geodetic Survey of 1881. For the surveyor this diurnal variation, and the secular variation, presently to be described, are particularly important.

TABLE OF THE DAILY VARIATION OF THE DECLINATION.

(A + sign indicates a deflection of the north end of the needle to the westward and a — sign to the eastward.)

Month.	6 A. M.	7 A. M.	8 A. M.	9 A. M.	10 A. M.	11 A. M.	12 M.	1 P. M.	2 P. M.	3 P. M.	4 P. M.	5 P. M.	6 P. M.
	′	′	′	′	′	′	′	′	′	′	′	′	′
January	—0.6	—1.2	—2.1	—2.5	—1.6	+0.3	+2.3	+3.4	+3.3	+2.5	+1.5	+0.9	+0.6
February	—1.2	—1.9	—2.5	—2.5	—1.5	+0.2	+2.0	+3.0	+3.0	+2.4	+1.7	+1.2	+0.8
March	—1.8	—2.9	—3.7	—3.4	—1.8	+0.6	+2.7	+3.9	+3.9	+3.2	+2.3	+1.6	+1.0
April	—2.6	—3.5	—4.0	—3.4	—1.5	+1.1	+3.6	+5.1	+5.2	+4.3	+3.0	+1.8	+0.9
May	—3.7	—4.7	—4.7	—3.2	—0.8	+1.9	+4.1	+5.1	+4.9	+3.9	+2.5	+1.2	+0.4
June	—3.9	—5.0	—5.1	—3.8	—1.2	+1.7	+4.0	+5.0	+4.8	+3.8	+2.6	+1.6	+0.9
July	—4.2	—5.4	—5.4	—4.0	—1.5	+1.5	+3.9	+5.3	+5.4	+4.5	+3.3	+2.0	+1.2
August	—4.7	—5.7	—5.5	—3.7	—0.6	+2.9	+5.4	+6.3	+5.5	+3.8	+2.0	+0.9	+0.5
September	—3.5	—4.5	—4.5	—2.8	—0.1	+3.2	+5.2	+5.5	+4.5	+3.0	+1.7	+0.8	+0.3
October	—1.3	—1.7	—2.2	—1.9	—0.8	+0.8	+2.6	+3.2	+3.0	+2.2	+1.1	+0.3	—0.4
November	—1.2	—1.7	—1.9	—1.5	—0.4	+1.1	+2.3	+2.8	+2.6	+1.9	+1.2	+0.6	+0.1
December	—0.7	—1.0	—1.4	—1.6	—1.1	+0.3	+1.9	+3.0	+3.0	+2.3	+1.3	+0.6	+0.1

The correction of observed bearings to the daily *mean* position of the needle is readily effected by adding or subtracting the numbers of this table, *irrespective of the signs*, according to the following rule: *Before 11 a. m. subtract the tabular minutes from N. W. and S. E. bearings and add them to N. E. and S. W. bearings; after 11 a. m. add the tabular minutes to N. W. and S. E. bearings and subtract them from the N. E. and S. W. bearings.*

The secular variation of the magnetic declination is probably of a periodic character, but requires several centuries for the completion of a cycle. During many years, therefore, the movement of the needle is progressively in one direction. The amount of the annual change of declination varies for different places and times, and it is on this account that over nearly the whole of the United States the effect of the secular variation is, at present, to *increase* the west declinations or *decrease* the east declinations; that is, the needle is moving westward. On parts of the Pacific coast the effect is opposite, the needle there moving in an easterly direction.

The annual change in declination, as already intimated, varies slightly from year to year. Its approximate value for any given locality may be taken from the accompanying map of Isogonic Lines, upon which also the amount of the annual change for the epoch and place have been noted. A *plus* sign in the annual change indicated increasing west declination or decreasing east declination, and a *minus* sign increasing east or decreasing west declination.

The Isogonic Lines for any given epoch are imaginary lines on the surface of the earth joining points whose declination are at that time equal. An *agonic line* is one joining points of zero magnetic declination or points where the magnetic meridian coincides with the astronomical meridian.

The Isogonic Chart which accompanies this article is a reduction of that of the United States Coast and Geodetic Survey for 1890, the latest published. The approximate declination for any place may either be directly taken from it or inferred by simple interpolation.

The Table of Formulæ which follows is the result of an extended investigation by Professor Charles A. Schott and published in the United States Coast Survey Report for 1888. These formulæ are the best known statement of the law of change of the declination for the given stations. The letter *D* in the last column stands for declination, a plus sign indicating west declination; a minus sign, east declination. The letter *m* stands for the time, expressed in years and fraction of a year, which has elapsed since 1850; or, in other words, is equal to *t*—1850. Although the formulæ are strictly only true for any time within the limits of observation, always prior to 1888, they may also be used for estimations beyond these limits. As illustrative of the use of the expressions, the following steps in the computation of the declinations for Philadelphia and Denver for July 1st, 1893, are given. The only points that need to be specially noted are that care must be exercised in properly taking out the sines of angles greater than 180°, and that the parts of a year are to be expressed fractionally, as, for example, in our case, 1893.5. The value of *m* is then $1893.5 - 1850 = 43.5$. It will not harm again to remind the reader that values of the declination, whether taken from the map or derived from the formulæ, are liable to considerable error, and that observation can alone yield accurate results.

PHILADELPHIA:

$D = + 5.36° + 3.17 \sin (1.50° \times 43.5 - 26.1°) + 0.19 \sin (4.0° \times 43.5 + 146°).$

$D = + 5.36° + 3.17 \sin 39.15° + 0.19 \sin 320°.$

$D = + 5.36° + 3.17 \sin 39° 9' - 0.19 \sin 40°.$

$D = + 5.36° + 2.00° - 0.12°.$

$D = + 7.24°$, *i. e.*, west declination.

DENVER:

$D = - 15.30° + 0.011° \times 43.5 + 0.0005° (43.5)^2.$

$D = - 15.30° + 1.42°.$

$D = - 13.88°$, *i. e.*, east declination.

EXPRESSIONS FOR THE MAGNETIC DECLINATION AT VARIOUS PLACES.

Name of Station.	Latitude.	Longitude.	Expression for the Magnetic Declination.
	° ′	° ′	
Paris, France,	+48 50.2	−2 20.2	$D = +6°.479 + 16°.002 \sin (0.765\, m + 118°46'.5) + [0.85 - 0.35 \sin (0.69\, n)] \sin [(4.04 + 0.0054\, n + .000035\, n^2) n]$
St. George's Town, Bermuda,	+32 23	+64 42	$D = +6.95 + 0.0145\, m + 0.00056\, m^2$*
Rio de Janeiro, Brazil,	−22 54.8	+43 09.5	$D = +2.19 + 9.91 \sin (0.80\, m - 10.4)$*
Saint John's, Newfoundland,	+47 34.4	+52 41.9	$D = +21.94 + 8.89 \sin (1.05\, m + 63.4)$*
Quebec, Canada,	46 48.4	71 14.5	$D = +14.66 + 3.03 \sin (1.4\, m + 4.6) + 0.61 \sin (4.0\, m + 0.3)$
Charlottetown, Prince Edward Island,	46 14	63 27	$D = +15.95 + 7.78 \sin (1.2\, m + 49.8)$
Montreal, Canada,	45 30.5	73 34.6	$D = +11.88 + 4.17 \sin (1.5\, m - 18.5) + 0.36 \sin (4.9\, m + 19)$
Eastport, Me.,	44 54.4	66 59.2	$D = +15.18 + 3.79 \sin (1.25\, m + 31.1)$*
Bangor, Me.,	44 48.2	68 46.9	$D = +13.86 + 3.55 \sin (1.30\, m + 8.6)$
Halifax, Nova Scotia,	44 39.6	63 35.3	$D = +16.18 + 4.53 \sin (1.0\, m + 46.1)$*
Burlington, Vt.,	44 28.5	73 12.0	$D = +10.81 + 3.65 \sin (1.30\, m - 20.5) + 0.18 \sin (7.0\, m + 132)$
Hanover, N. H.,	43 42.3	72 17.1	$D = +9.80 + 4.02 \sin (1.4\, m - 14.1)$*
Portland, Me.,	43 38.8	70 16.6	$D = +11.40 + 3.28 \sin (1.30\, m + 2.7)$
Rutland, Vt.,	43 36.5	72 55.5	$D = +10.03 + 3.82 \sin (1.5\, m - 24.3)$
Portsmouth, N. H.,	43 04.3	70 42.5	$D = +10.71 + 3.36 \sin (1.44\, m - 7.4)$
Chesterfield, N. H.,	42 53.5	72 24	$D = +9.60 + 3.84 \sin (1.35\, m - 16.1)$*

* Approximate Expression.

EXPRESSIONS FOR THE MAGNETIC DECLINATION AT VARIOUS PLACES.

Name of Station.	Latitude. ° ′	Longitude. ° ′	Expression for the Magnetic Declination.
Newburyport, Mass.,	42 48.9	70 49.2	$D=+10.07°+3.02° \sin(1.35\,m-1.0°)$
Williamstown, Mass.,	42 42.8	73 13.4	$D=+8.84+3.13 \sin(1.4\,m-14.0)$*
Albany, N. Y.,	42 39.2	73 45.8	$D=+8.17+3.02 \sin(1.44\,m-8.3)$
Salem, Mass.,	42 31.9	70 52.5	$D=+9.98+3.85 \sin(1.4\,m-5.1)$*
Oxford, N. Y.,	42 26.5	75 40.5	$D=+6.19+3.24 \sin(1.35\,m-18.9)$
Cambridge, Mass.,	42 22.9	71 07.7	$D=+9.54+2.69 \sin(1.30\,m+7.0)$ $+0.18 \sin(3.2\,m+44)$
Boston, Mass.,	42 21.5	71 03.9	$D=+9.48+2.94 \sin(1.3\,m+3.7)$
Provincetown, Mass.,	42 03.1	70 11.3	$D=+9.67+3.04 \sin(1.3\,m+11.0)$*
Providence, R. I.,	41 50.2	71 23.8	$D=+9.10+2.99 \sin(1.45\,m-3.4)$ $+0.26 \sin(7\,m+84)$
Hartford, Conn.,	41 45.9	72 40.4	$D=+8.06+2.90 \sin(1.25\,m-26.4)$
New Haven, Conn.,	41 18.5	72 55.7	$D=+7.78+3.11 \sin(1.40\,m-22.1)$
Nantucket, Mass.,	41 17.0	70 06.0	$D=+8.61+2.83 \sin(1.35\,m+19.7)$
Cold Spring Harbor, Long Island, N. Y.,	40 52	73 28	$D=+7.19+2.52 \sin(1.35\,m-11.4)$
New York City, N. Y.,	40 42.7	74 00.4	$D=+7.04+2.77 \sin(1.30\,m-18.1)$ $+0.14 \sin(6.3\,m+64)$
Bethlehem, Pa.,	40 36.4	75 22.9	$D=+5.40+3.13 \sin(1.55\,m-38.3)$
Huntingdon, Pa.,	40 31	78 02	$D=+3.76+2.93 \sin(1.48\,m-35.2)$
New Brunswick, N. J.,	40 29.9	74 26.8	$D=+5.11+2.94 \sin(1.30\,m+4.2)$
Jamesburg, N. J.,	40 21	74 27	$D=+6.03+2.94 \sin(1.40\,m-22.4)$

* Approximate Expression.

EXPRESSIONS FOR THE MAGNETIC DECLINATION AT VARIOUS PLACES.

Name of Station.	Latitude.	Longitude.	Expression for the Magnetic Declination.
	° ′	° ′	° ° °
Harrisburg, Pa.,	40 15.9	76 52.9	$D=+2.93+2.98 \sin(1.50\,m+0.2)$
Hatborough, Pa.,	40 12	75 07 *	$D=+5.17+3.16 \sin(1.54\,m-16.7)$ $+0.22 \sin(4.1\,m+157)$
Philadelphia, Pa.,	39 56.9	75 09.9	$D=+5.36+3.17 \sin(1.50\,m-26.1)$ $+0.19 \sin(4.0\,m+146)$
Chambersburg, Pa.,	39 55	77 40	$D=+2.79+3.10 \sin(1.55\,m-30.6)$ $+0.20 \sin(4.6\,m-124)$
Baltimore, Md.,	39 17.8	76 37.0	$D=+3.20+2.57 \sin(1.45\,m-21.2)$
Washington, D. C.,	38 53.3	77 00.6	$D=+2.73+2.57 \sin(1.45\,m-21.6)$ $+0.14 \sin(12\,m+27)$
Cape Henlopen, Del.,	38 46.7	75 05.0	$D=+4.01+3.22 \sin(1.35\,m-25.2)$
Williamsburg, Va.,	37 16.2	76 42.4	$D=+2.33+2.56 \sin(1.5\,m-38.1)$
Cape Henry, Va.,	36 55.6	76 00.4	$D=+2.42+2.25 \sin(1.47\,m-30.6)$
New Berne, N. C.,	35 06	77 02	$D=+0.63+2.56 \sin(1.45\,m-18.2)$*
Milledgeville, Ga.,	33 04.2	83 12	$D=-3.10+2.53 \sin(1.40\,m-61.9)$*
Charleston, S. C.,	32 46.6	79 55.8	$D=-1.82+2.75 \sin(1.40\,m-12.1)$*
Savannah, Ga.,	32 04.9	81 05.5	$D=-2.13+2.55 \sin(1.40\,m-40.5)$*
York Factory, British North America,	56 59.9	92 26	$D=+7.34+16.03 \sin(1.10\,m-97.9)$
Fort Albany, British North America,	52 22	82 38	$D=+15.78+6.95 \sin(1.20\,m-99.6)$*
Duluth, Minn., and Superior City, Wis.,	{ 46 45.5 / 46 39.9 }	{ 92 04.5 / 92 04.2 }	$D=-7.70+2.41 \sin(1.4\,m-120.0)$*

* Approximate Expression

EXPRESSIONS FOR THE MAGNETIC DECLINATION AT VARIOUS PLACES.

Name of Station.	Latitude.	Longitude.	Expression for the Magnetic Declination.
	° ′	° ′	
Sault de Ste. Marie, Mich.,	46 29.9	84 20.1	$D = +1°.54 + 2°.70 \sin(1.45\,m - 58°.5)$
Pierrepont Manor, N. Y.,	43 44.5	76 03.0	$D = +5.95 + 3.78 \sin(1.4\,m - 22.2)$
Toronto, Canada,	43 39.4	79 23.5	$D = +3.60 + 2.82 \sin(1.4\,m - 44.7)$
			$+ 0.09 \sin(9.3\,m + 136)$
			$+ 0.08 \sin(19\,m + 247)$
Grand Haven, Mich.,	43 05.2	86 12.6	$D = -4.95 + 0.0380\,m + 0.00120\,m^2$
Milwaukee, Wis.,	43 02.5	87 54.2	$D = -4.12 + 3.60 \sin(1.45\,m - 64.5)$*
Buffalo, N. Y.,	42 52.8	78 53.5	$D = +3.66 + 3.47 \sin(1.4\,m - 27.8)$
Detroit, Mich.,	42 20.0	83 03.0	$D = -0.97 + 2.21 \sin(1.5\,m - 15.3)$
Ypsilanti, Mich.,	42 14	83 38	$D = -1.20 + 3.40 \sin(1.40\,m - 4.1)$
Erie, Pa.,	42 07.8	80 05.4	$D = +2.17 + 2.69 \sin(1.5\,m - 27.3)$
Chicago, Ill.,	41 50.0	87 36.8	$D = -3.77 + 2.48 \sin(1.45\,m - 62.5)$
Michigan City, Ind.,	41 43.4	86 54.4	$D = -3.23 + 2.42 \sin(1.4\,m - 48.0)$
Cleveland, Ohio,	41 30.4	81 41.5	$D = +0.47 + 2.39 \sin(1.30\,m - 14.8)$
Omaha, Neb.,	41 15.7	95 56.5	$D = -9.30 + 3.34 \sin(1.30\,m - 54.7)$
Beaver, Pa.,	40 44	80 20	$D = +1.41 + 2.72 \sin(1.40\,m - 39.6)$
Pittsburgh, Pa.,	40 27.6	80 00.8	$D = +1.85 + 2.45 \sin(1.45\,m - 28.4)$
Denver, Colo.,	39 45.3	104 59.5	$D = -15.30 + 0.011\,m + 0.0005\,m^2$
Marietta, Ohio,	39 25	81 28	$D = +0.02 + 2.89 \sin(1.4\,m - 40.5)$
Athens, Ohio,	39 19	82 02	$D = -1.51 + 2.63 \sin(1.4\,m - 24.7)$
Cincinnati, Ohio,	39 08.4	84 25.3	$D = -2.59 + 2.43 \sin(1.42\,m - 37.9)$

* Approximate Expression.

EXPRESSIONS FOR THE MAGNETIC DECLINATION AT VARIOUS PLACES.

Name of Station.	Latitude.	Longitude.	Expression for the Magnetic Declination.
	° ′	° ′	° ° °
Saint Louis, Mo,	38 38.0	90 12.2	D=− 5.91+ 3.00 sin (1.40 *m*−51.1)*
Nashville, Tenn.,	36 08.9	86 48.2	D=− 3.57+ 3.33 sin (1.35 *m*−68.5)*
Florence, Ala.,	34 47.2	87 41.5	D=− 4.25+ 2.33 sin (1.3 *m*−52.8)
Mobile, Ala.,	30 41.4	88 02.5	D=− 4.38+ 2.69 sin (1.45 *m*−76.4)
Pensacola, Fla.,	30 20.8	87 18.3	D=− 4.40+ 3.16 sin (1.4 *m*−59.4)
New Orleans, La.,	29 57.2	90 03.9	D=− 5.20+ 2.98 sin (1.40 *m*−69.8)
San Antonio, Tex.,	29 25.4	98 29.3	D=− 7.40+ 2.88 sin (1.35 *m*−81.8)*
Key West, Fla.,	24 33.5	81 48.5	D=− 4.31+ 2.86 sin (1.30 *m*−23.9)
Havana, Cuba,	23 09.3	82 21.5	D=− 4.25+ 2.74 sin (1.25 *m*−23.3)*
Kingston, Port Royal, Jamaica,	17 55.9	76 50.6	D=− 3.81+ 2.39 sin (1.10 *m*−10.6)
Barbados, Caribbee Islands,	13 05.7	59 37.3	D=− 1.38+ 2.84 sin (1.10 *m*+09.4)
Panama, New Granada,	8 57.1	79 32.2	D=− 5.66+ 2.22 sin (1.10 *m*−27.8)
Acapulco, Mexico,	16 50.5	99 52.3	D=− 4.48+ 4.41 sin (1.0 *m*−85.7)*
Vera Cruz, Mexico,	19 11.9	96 08.8	D=− 5.09+ 4.22 sin (1.2 *m*−63.4)*
City of Mexico, Mexico,	19 26.0	99 11.6	D=− 5.34+ 3.28 sin (1.0 *m*−87.9)*
San Blas, Mexico,	21 32.5	105 18.4	D=− 5.21+ 4.26 sin (1.15 *m*−96.5)
San Lucas, Lower Cal., Mexico,	22 53.3	109 54.7	D=− 5.94+ 3.68 sin (1.20 *m*−116.8)*
Magdalena Bay, Lower California,	24 38.4	112 08.9	D=− 6.33+ 4.17 sin (1.15 *m*−119.2)*
Cerros Island, Lower Cal., Mexico,	28 04	115 12	D=− 7.40+ 4.61 sin (1.05 *m*−107.0)
El Paso, Tex.,	31 45.5	106 27.0	D=− 9.08+ 3.40 sin (1.3 *m*−108.4)

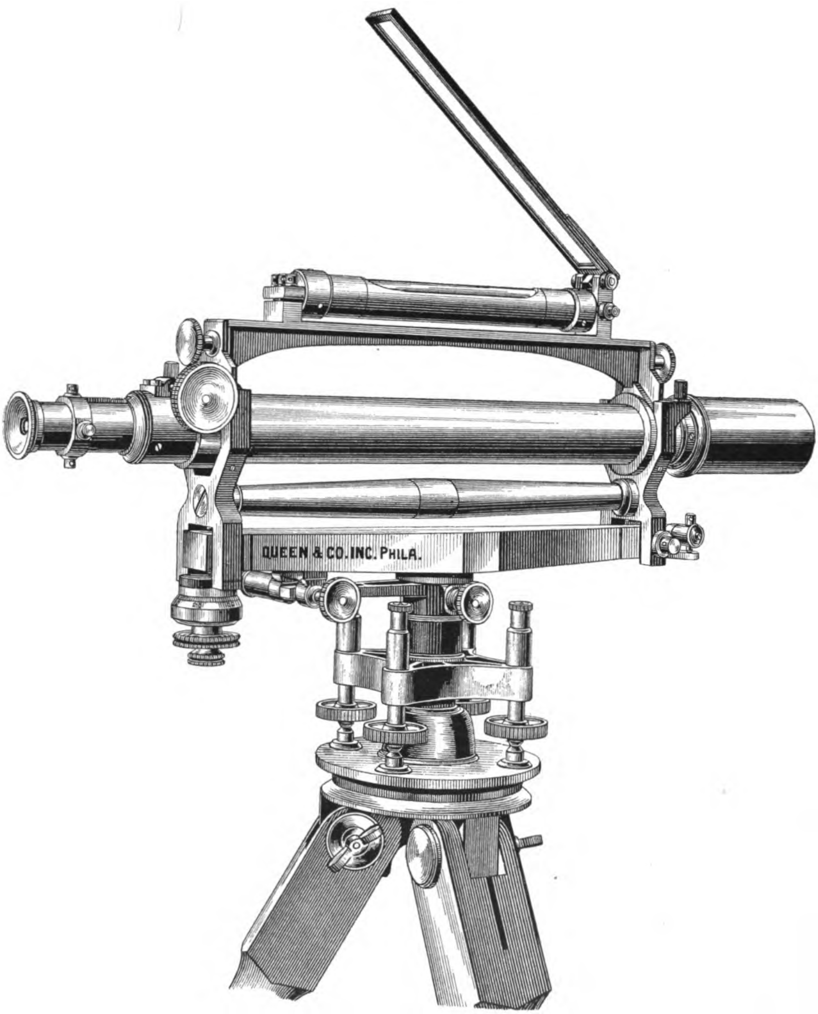
* Approximate Expression.

EXPRESSIONS FOR THE MAGNETIC DECLINATION AT VARIOUS PLACES.

Name of Station.	Latitude.	Longitude.	Expression for the Magnetic Declination.
	° ′	° ′	° ° °
San Diego, Cal.,	32 42.1	117 14.3	D=—10.32+ 3.00 sin (1.10 *m*—126.5)
Santa Barbara, Cal.,	34 24.2	119 43.0	D=—11.52+ 3.32 sin (1.10 *m*—123.1)
Monterey, Cal.,	36 36.1	121 53.6	D=—13.25+ 2.83 sin (1.10 *m*—144.0)
San Francisco, Cal.,	37 47.5	122 27.3	D=—13.94+ 2.65 sin (1.05 *m* —135.5)
Cape Mendocino, Cal.,	40 26.3	124 24 3	D=—15.25+ 2.45 sin (1.10 *m*—128.0)*
Salt Lake City, Utah,	40 46.1	111 53.8	D=—12.40+ 4.25 sin (1.4 *m* - 121.6)*
Vancouver, Wash.,	45 37.5	122 39.7	D=—17.93+ 3.12 sin (1.35 *m*—134.1)*
Walla Walla, Wash.,	46 04	118 22	D=—17.80+ 3.30 sin (1.3 *m*—129.0)*
Cape Disappointment, Wash.,	46 16.7	124 02.8	D=—19.39+ 2.54 sin (1.25 *m*—158.7)
Seattle, Wash.,	47 35.9	122 20.0	D=—19.19+ 3.14 sin (1.4 *m*—136.1)*
Port Townsend, Wash.,	48 07.0	122 44.9	D=—18.84+ 3.00 sin (1.45 *m*—122.1)
Nee-ah Bay, Wash.,	48 21.8	124 38.0	D=—19.83+ 2.91 sin (1.40 *m*—141.6)
Nootka, Vancouver Island,	49 35.5	126 37.5	D=—21.25+ 2.74 sin (1.30 *m*—152.0)*
Captain's and Iliuliuk Harbors,	53 52.6	166 31.5	D=—18.01+ 1.82 sin (1.3 *m*— 69.6)
Sitka, Alaska,	57 02.9	135 19.7	D=—25.79+ 3.30 sin (1.30 *m*—104.2)
St. Paul, Kadiak Island,	57 48.0	152 21.3	D=—22.21+ 5.18 sin (1.35 *m*— 72.5)
Port Mulgrave, Alaska,	59 33.7	139 45.9	D=—24.03+ 7.77 sin (1.30 *m*— 85.8)
Port Etches, Alaska,	60 20.7	146 37.6	D=—23.71+ 7.89 sin (1.35 *m*— 80.9)
Port Clarence, Alaska,	65 16	166 50	D=—18.98+ 7.99 sin (1.3 *m*— 68.4)*
Chamisso Island, Alaska,	66 13	161 49	D=—23.62+ 7.64 sin (1.3 *m*— 64.0)*
Petropavlovsk, Siberia,	53 01	201 17	D=— 3.35+ 2.97 sin (1.3 *m*+ 12.2)

*Approximate Expression.

"QUEEN" PRECISION LEVEL.



A 1526. **Price, $250.00**

DESCRIPTION

OF THE

ENGINEERS' LEVEL.

THE Engineers' Level consists essentially of a horizontally-directed telescope combined with a spirit-level parallel with it, and the whole suitably supported on, and capable of revolution about, a vertical axis.

The telescope of the Engineers' Level is usually of a longer focus, of larger aperture, and of higher power than that of the transit. A full description of the optical characteristics of the telescope will be found in the article entitled "*The Telescopes of Engineering Instruments.*"

The cross hair-ring is usually provided with two threads, one horizontal and the other vertical, the ring being adjustable for the horizontality and verticality of these threads. Sometimes stadia wires are added for conveniently reading off distances on the rod.

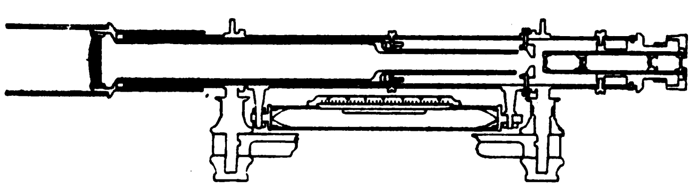


Fig. 50.

The ocular slide, Fig. 50, is provided with a set of centering-screws accessible from the outside of the telescope. The process of centering the eye-piece can thus be accomplished with convenience. The eye-tube is moved in and out by means of a smoothly-working screw adjustment, which obviates any disturbance of the telescope and permits the focusing on the hairs to be performed with great accuracy.

The object slide is covered by a protector. The set of adjusting screws at the middle of the telescope and accessible from the outside are intended for centering the object-glass and its slide with respect to the mechanical axis of the telescope.

A rack and pinion movement is attached to the object-slide and operated by a milled head placed near the middle of the telescope.

The sun-shade is an open brass cap supplied with every level and always to be used for the best results.

The collars or rings fitting on the telescope-tube and supporting it when resting on the wyes, are usually about twelve inches apart. They are made of the hardest bell metal and very accurately turned to exactly the same diameter.

The wyes upon which the collars rest are made of the best bell metal and shaped to precise similarity. They are each attached to the level-bar by means of two adjustable nuts. The telescope is held firmly in position by clips fastened by means of pins. In order to insure the correct position of the cross-wires a small projecting piece extends from the telescope and is brought in contact with a similar piece attached to one of the wyes.

The level bar, made of the best bell metal, is usually of square cross-section, and has attached to its middle the inner axis or "centre" of the instrument.

A vertical micrometer screw with graduated head is, in the finest grade of leveling instruments, attached to one end of the level-bar for the purpose of setting the bubble in refined work.

The centres, Fig. 51, are compound; the inner one attached to the level-bar is a long cone, of the hardest bell metal and held in place by means of the centre screw placed at its lowest extremity; the outer "centre" is made of hard red metal and fits into the socket of the leveling head. Both "centres" are accurately turned in the lathe between dead centres. The three metals used respectively for the inner centre, the outer centre, and the socket of the leveling head are selected so as to secure the smallest coefficient of friction and great durability.

The clamp and tangent movement is attached to the inner "centre," and is of the same form as that supplied with QUEEN & Co.'s engineering transits.

The leveling head has the usual plates and leveling screws, as shown in the foregoing section. It is usually clamped to the tripod head.

The fine spirit-level, of about eight inches in length, is usually attached below the telescope, and furnished with adjusting screws which, at one end of the level tube, permit lateral or

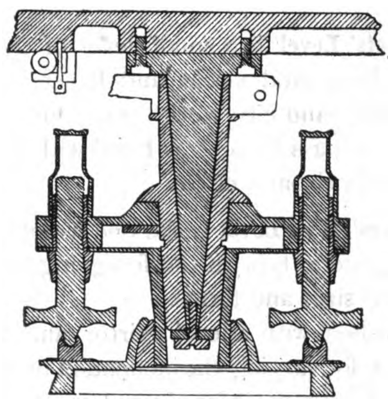


Fig. 51.

horizontal motion, and, at the other end, vertical motion. In some forms of the leveling instrument it is found advantageous to place the spirit-level above the telescope. For a complete description of the spirit-level, its construction and theory, the reader is referred to the article of this Manual entitled "*The Spirit-levels of Engineering Instruments.*"

A reflector is sometimes attached for the purpose of allowing the position of the bubble to be read from the eye-end of the telescope, without change of position of the observer. If the spirit-level is below the telescope, the reflector is attached at the side; if above the telescope, the reflector is mounted over it.

The Forms of the Level range from the Simple Dumpy Level through various styles of the Engineers' Level to the higher types of the Precision Level. The following are taken as representing the chief classes:

The Dumpy Level is a compact instrument possessing the smallest number of adjustments, and is hence least liable to derangement from rough usage. It is without wyes, and its telescope tube forms one rigid piece with the level-bar. Only the line of sight and the spirit-level are adjustable by the engineer. With intelligent usage, the QUEEN & Co. Dumpy Level, made in a large and powerful form, is often capable of results equal to those secured by the more complicated wye level.

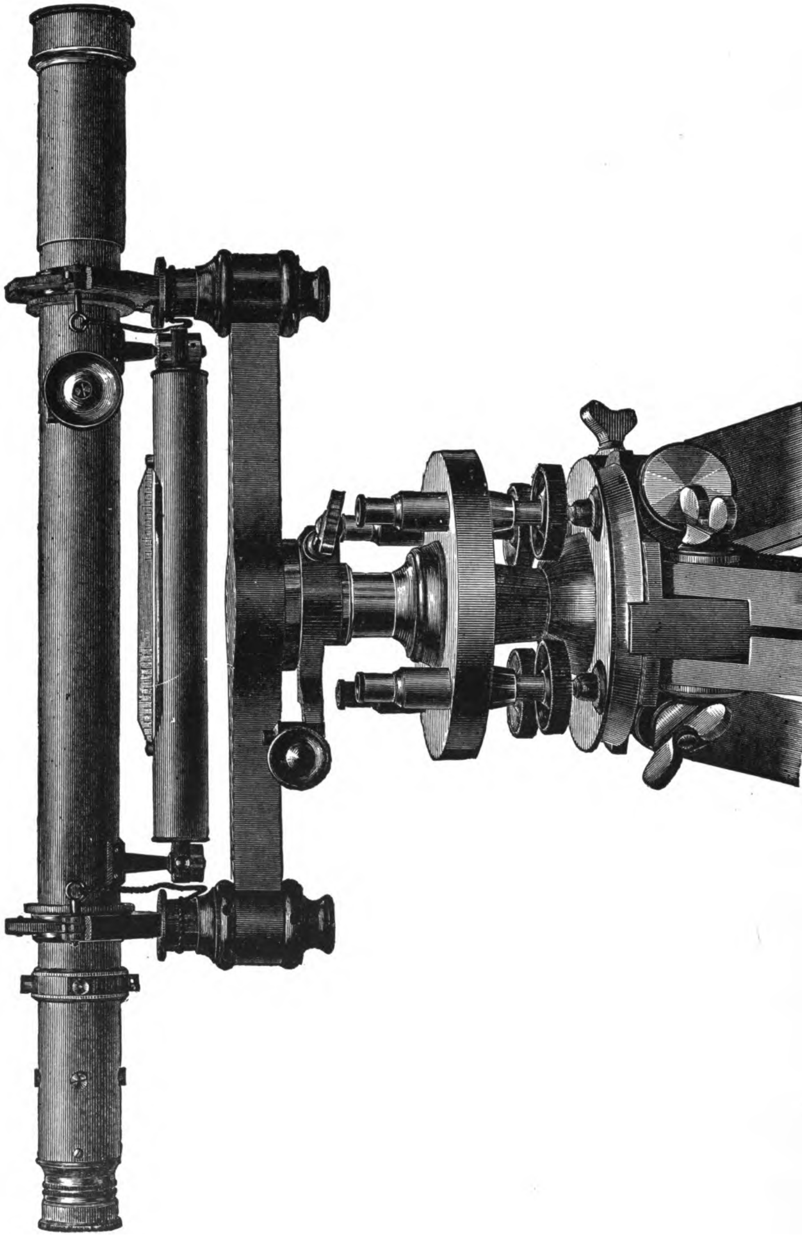
The Architects' Level is a small level of the wye form, furnished with a horizontal circle, and hence adapted to many kinds of building and city work. One form of it, called the "Architect's Compass Level," is fitted with a compass-box, in addition to the horizontal circle.

The Engineers' Wye Level is the one we have taken as representing the general type in the foregoing description, and is made in several sizes and forms.

When furnished with a level mirror and a graduated micrometer screw for varying the inclination of the telescope with respect to the level axis, it is adapted to the higher methods of manipulation required in hydrographic and other precise work.

The Precision Level, adapted to the highest grade of leveling, is furnished with the requisites for testing the performance of every feature, and for eliminating all forms of error. It is provided with a finely-graduated horizontal circle, a vertical micrometer screw, having a graduated head; a fine reversible spirit-level, and a telescope of the most accurate optical and mechanical construction.

"QUEEN" ENGINEERS' LEVEL.



A 1528.

Price, $110.00.

THE ADJUSTMENTS

OF THE

ENGINEERS' LEVEL.

THE adjustments of an engineers' level may be conveniently treated of under two heads: (1) The maker's adjustments, or those which the scientific maker gives the instrument in the course of its construction and testing; and (2) The field adjustments, or those which require occasional verification by the engineer.

THE MAKER'S ADJUSTMENTS.

It is necessary that the following conditions be realized in the construction and adjustment of a good level:

(1) The lenses of the objective and of the eye-piece of the telescope truly centred in their respective cells.

(2) The optical axis of the system of lenses coinciding with the mechanical axis of the tube, in all the relative positions of the objective and eye-piece, the lenses remaining always at right angles to this axis.

(3) The cross-hairs, during each observation in the common focus of the object-glass and eye-piece.

(4) The cross-hairs truly centred with respect to the mechanical axis of the telescope.

(5) The collars truly circular and of exactly the same diameter.

(6) The wyes of exactly equal shape.

(7) The horizontal cross-hair (all other adjustments made) at right angles to the vertical axis of the instrument, and the vertical one vertical.

(8) The line of sight at right angles to the vertical axis of the instrument, or coinciding with the axis of collimation.

(9) The axis of the telescope level lying in the same plane as the line of collimation, or not "crossed" with respect to it.

(10) The axis of the telescope level parallel with the line of sight.

(11) The telescope level of a sensitiveness corresponding to the magnifying power of the telescope.

(12) The telescope level of equal sensitiveness throughout its entire scale.

(13) The axis of the accessory levels, attached to the leveling head, at right angles to the vertical axis of the instrument.

This list is to be taken as but fairly representing the principal adjustments to be accomplished by the maker. It is not intended to be absolutely exhaustive.

THE FIELD ADJUSTMENTS.

The following practical methods for detecting and correcting the errors of adjustment of the Engineers' Level are given for use in the field. An explanation of the nature of each error is incidentally embodied.

There are but two principal adjustments to be verified by the engineer, viz.: that

I. The sight-axis of the telescope and the axis of the telescope level parallel.

II. The axis of the telescope level at right angles to the vertical axis of the instrument.

All other adjustments are subsidiary and accessory to these, and will be explained in their proper places. The sequence of these adjustments is, as here stated, in the case of any adjustable wye level, like the Engineer's or Precision Level. The Dumpy Level, however, requires the converse order, as hereafter explained.

First Adjustment:—*To make the line of sight parallel to the axis of the telescope level.*

This adjustment may be performed by two methods, each of which commends itself, under different circumstances. The first is called the Instrumental Method, because it depends only on manipulation of the instrument itself; the second, requiring also readings on the leveling rod, is called the Rod Method.

I. The Instrumental Method divides this adjustment into the two operations, (*a*) of bringing the line of sight into the geometrical axis of the rings or collars, and (*b*) of making the axis of the telescope level parallel to the bottoms of the collars. Assuming that the rings are of exactly the same diameter, this indirect method of making the sight-axis and the level-axis parallel to the line joining the bottoms of the collars brings these axes parallel to each other. We may now briefly analyze each of these sub-adjustments.

(*a*) *To bring the line of sight into the geometrical axis of the rings.*

DETECTION OF THE ERROR:—Direct the telescope to as distant an object as may still be clearly defined. After loosening the wye clips, carefully rotate the telescope upon the wyes and note whether the intersection of the cross-hairs remains on a given stationary point of the image. If the wires appear to move with respect to the image, the line of sight is not in the axis of the rings. The line of sight being determined by the optical centre of the objective and the point of intersection of the cross-hairs, both points should be brought into the axis of the rings, and in all conditions of use of the telescope remain there. For a description of the centering of the telescope, the reader is referred to the article of this Manual entitled "*The Telescopes of Engineering Instruments.*" It is now, in the first place, assumed that the optical centre of the objective is in the axis when the objective is in position for viewing a distant object. In the second place, the deviation of the line of sight during rotation of the telescope on the wyes is, therefore, due to the eccentric position of the intersection of the cross-hairs.

CORRECTION OF THE ERROR:—Giving attention to each wire in turn, note the position of the rotated telescope, which gives the maximum deviation of the wire from the selected point of the image. Then by means of the proper set of capstan-headed screws of the cross-hair ring, bring each wire in turn half way back toward the point of the image. Repeat until the centre of the cross-hairs remains accurately bisecting a point of the image during a complete revolution of the telescope on the wyes.

The centering of the objective slide is an accessory adjustment, and may be undertaken after the centering of the cross-hairs has been effected by the preceding method. It is only necessary to focus on a very near object by means of the slide, and then rotating the telescope in its wyes as before, correct half the deviation of each thread in turn by means of the slide-centering screws. See also the article on "*The Telescopes of Engineering Instruments*," already mentioned.

(*b*) *To make the axis of the telescope-level parallel to the bottoms of the rings.*

DETECTION OF THE ERROR:—Clamp the axis of the instrument, and carefully level, particularly with the pair of leveling screws lying parallel to the telescope. Now gently reverse the telescope end for end in the wyes, and note whether the bubble returns to the same central reading. If the bubble deviates from its original position, this deviation is double the error.

CORRECTION OF THE ERROR:—Correct one-half of the deviation observed on reversal in the wyes by means of the vertical adjusting screws of the level-tube. Level again, and, as a check, repeat the operation.

The crosswise position of the level, or the condition in which the level axis is not in the same vertical plane with the line of sight, is to be carefully avoided in connection with all adjustments and uses of the level. After every adjustment of the level-tube, careful examination should be made for the crossing. This condition is tested for by turning the telescope slightly on the wyes and noting whether the bubble still continues to remain central. If not, adjust by means of the lateral adjusting screws of the level-tube until, on rocking to and fro on the wyes, the bubble remains stationary. Compare the paragraph on "the crosswise position of the level" in the article of this Manual entitled "*The Spirit-levels of Engineering Instruments.*" The importance of this adjustment lies in the fact that the error of crossing of the level may produce quite a material divergence of the line of sight from the horizontal direction, if the telescope happens to be turned slightly round in the wyes, or if the instrument is not accurately leveled in the direction perpendicular to the line of sight.

When, as in the Dumpy Level and in the Engineers' Transit, the telescope does not revolve in wyes about the line of sight, the following method, due to Helmert, may be used to detect and adjust for the crosswise position of the level axis. All other adjustments accurately made, set up the instrument with the line of sight parallel to two leveling screws, and direct it to a rod placed at a distance of several hundred feet. Then, by means of the other set of leveling screws, slightly rotate the telescope about the line of the parallel set, at the same time that, by means of the parallel set, the level is kept to zero reading. The deviation of the line of sight thus caused and read off on the rod, will be a measure of the crossing error, provided allowance is made for the very small variation in the height of the line of sight. The adjustment for the crossing is to be effected by means of the lateral adjusting screws of the level.

The inequality in diameter of the rings may be found by means of a striding level which is read both in the direct and reversed positions on the rings, for each of the two positions of the telescope in the wyes, direct and reversed. The bubble movement, due alone to reversal of the telescope in the wyes, measures twice the inequality of the rings; but the inequality, or angle at the apex of the arc formed, is also twice the angle made by the axis of the rings with the edge. Therefore, one-fourth of the bubble movement, due to reversal of telescope, equals the inequality of rings expressed in bubble divisions. This, multiplied by the angular value of a division of the level, gives the angular value of the inequality.

If the instrument is properly made, the rings are so nearly of equal diameter that the assumption of equality required in the foregoing adjustment leads to errors quite inappreciable except in the highest class of work.

II. The Rod Method requires the use both of the instrument and of the leveling rod, and is frequently spoken of as the "peg adjustment." It has, in one form, been already described under the head of the "Fourth Adjustment" of the Engineers' Transit, and, as there given, is also applicable to the Engineers' Level. The rod method, being a direct one, and independent of the diameter of the rings, is of great practical importance, and is therefore here given in another form.

DETECTION OF THE ERROR:—Drive two stakes, several hundred feet apart, on nearly level ground. Set up the instrument successively in two symmetrical positions, as, Fig. 52, either in I and J, or in K and L, and near the rods. If we suppose the positions to be I and J, the eye-hole is to be brought very near the rod in setting up, and the height of the eye-end may then be found by looking through the objective, and with a sharp pencil point marking the centre of the small field upon the rod. If the positions used are K and L, the readings on the rods near by are made through the telescope by moving out the focusing slide far enough to secure distinct vision.

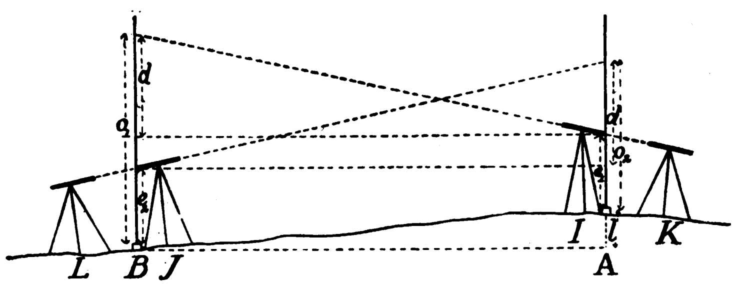


Fig. 52

Letting e_1 equal the reading on the near rod for the instrumental position either in I or in K, o_1 the reading on the distant rod for the same position, e_2 the reading on the near rod for the instrumental position either in J or in L, o_2 the reading on the distant rod for the same position, $+l$ the elevation of A above B, and $+d$ the *upward* deviations, as measured on the distant rod, of the line of sight from the axis of the level, we have the evident relations—

$$o_1 = e_1 + l + d \qquad (1)$$

$$o_2 = e_2 - l + d \qquad (2)$$

Whence, by simple elimination in (1) and (2), we easily find the following:

$$\tfrac{1}{2}(o_1+o_2)-\tfrac{1}{2}(e_1+e_2)=d \qquad (3)$$

$$\tfrac{1}{2}(o_1-o_2)-\tfrac{1}{2}(e_1-e_2)=l \qquad (4)$$

Also from equation (2) we have—

$$o_2-d=e_2-l \qquad (5)$$

Equation (3) gives the upward deviation d, which, applied in (2), would give l. It is, however, convenient to use (4) to find l, and then use (5) as a check on the work.

Example—

	$o_1=5.428$ ft.	$e_1=5.122$ ft.
	$o_2=5.175$ "	$e_2=5.469$ "
Half sums,	5.3015	5.2955
Half differences,	0.1265	—0.1735

Whence $d=0.006$ and $l=0.300$

Also, $o_2-d=5.169$ and $e_2-l=5.169$

Correction of the Error:—With the instrument remaining in the last position—namely, either in J or in L—set the target of the distant rod to the reading o_2-d, remembering that $+d$ is an upward, and $-d$ a downward deviation of the line of sight, and that, hence, d for an upward deviation is subtractive from the last distant rod reading, and, for a downward reading, additive to it. Now, taking care to keep the level-bubble at zero reading, adjust the horizontal cross wires, by means of the set of capstan-headed screws at right angles to it, until the wire intersects the adjusted target of the distant rod. The line of sight is then parallel to the axis of the level.

Second Adjustment:—*To bring the axis of the telescope level at right angles to the vertical axis of the instrument.*

This adjustment is intended to obviate the necessity of re-leveling the instrument upon revolving the telescope horizontally.

Detection of the Error:—Carefully level the instrument. Revolve on the vertical axis 180° and re-read the level. The bubble deviation will be equal to double the error.

CORRECTION OF THE ERROR:—Correct half of the bubble deviation by means of the screws at the end of the level-bar which vertically adjust the wye. Then level by means of the leveling screws, and repeat the observation as a check.

The Adjustments of the Dumpy Level are the same two already described in this article. But owing to the telescope being immovably attached to the level-bar, they must be performed in the inverse order. The parallelism between the sight-axis and the level axis can, indeed, be secured either by means of the vertical adjusting screws of the level tube, or by means of the adjusting screws of the cross-wires. But since the level axis is also to be at right angles to the vertical axis of the instrument, this adjustment of the level is first secured, and then the line of sight rendered parallel to the level-axis by means of the cross-hair adjusting screws, according to the rod methods of adjustment described in this article, and under the "Fourth Adjustment" of the Engineers' Transit.

The Second Adjustment of this article must then be performed, first, by carefully leveling, revolving the whole instrument horizontally 180°, and correcting one-half the bubble deviation by means of the vertical adjusting screws of the level-tube. The First Adjustment of this article is then performed by some form of the Rod Method. Here the final result is to determine a rod reading for a horizontal position of the line of sight, and hence enable the cross-hairs to be brought to that reading when the level is at the zero reading.

Queen & Co., realizing the advantage which accrues to the engineer from the use of a Level adjusted in every part with thorough accuracy, pay special attention to each detail conducive to this result. Whatever adds to the permanency of the adjustments is considered essential, and each instrument sent out is first subjected to a complete and accurate adjustment.

LENGTH MEASUREMENT

IN

ENGINEERING.

ONE of the most important practical operations to be performed by the engineer is the measurement of length. The true theory of such measurement, and the best means of attaining the degree of accuracy proper to each kind of work, should therefore be familiar. And yet, owing to the frequent laxity of opinion existing on this subject, we would offer no apology for making a brief review of the matter here.

It is not necessary to remind the capable engineer that one of the most weighty considerations in his work is the *degree of error allowable*, profitable, or unavoidable in each given case, with the given appliances. It is only the young and untrained engineer who would, for instance, take a measuring unit possessing an unknown error probably as great as 1 in 1,000, and then by much expenditure of time and labor in the actual measurement, endeavor to reduce the latter's error to 1 in 10,000.

There should exist a proper *proportionality of error* between the various kinds of measurements, as of length, angle, and time, made by the engineer in any given work. For a surveyor using a compass giving bearings to quarters of a degree it would be as absurd to think of measuring the lines run by means of a base-line apparatus, such as used in refined geodetic work, as it would for the geodetic engineer, measuring the angles of his triangles to within a few seconds, to contemplate using an old-fashioned surveyor's chain on his base-lines.

It is, however, of the highest importance always to use the most nearly accurate unit of length measurement which the class of work will warrant. And this, for the reason that the original error of length in chain, tape, or bar used will accumulate to serious proportions when a long line is measured. The fact that in his work such errors always enter with the same sign and hence are cumulative in character should be sufficient caution to the engineer against introducing a constant error by the choice of an uncertain unit of length measurement.

There are, on the other hand, purely accidental errors of length measurement, which, as the theory of probabilities informs us, are largely compensated by each other. Such errors are those arising from setting the pins or marking the lengths. At first view one should think that these errors would far outweigh any moderate constant errors of the chain or tape. But such an illusion can readily be dispelled by considering a practical case. When, for instance, a mile's length is measured by means of a chain 66 feet long, the very process of end to end measurement gives in effect a mean or average length to the chain, similar to that which would be derived by measuring the length of the chain itself 80 times ($80 \times 66 = 5280$), and taking the mean. Let us suppose the "mean error" ε of a single measurement to be 0.4 inch. Then, if m equals the number of measurements and R the probable error of their sum, we have from the Method of Least Squares:

$$R = .6745 . \varepsilon . \sqrt{m}$$

or for our case, approximately:

$$R = \tfrac{2}{3} \times .4 \times 9 = 2.4 \text{ inches.}$$

That is, the most probable total error in the mile arising from marking the lengths, would be 2.4 inches.

But if, on the other hand, the chain used had been 0.2 inch too long or too short, 80 measurements would have increased this error to a total of 16 inches. In other words, the final error, so far as it depends on the unavoidable inaccuracy of marking the lengths, is proportional to but the square root of the number of measurements, whereas, so far as it depends on the faulty unit, it is directly proportional to the number of measurements. It is therefore plain that a *constant error* in the unit of measurement employed is of much more serious consequence than the *purely accidental errors* which accompany a careful use of the unit.

Realizing the necessity for accuracy in the units of length measurements used by the engineer and comprehending the public appreciation of all that advances the character and standard of engineering work, QUEEN & Co. have brought all the resources of their relations with men of science and expert mechanicians in this country and abroad, to bear upon the practical solution of the problem.

DESCRIPTION

OF THE

PLANE TABLE.

THE plane table is a well-made and properly mounted drawing-board carrying on it an alidade provided with a telescopic line of sight and a ruler of fiducial edge. Its purpose is to enable angles to be transferred from nature to a sheet of paper attached to the drawing-board.

The Tripod and Head are usually larger and heavier than those used with the ordinary transit. The tripod head is of the usual type, and may be of the shifting sort, so as to allow a slight lateral motion.

The metallic plate, which is fastened to the table, has projecting from its centre a finely-turned conical spindle, and there is added the usual clamp and tangent motion. In all of the QUEEN & Co. types of the plane table the head is made large enough to afford a perfectly firm bearing service.

The Drawing Board is of rectangular shape, usually 24x30 inches, and is made of well-seasoned wood so joined together as to obviate warping, and is provided with spring clamps for keeping the paper properly stretched. The board is also provided with suitable levels.

The Plumbing Arm has a sharp point at one end and a plummet suspended from the other, and enables any point on the ground to be transferred to its proper position on the board.

The Declinator consists of a rectangular compass-box provided with carefully wrought edges whose directions coincide with the lines conceived as passing through the zero points of the graduated circle of the compass. By means of it the table may be oriented, or lines drawn on the board parallel to any given line on the ground.

The Alidade consists essentially of a metallic straight-edge about 22 inches long and 2 inches wide, to which, at its centre, is attached a column carrying the telescope. The alidade has attached to it either one round or two cross-levels adjusted with respect to the lower surface of the ruler, and of use in leveling the table. In the best form of alidade a level is placed at right angles to the line of sight, and the horizontal axis of the telescope may by means of this level and a suitable adjusting screw be kept horizontal independently of the leveling of the table.

The Telescope has no lateral motion with respect to the straight-edge, being rigidly connected with it, and with it may be moved to any part of the table. The telescope is, however, capable of a vertical motion on a transverse axis which carries a graduated arc with clamp and tangent motion, and so permits the small vertical angles to be read off. The telescope has attached to it a level whose plane is adjustable to a position parallel to the line of sight. A striding level is also sometimes provided for the transverse axis of the telescope. Stadia wires are, on account of their convenience in measuring distances, always inserted.

If the level is attached parallel to the line of sight of the telescope two readings are required for a vertical angle, one for the direction of the point and one for the horizontal direction. If, however, the level is attached to the vernier arm of the vertical arc, one reading of the circle after the bubble is brought to zero suffices to give the vertical elevation of the point.

The Forms of the Plane Table furnished by QUEEN & Co. vary according to the grade of work for which they are intended. The chief differences lie in the size of the table, the size and power of the telescope, the sensitiveness and positions of the levels furnished, and the accessory conveniences attached. Of all these, a full description is given in QUEEN & Co.'s catalogue.

THE ADJUSTMENTS

OF THE

PLANE TABLE.

THE adjustments of the plane table may be conveniently stated under two heads: (1) The maker's adjustment are those which the scientific maker gives the instrument during its construction and testing, and (2) The field adjustments are those which have occasionally to be verified by the engineer.

THE MAKER'S ADJUSTMENTS.

It is necessary that the following conditions be met in the construction and adjustment of a good plane table:

1. The upper surface of the table or drawing-board, as nearly as possible, a true mathematical plane.

2. The vertical axis of the table at right angles to the plane of the board.

3. The feather edge of the ruler a mathematically straight line.

4. The plane of the plate-levels parallel to the lower surface of the alidade ruler.

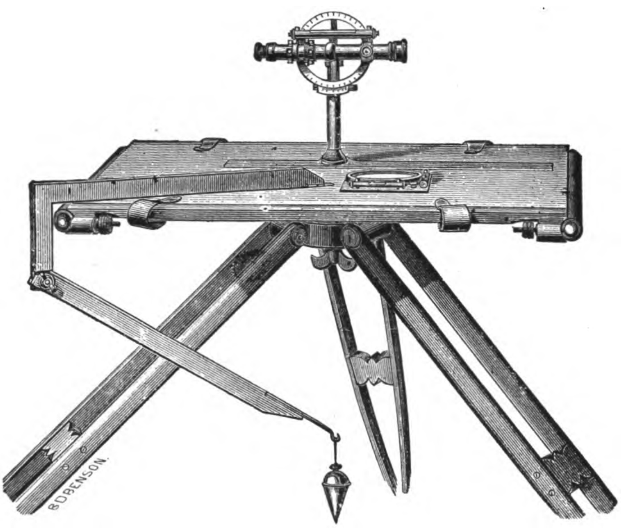
5. The lenses of the objective and of the eye-piece of the telescope truly centered in their respective cells.

6. The optical axis of the telescopic system of lenses coinciding with the mechanical axis of the tube in all the relative positions of objective and eye-piece at the same time that the lenses always remain at right angles to this axis.

7. The stadia and cross wires, during an observation, in the common focus of the object-glass and the eye-piece.

8. The vertical cross-hair at right angles to the horizontal axis of the telescope, and the horizontal cross-hair accurately at right angles to the former.

"QUEEN" PLANE TABLE.



A 1522. **Price, $200.00**

9. The line of sight at right angles to the horizontal axis of the telescope or coinciding with the axis of collimation.

10. The axis of the telescope-level lying in the same plane as the line of sight, or not "crossed" with respect to it.

11. The axis of the telescope-level parallel with the line of sight.

12. The axis of the level attached to the vernier arm of the vertical arc horizontal when the vernier reads zero.

13. The horizontal axis at right angles to the vertical axis of the table, and hence parallel to the plane of the table.

14. The plane of the vertical arc parallel to the vertical axis of the instrument.

15. The vertical arc without appreciable errors of graduation or of eccentricity.

16. The vernier of the vertical arc reading zero either when the level attached to its arm reads zero, or when the telescope reads zero and the line of sight is horizontal.

This list, while not exhaustive, will serve to direct the attention of the engineer to some of the more essential requisites of a well-constructed instrument.

THE FIELD ADJUSTMENTS.

The following practical methods for detecting and correcting the errors of adjustment of the plane table are given for use in the field.

They are so similar to those stated under the head of the Engineer's Transit and the Engineer's Level as to require but little further explanation.

The principal conditions are:

1. That the plane of the table shall be approximately horizontal during use.

2. That the feather edge of the ruler shall, under all conditions, if it does not coincide or is not parallel with the projection on the table of the line of sight of the telescope, at any rate make a constant angle with it.

3. That the horizontal axis of the telescope shall be truly horizontal during a pointing at some altitude.

First Adjustment:—*To make the axes of the plate levels parallel to the plane of the table.*

DETECTION OF THE ERROR:—With the alidade placed in any marked position, carefully level the table and note the readings of the levels. Now delicately lift the alidade from the table and replace it, when reversed, in exactly the same position on the board.

The consequent displacement of the bubbles will be twice the error of adjustment of the bubble tubes.

CORRECTION OF THE ERROR:—Bring the bubbles half-way back to the centres of the tubes by raising or lowering either end of the tubes by means of the adjusting screws. Then accurately level the table by means of the plate screws and repeat the operation.

Second Adjustment:—*To make the line of sight coincide with the line of collimation, or to make the line of sight perpendicular to the horizontal axis of the telescope.*

This adjustment is absolutely essential in instruments where the telescope of the alidade may be transited. It is made in the manner already described in the article of this Manual on the adjustments of the Transit. In case the telescope does not transit, it may be reversed by lifting it from its horizontal bearings.

In this connection it should be clearly understood that it is not necessary that the projected line of sight should coincide or be parallel with the fiducial edge of the ruler. It may make any small constant angle, since this only occasions a constant difference of direction of lines on the table as compared with the lines on the ground, and this displacement of the drawing is of no consequence on removal of the drawing from the table.

Third Adjustment:—*To make the line of collimation revolve in a vertical plane.*

The detection and correction of this error are the same as in the case of the third adjustment of the transit instrument.

Instead, however, of doing this adjustment elaborately, it will usually suffice to level the table; sight to a long plumb-line, and note whether in moving the telescope through a vertical arc the cross-threads continually bisect the line; and if they do not, raise or lower one end of the transverse axis until this is accomplished.

Fourth Adjustment:—*To make the axis of the telescope-level parallel to the line of sight.*

This adjustment may be tested by one of the peg-adjustment methods described in treating the adjustments of the transit and the level.

Fifth Adjustment:—*To make the vertical arc read zero when the telescope-level reads zero.*

This adjustment assumes that when the level reads zero, the line of sight is horizontal. The error may be noted by simple inspection, and if the vernier cannot be accurately adjusted to a zero reading, it is convenient to record the index error and apply this to readings of vertical angles.

Sixth Adjustment:—*To test the truth of the fiducial edge of the ruler.*

Draw a fine line along the edge of the ruler and then reverse the alidade and replace upon the line. If, now moving the alidade along in the direction of the line, it coincides at every point, the edge is mathematically straight. If not, it will be necessary to have it ground straight by the maker.

QUEEN & Co. deem it important to examine carefully and verify every adjustment before sending out an instrument; and, with careful usage, the adjustments of the Plane Table should require very little attention on the part of the engineer.

THE SOLAR TRANSIT

AND ITS METHOD OF DETERMINING

THE ASTRONOMICAL MERIDIAN.

THE **Solar Attachment** as shown in the accompanying cut consists of a small telescope mounted on a horizontal axis, which rests upon two standards connected to a circular base. This base is the socket of the so-called polar axis, and is attachable at its lower extremity to the horizontal axis of the telescope. The solar telescope is thus capable of being turned on its own horizontal axis and on its polar axis. A small level is applied parallel to the solar telescope. Two pointers are also attached for use as a species of finder, the sun appearing in the field of view of the telescope when the shadow of one of these pointers is thrown on the other. The solar telescope is provided with a right-angled prism for conveniently observing the sun when it is at a considerable altitude. It is, of course, provided with shade glasses for the purpose of reducing the intensity of the solar rays transmitted. The small graduated circle sometimes attached to the polar axis enables the hour angle to be read off. Clamp and tangent are provided both for the vertical and for the hour angle movement.

The Solar Compass is furnished with a special polar axis placed parallel to the plane of the sights and adjustable by means of a graduated arc to the latitude of the observer. Attached to this polar axis is an arm carrying an arc for setting off the declination of the sun, and the line of collimation is determined by a lens at one end of the movable arm and graduated lines on a silver plate at the other end.

The solar compass may be considered to have been displaced by the addition of the solar attachment to the engineer's transit. If, however, any one should still prefer to work with a solar compass, its construction and use may readily be comprehended by one who has mastered the theory of the solar transit. We therefore limit ourselves to a description of the construction and manipulation of the Solar Transit.

The principal object of every solar attachment, whether it be combined with the compass to form the solar compass or with the engineer's transit to form the solar transit, is to enable surveyors to find the direction of the true or astronomical meridian.

In every complete instrument, whether solar compass or solar transit, there are two movements to be accomplished at the same time in order to bring the sun's image into the centre of the field of the solar attachment, and thus also the line of sight of the instrument into the meridian.

These two movements are, first, one of the solar attachment in hour angle, and second, one of the line of sight of the instrument itself in an azimuthal or horizontal direction.

There are in every instrument means for adjusting the instrument to the latitude of the place in order that a true polar axis may be furnished on which to rotate the attachment in hour angle, and means also for adjusting the instrument to the declination of the sun.

The astronomy necessary to an intelligent explanation of the use of the solar transit or of the solar compass as means for finding the true meridian, must now be given in the following brief definitions.

The line ZN in the accompanying figure represents the direction of the plumb-line or vertical line, passing through the eye of the observer at O. Z is the zenith, N is the nadir. Every plane passing through ZN is a *vertical plane*. The planes ZSB and ZEM are vertical planes. The horizon or plane MBL is at right angles to the plumb-line or vertical line ZN.

The Altitude of a star S is the angular distance of the star above the horizon as measured on the vertical circle passing through the star. The altitude of S is the arc BS. *The zenith distance* of a star is the angular distance of the star from the zenith measured on the vertical circle passing through the star. The zenith distance of S is ZS. Altitude + Zenith Distance = 90°.

The Meridian is the vertical circle which passes through the poles of the heavens, and in the figure is the circle $MZPLNP'$.

The Azimuth of a star is the angular distance measured from the south point *M*, on the horizon, eastward to the vertical circle passing through the star. The azimuth of the star *S* is the arc *MB*.

The Polar Axis, *PP*, of the celestial sphere is parallel to the axis of the earth, and the elevation of the north pole, *P*, above the horizon is equal to the latitude of the place. The great circle *EQ*, at right angles to the polar axis, represents the *celestial equator*.

The Hour Circle or **Circle of Declination** of a star is the great circle which passes through the star and is at right angles to the equator. *PSDP'* is such a circle of declination.

The Declination of a star is the angular distance either north

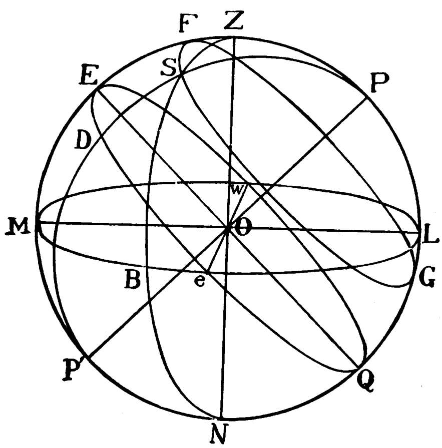


Fig. 33.

or south of the celestial equator as measured on a circle of declination or hour circle of the star. *DS* is the arc measuring the north declination of the star *S*.

The Polar Distance of a star is the complement of the declination, and in the figure is represented by the arc *PS*.

The Hour Angle of a star is the angular distance measured either west or east from the meridian, or the celestial equator, to the circle of declination or hour circle passing through the star. *ED* is the arc measuring the hour angle of the star *S*.

The Latitude of the Place of Observation is represented **in** the figure by the arc, *LP*, or its equal, *EZ*; *the co-latitude* **is** therefore equal to the arc *PZ*, or its equal, *ME*.

ADJUSTMENT AND USE

OF

THE SOLAR TRANSIT.

IT is, in the first place, implied that all the adjustments oi the transit instrument heretofore described shall have been accurately made. In addition to these the two following adjustments are to be accomplished.

First Adjustment:—*To bring the "polar axis" at right angles to the line of sight and to the horizontal axis of the main telescope.*

This may be accomplished by leveling the whole instrument carefully, and after bringing the bubble of each telescope-level to its zero reading so adjust the screws at the base of the "polar axis" that a distant object may be simultaneously bisected in both telescopes.

Another method for accomplishing the same adjustment is to bring the bubble of each telescope-level central as before and then by revolving the solar telescope around its polar axis, note whether its bubble remains central; if so the polar axis is at right angles to the plane containing the line of sight and the horizontal axis of the main telescope. If the bubble of the solar telescope in revolving about the polar axis does not remain central correct half the bubble displacement by means of the adjusting screws at the base of the polar axis, and the other half by revolving the solar telescope on its horizontal axis. Verify by repetition.

The Second Adjustment:—*To bring the line of sight of the solar telescope parallel to the axis of its level.*

This may be effected by bringing both telescopes into the same vertical plane at the same time that ·oth telescopes are carefully made horizontal by means of their respective levels. Then measure the distance between the axes of the two telescopes and note whether the two lines of sight of the instrument include an equal space on a rod set at some distance from the instrument. If they do not, move the cross-hairs of the solar telescope until the space included between the lines of sight of the two telescopes as noted on the rod is the same as the distance between the two axes of the telescopes as previously measured.

METHOD OF USING THE SOLAR TRANSIT.

The central principle to be applied in the use of the solar transit is the following: The attachment's *axis*, *placed at right angles to the sight line of the larger telescope*, can become a *true polar axis* only on two conditions: First, that the sight-line of the larger telescope lie in the plane of the celestial equator, and secondly, that this same sight-line—and hence also the "polar axis"—lie in the meridian.

When the "polar axis" is a true one—namely, lies in the meridian and is also at the elevation above the horizon equal to the latitude, the solar telescope may be revolved upon the polar axis in an east and west, or hour-angle direction and its line of sight thus, and thus only, brought upon the sun.

Conversely, if the proper setting be made, first to the declination of the sun, and secondly to the co-latitude of the place, *ME*, Fig. 33, and the sun then brought into the centre of the field of the small solar telescope by simultaneously moving the main instrument on its vertical axis and revolving the attachment on its "polar axis," this "polar axis," and hence also the line of sight of the main telescope, must have been brought into the meridian.

I. Determination of the Meridian.

First, set the solar telescope to the declination of the sun by the following method. From the *Nautical Almanac* find the declination for the day and hour of the observation and apply the correction for refraction as explained later. Then incline the main telescope *downwards* from a horizontal position through this corrected declination angle if the sun is *north* of the equator, or incline it *upwards* if the sun has a *south* declination.

Clamp the main telescope in this position and then make the solar telescope horizontal by means of its attached level. The solar telescope will thus have been elevated or depressed through an angle from its parallel position with the main telescope equal to the corrected declination angle. Clamp the solar telescope on its horizontal axis.

Secondly, find the co-latitude of the place of observation, if it is not known, by the method given below, and then elevate the line of sight of the main telescope through this angle of the co-latitude by means of the vertical circle of the instrument.

Thirdly, by simultaneously revolving the transit on its vertical axis, and the solar attachment on its polar axis, bring the sun accurately into the centre of the field of the solar telescope, and the line of sight of the main instrument must consequently lie in the plane of the meridian of the place. The direction of this meridian may then be readily staked off on the ground, or the declination of the magnetic needle may at once be read off.

The time of day giving the best results in the use of the solar transit is from 7 to 10 A. M. and from 2 to 5 P. M. Earlier than 7 A. M. and later than 5 P. M. refraction introduces uncertain errors. Between 10 A. M. and 2 P. M. errors in declination or in latitude greatly affect the azimuth. Since the hour angle has different signs before and after noon, the azimuth error also changes sign, and the azimuth error due to errors in declination and in latitude are best eliminated by taking the mean of two observations made at the same hour angle, one before and the other after noon.

II. Determination of the Latitude.

After carefully leveling bring the line of sight of the solar telescope into the same plane with that of the main telescope. Clamp the solar telescope upon its polar axis.

Now set off the sun's declination for noon by the method already described under "Determination of Meridian." Clamp the solar telescope upon its horizontal axis.

Then, about ten minutes before the culmination of the sun, begin observation for latitude by elevating the main telescope and moving it in azimuth until the sun is seen in the solar.

By means of the azimuthal tangent-screw and the vertical tangent-screw of the main telescope keep the sun in the centre of the field of the solar until the sun begins to lessen its altitude.

Read off the altitude of the vertical circle of the instrument and this will be the co-latitude, excepting the correction for refraction and instrumental errors. The correction for refraction for the given altitude may be taken from the "*Table of Mean Refraction*" at the end of this Manual. Since the effect of these instrumental errors on the "determination of the meridian" is eliminated by using the value of the co-latitude directly determined by means of the instrument, it is usually preferable to employ this value.

III. Determination of the Time.

The solar attachment sometimes has a small hour-circle attached to the polar axis, in which case the apparent time may at once be read off as an hour angle of the sun from the meridian. This apparent time must then be corrected by applying the equation of time as given in the *Nautical Almanac*.

If no hour circle is attached the time may be found immediately upon getting the meridian by clamping both the vertical axis of the main telescope and the polar axis of the solar, and then turning each of the telescopes down on their horizontal axes until they are level and measuring the angle between the two directions. This angle converted into time will be the apparent time, which must, as before, be corrected for the equation of time in order to get the mean time.

THE CORRECTIONS FOR HOURLY CHANGE AND REFRACTION.

The hourly change of the declination is readily applied. The solar ephemeris of the *Nautical Almanac* gives the declinations of the sun for Greenwich mean noon of the date. According as we use "Eastern," "Central," "Mountain," or "Western" time, we are approximately 5, 6, 7, or 8 hours west of Greenwich, and the declination of the sun for Greenwich mean noon as given by the ephemeris is therefore the declination at our station for the same date, but either for 7, 6, 5, or 4 o'clock A. M.

Knowing then the declination for a given hour, we find the number of hours elapsing between that hour and the time of the observation, and multiplying the hourly change by this number, apply the result with proper sign to the tabular declination. If the standard time differs considerably from the local time the known longitude of the place west from Greenwich may be used where extreme accuracy is required.

The Refraction Correction, whenever the altitude of the sun is known, can easily be taken from the "*Table of Mean Refraction*," placed among the tables at the end of this Manual. When an observation is to be made out of the meridian, as is usually the case with the solar transit, the refraction correction to the declination varies, not only with the declination but also with the hour angle of the sun and with the latitude of the place. The correction may then readily be computed according to the following formula, whose equivalents are derived *in extenso* in works on practical astronomy. If we let N be an auxiliary angle such that

$$\text{Tan. } N = \text{Cot. } \phi \cos. t,$$

where ϕ is the latitude and t the hour angle, the refraction correction to the declination, C_r, is

$$C_r = 57.7'' \cot. (\delta + N),$$

where δ equals declination, and is plus or minus when the sun is respectively north or south of the equator, and N is determined by the preceding formula. Tables for a day's work at the given latitude of place and for given hour angles and declinations of the sun can be readily prepared in advance by means of the latter formula.

THE STADIA

AND

THE GRADIENTER.

A DISTANCE-MEASURER is an instrument furnished with devices for determining distance from a single point of observation. The Germans call such an instrument a distanzmesser, and the French designate it a telemeter. The term tachymeter has come to be used in Germany and elsewhere for an instrument which, in addition to the features of an engineer's transit, also possesses those of a distance-measurer or telemeter.

Two kinds of distance-measurers are in use. The first class possesses in itself some line which is in fact the base of the triangulation. The military distance-measurers are of this class, and often consist of two telescopes mounted on the same base, and about a meter apart. The second class is characterized by measurements made upon a rod held at the point whose distance is to be determined. This is the only distance-measurer considered in engineering other than military, and we therefore limit ourselves to a review of this class, or to the distance-measurer proper.

The simple basis of all distance measurements with the rod lies in the principle that the same object at a great distance subtends a less angle than when near at hand, or that the same angle intercepts more, say of a rod, in proportion as the distance increases.

The forms of distance-measurers are really quite numerous, if we would include all the European types. It is, however, here only necessary to speak of (1) The Vertical Circle as a distance-measurer; (2) The Screw distance-measurer, or Gradienter, and (3) The Thread distance-measurer, or Stadia wires.

I. **The Vertical Circle** of an engineer's transit or any other means for measuring vertical angles, can be used for determining distance as follows:

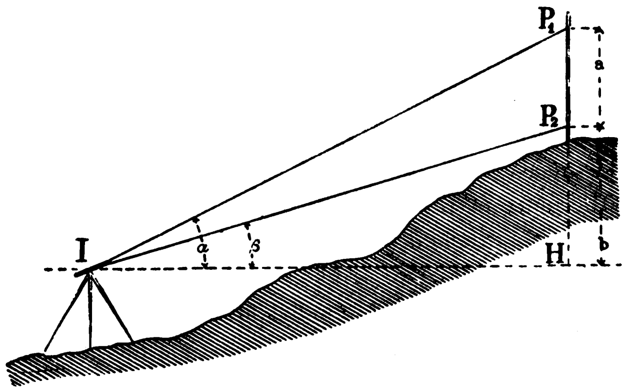


Fig. 34.

Let PL represent a rod, to two points, P_1 and P_2 of which the line of sight is successively directed, and the altitudes α and β, respectively, of the points measured. Let P_1P_2 in Fig. 34 $= a$, and $P_2H = b$, and hence $P_1H = a + b$, and let the distance $IH = D$.

Then we have:

$$a + b = D \tan. \alpha, \text{ and } b = D \tan. \beta,$$

whence,

$$D = \frac{a}{\tan. \alpha - \tan. \beta} \qquad (1)$$

or, for logarithmic calculation,

$$D = \frac{a \cos. \alpha \cos. \beta}{\sin. (\alpha - \beta)} \qquad (2)$$

Formulæ (1) and (2) permit the distance to be computed in terms of an intercepted length on the rod, and of two measured angles.

Incidentally it lies very near to call attention to the fact that if heights instead of distances are required, the following formulæ result as convenient for logarithmic calculation:

$$b = \frac{a \cos. \alpha \sin. \beta}{\sin. (\alpha - \beta)} \qquad (3)$$

$$a + b = \frac{a \sin. \alpha \cos.}{\sin. (\alpha - \beta)} \qquad (4)$$

These formulæ possess, as suggested by Dr. Jordan, some decided advantages as a rapid means of leveling over a rough country, where the computations become a secondary matter.

THE GRADIENTER.

II. **The Gradienter** is next to be described as a means for distance-measuring. It consists of a finely-cut screw, which takes the place of the vertical tangent screw, and moves the clamping-arm attached to the horizontal axis. It acts against a strong spring, so as to produce positive motion of the arm in either direction. The screw has attached to it a graduated silvered head with fifty equal divisions. Parallel to the screw there is attached a graduated scale, which indicates the complete revolutions of the screw. The whole revolutions of the screw are thus read off on the parallel scale, and the parts of a turn on the graduated head.

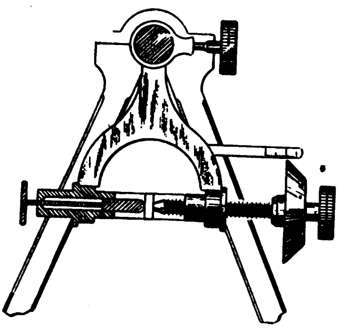


Fig. 35.

The distance between the threads of this screw is such that a single revolution causes the horizontal cross-hair of the telescope to appear to move over .01 foot of the rod for one division of the graduated head when the rod is at a distance of 100 feet from the instrument.

This screw has two chief uses, namely: (1) that of establishing grades, and (2) that of measuring distances. Grades may be laid off by first taking the reading of the gradienter when the telescope is level, and then allowing 1 foot per 100 for each division of the graduated head, set off to the desired grade. For instance, to set off a grade of 3.45 feet per 100 feet, it is necessary to move the gradienter 3.45 revolutions of the screw.

A grade may be measured by finding the reading of the gradienter when the telescope is level, and then turning the graduated head until the line of sight points in the proper direction, read the number of revolutions and fraction of a revolution, and this number will be the grade in feet per hundred.

Distances may be measured either (1) by observing the distance on the graduated rod passed over by one revolution of the screw, or (2) by taking an assumed length on the rod and finding the difference of readings for this length. In the latter method, 100 times the assumed length on the rod divided by the difference of readings equals the distance away of the rod.

GRADIENTER WITH LINE OF SIGHT INCLINED.

It is assumed that the rod is always to be held vertically. The use of the rod at right angles to the line of sight is considered to introduce additional trouble and error.

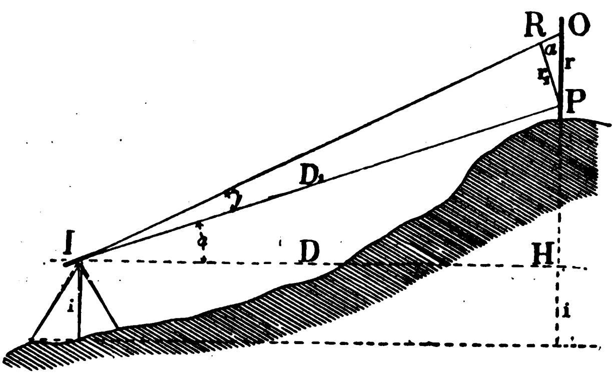


Fig. 36.

The theory of the use of the gradienter for inclined sighting may be readily inferred from Fig. 36:

Let $IH = D =$ Horizontal distance of the point.

$IP = D_1 =$ Direct distance of the point.

$PO = r =$ Length of the vertical rod included by the angle γ.

$PR = r_1 =$ Length of inclined rod included by the angle γ.

Then $D \tan. (\alpha + \gamma) = D \tan. \alpha + r.$ (1)

$$\text{or } D = \frac{r}{\tan. (\alpha + \gamma) - \tan. \alpha} \qquad (2)$$

whence, by development and transformation,

$$D = r\,(\cot.\gamma\cos.^2 a - \sin.a\cos.a) \qquad (3)$$

and, finally, $D = r\,(\cot.\gamma\cos.^2 a - \tfrac{1}{2}\sin.^2 a)$ (4)

Dividing (3) by cos. a we get

$$D_1 = r\,(\cot.\gamma\cos.a - \sin.a) \qquad (5)$$

If, in the second terms of equations (4) and (5) we add and subtract $r\cot.\gamma$, we get the following forms, which, involving only the sine, are adapted to accurate computation :

$$D = r\cot.\gamma - r\,(\cot.\gamma\sin.^2 a + \tfrac{1}{2}\sin.^2 a) \qquad (6)$$

$$D_1 = r\cot.\gamma - r\,(\cot.\gamma\, 2\sin.^2 \tfrac{1}{2} a + \sin.a) \qquad (7)$$

The latter formulæ (6) and (7), although frequently used, do not give the tabular factors in quite as convenient a form as formulæ (4) and (5).

If we let $\cot.\gamma = 100$, the value usually adopted in QUEEN & Co.'s gradienters, and also let $100\cos.^2 a - \tfrac{1}{2}\sin.2a = F$ and $100\cos.a - \sin.a = F_1$, the formulæ (4) and (5) assume the form

$$D = r\,F$$
$$D_1 = r\,F_1$$

that is, simple multiplication of the difference of two readings on the rod, r, by the proper factor, gives either the horizontal distance, or the direct distance, as desired. The values of F and F_1 are given in *The Gradienter Table* at the end of this Manual.

THE STADIA METHOD.

III. **The Stadia wires**, so-called, are inserted in the common focus of the objective and eye-piece. The accompanying figure will show the arrangement of the wires, the three horizontal being used for stadia purposes. The distance between the central and lower or upper one may sometimes be conveniently used instead of the distance between the upper and lower.

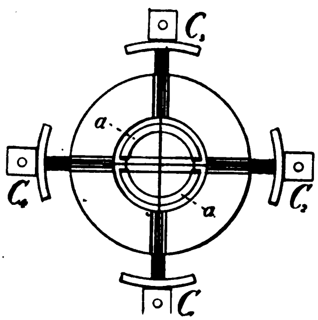


Fig. 37.

In many instances the wires are made adjustable so that they may be set for a distance of a hundred feet from the front focus of the objective. In QUEEN & Co.'s instruments the upper and lower wires are simultaneously adjustable from the central wire by means of the movable pieces marked *a a* in the figure.

THE OPTICAL THEORY OF THE STADIA.

If a Ramsden's ocular or its equivalent is used, the relations between the factors may be diagrammatically represented by the accompanying figure in which O represents the objective of the telescope, E the eye-piece, w the interval between the wires, r the length intercepted on the rod by the wires, f

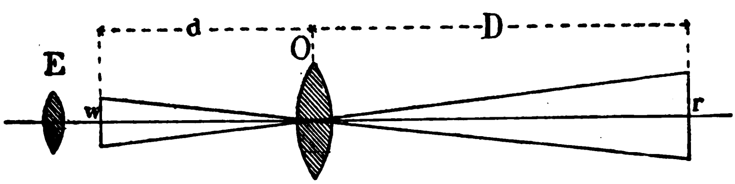


Fig. 38.

the focal length of the object glass, D_o the distance of the rod from the objective, D_f the distance of the rod from a point in front of the object glass equal to the focal length f, d the distance of the wires from the objective. Then from the principles of optics we have:

$$\frac{1}{f} = \frac{1}{d} + \frac{1}{D_o} \qquad (1)$$

and from the figure we have by similar triangles:

$$\frac{w}{d}=\frac{r}{D_o} \tag{2}$$

From the equations (1) and (2) we readily derive the following:

$$D_o-f=\frac{f}{w}r \tag{3}$$

$$\text{or} \quad D_f=\frac{f}{w}r \,.$$

Accordingly D_f, or the distance of the rod from the front focus is proportional to the length, r, intercepted on the rod. It is to be particularly noted that this distance D_f and no other is the one to which the intercepted rod readings, r, are proportional.

It is not worth while here to indicate the special modifications of this simple theory, necessary to adapt it to the cases of the Huyghenian eye-piece, or that of the Porro eye-piece, the latter having been specially designed to make the intercept on the rod proportional to the distance of the rod as measured from the *centre* of the instrument.

If now we let D_c equal the distance of the stadia rod from the centre of the instrument and δ equal the distance of the objective from the centre of the instrument when the telescope is focused for the average of distances, we have:

$$D_c=D_o+\delta,$$

and inserting the value of D_o from equation (3), we have:

$$D_c=f+\delta+\frac{f}{w}r \tag{4}$$

where $f+\delta$ is a constant peculiar to the particular instrument. Therefore, letting $c=f+\delta$,

$$D_c=c+\frac{f}{w}r \tag{5}$$

Further $\frac{f}{w}$ is the coefficient of the instrument depending upon the focal length of the objective and the distance apart of the wires, and therefore letting $K = \frac{f}{w}$, equation (5) now becomes,

$$D_c = c + Kr \tag{6}$$

whence $$D - c = Kr, \text{ and } K = \frac{D_c - c}{r} \tag{7}$$

PRACTICAL DETERMINATION OF THE STADIA CO-EFFICIENT.

As a practical illustration of the formulæ last found, the following example is added:

Determine $c = f + \delta$ by actual measurement of f and of δ. Let, for example, $c = 1.5$ feet. Then measure 1.5 feet from the plumb-line, depending from centre of instrument, and mark it by a stake. This stake will be f in front of the objective. Call this point so marked A. From A measure and stake off the 50 foot point, the 100 foot point, 150 foot point, 200, 250, etc., to 500 or 1,000. D_c being the whole distance from centre of instrument, and c the distance of stake A, each of the measured distances 50 feet, 100 feet, etc., beyond A represents $D_c - c$ in formula (5), while r represents the particular rod reading for each case. The following represents a number of rod readings at $D_c - c$ distances. Five independent readings are taken for each point:

$D_c - c$ Feet.	Rod Readings. (1)	(2)	(3)	(4)	(5)	Mean R. Feet.	$\frac{D_c - c}{r}$
50	0.501	0.501	0.501	0.502	0.500	0.5010	99.804
100	1.000	1.000	1.000	1.001	1.002	1.0006	99.940
150	1.501	1.503	1.501	1.500	1.502	1.5014	99.907
200	2.005	2.007	2.002	2.005	2.005	2.0048	99 761
							4)399.412
							99.853 = K

Practically, 99.85 = K.

In the QUEEN & Co. instruments K is usually made equal to 100. Since this factor K, multiplied into r, gives the D, distance and not the D_e distance desired, the following method of adjusting the wires may sometimes be advantageously adopted. The formula (6) may be written in the form:

$$D = \left(\frac{c}{r} + K\right) r$$

Now if $\frac{c}{r} + K$ be made equal to 100, the readings of the rod mentally multiplied by 100, would give the distance from the centre of the instrument. Accordingly we must take, $K = 100 - \frac{c}{r}.$ For example let $r = 1.5$ feet corresponding to 150 feet as the average of distances it is desired to measure. Then $K = 100 - \frac{1.5}{1.5} = 99$, and $D_c = 100r$, as desired.

STADIA WITH INCLINED LINE OF SIGHT.

The use of the stadia, as thus far explained, is adapted only to horizontal sighting. If the line of sight is inclined to the horizon, the rod-reading becomes greater, and varies with the inclination. The general formulæ for any case may be derived from the accompanying figure, in which a represents the angle of elevation or depression, r the intercepted portion of the rod when held vertical; and hence, r cos. a the intercepted portion

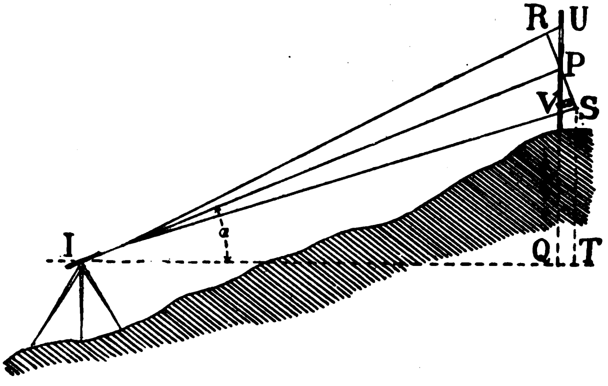


Fig. 39.

of the rod when held at right angles to the direction of the line of sight. IP or direct D_c, equals the direct distance, and

IQ, or horizontal D_c, equals the horizontal distance. But, evidently, for direct distance from the front focus we have:

$$D_f = Kr \cos. a$$

Whence,

$$\text{Direct Distance} = IP = c + Kr \cos. a \qquad (8)$$

$$\text{Horizontal Distance} = IQ = c \cos. a + Kr \cos.^2 a \qquad (9)$$

and

$$\text{Difference of Level} = PQ = c \sin. a + \tfrac{1}{2} Kr \sin. 2a \qquad (10)$$

These formulæ very closely approximate to the strictly mathematical conditions. A very small error is committed in assuming that $r \cos. a$ represents the intercepted portion of the rod when the rod is held at right angles to the line of sight, since the rod is not within a few minutes of arc of 90° to PR and PS. Again, for IT, the horizontal distance to the foot of the rod, $PS \sin. a$ would have to be added or subtracted, according to the inclination of the rod. But this also is small enough to be omitted in ordinary work. The formulæ (9) and (10) are the practical general formulæ for the stadia, giving respectively the horizontal distance and the difference of level.

The most complete tables adapted to these formulæ are the "*Hülfstafeln für Tachymetrie*," by Dr. W. Jordan. The use of these tables obviates all inconvenient arithmetical operations or the study of complicated reduction diagrams; and the heights and distances can, for ordinary accuracy, be directly taken from the tables, without interpolation. QUEEN & Co. furnish a special translation of the introduction to this work, and an adaptation of the tables to convenient use with any of their instruments.

GRADIENTER TABLE.

Angle of Elevation, a	$100 \cos.^2 a - \frac{1}{2} \sin. 2a$ or, Factor, F, for Horizontal Distance.	$100 \cos. a - \sin. a$ or, Factor F_1, for Direct Distance.	Angle of Elevation, a	$100 \cos.^2 a - \frac{1}{2} \sin. 2a$ or, Factor, F, for Horizontal Distance.	$100 \cos. a - \sin. a$ or, Factor, F_1, for Direct Distance.
° ′			° ′		
00 00	100.00	100.00	15 00	93.05	96.33
0 30	99.98	99.99	15 30	92.60	96.09
1 00	99.95	99.97	16 00	92.14	95 85
1 30	99.90	99.94	16 30	91.66	95 60
2 00	99.84	99.90	17 00	91.17	95.34
2 30	99.76	99.86	17 30	90.67	95.07
3 00	99.67	99.81	18 00	90.16	94.80
3 30	99.57	99.75	18 30	89.63	94.51
4 00	99.44	99 69	19 00	89.09	94 23
4 30	99.21	99.61	19 30	88.54	93.93
5 00	99.15	99.53	20 00	87.98	93.63
5 30	98.98	99.44	20 30	87.42	93 32
6 00	98.80	99.35	21 00	86.82	93.00
6 30	98.60	99.24	21 30	86.22	92.67
7 00	98.39	99.13	22 00	85.62	92.34
7 30	98.16	99.01	22 30	85.00	92.00
8 00	97.93	98.89	23 00	84.37	91.66
8 30	97.67	98.75	23 30	83.73	91.31
9 00	97.40	98.61	24 00	83 08	90.95
9 30	97.11	98.46	24 30	82.43	90.58
10 00	96.81	98.31	25 00	81.76	90.21
10 30	96.50	98.14	25 30	81.08	89.83
11 00	96.17	97.97	26 00	80.39	89.44
11 30	95.83	97 79	26 30	79.69	89.05
12 00	95.47	97.61	27 00	78.98	88.65
12 30	95.10	97.41	27 30	78.27	88.24
13 00	94.72	97.21	28 00	77.54	87.82
13 30	94.32	97.00	28 30	76.81	87.40
14 00	93.93	96.79	29 00	76 07	86.98
14 30	93 49	96.56	29 30	75.32	86.54
15 00	93.05	96.33	30 00	74.56	86.10

NOTE.—The difference of the rod-readings r, for 100 divisions of the graduated head of the Gradienter screw, multiplied by F, gives the horizontal distance of the rod from the horizontal axis of the telescope; the same r, multiplied by F_1 gives the direct distance.

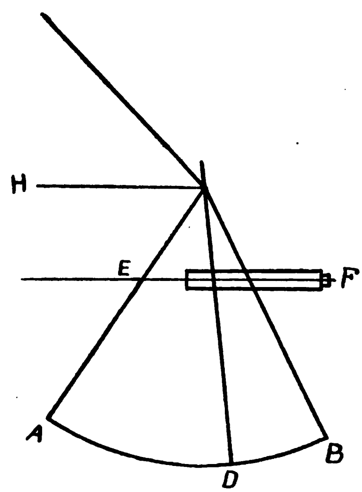
TABLE OF MEAN REFRACTION.

Temperature, 50° F. Barometric Pressure Reduced to 50° F., 30 in.

Apparent Altitude.	Mean Refraction.	Apparent Altitude.	Mean Refraction.	Apparent Altitude.	Mean Refraction.
0° 00′′	33′ 47.9′′	16° 00′	3′ 20.8′′	41° 00′	1′ 07.0′′
1 00	24 22.3	17 00	3 08.6	42 00	1 04.7
2 00	18 23.1	18 00	2 57.7	43 00	1 02.5
3 00	14 28.7	19 00	2 47.8	44 00	1 00.3
4 00	11 48.8	20 00	2 38.9	45 00	0 58.3
5 00	9 54.8	21 00	2 30.8	46 00	0 56.3
6 00	8 30.3	22 00	2 23.4	48 00	0 52.5
6 30	7 55.9	23 00	2 16.6	50 00	0 48.9
7 00	7 25.6	24 00	2 10.3	52 00	0 45.5
7 30	6 58.7	25 00	2 04.5	54 00	0 42.3
8 00	6 34.7	26 00	1 59.0	56 00	0 39.3
8 30	6 13.2	27 00	1 54.0	58 00	0 36.4
9 00	5 53.7	28 00	1 49.3	60 00	0 33.7
9 30	5 36.0	29 00	1 44.8	62 00	0 31.0
10 00	5 20.0	30 00	1 40.7	64 00	0 28.4
10 30	5 05.4	31 00	1 36.8	66 00	0 26.0
11 00	4 51.9	32 00	1 33.1	69 00	0 22.4
11 30	4 39.5	33 00	1 29.6	72 00	0 19.0
12 00	4 28.1	34 00	1 26.2	75 00	0 15.6
12 30	4 17.5	35 00	1 23.1	78 00	0 12.4
13 00	4 07.7	36 00	1 20.1	80 00	0 10 3
13 30	3 58.5	37 00	1 17.2	83 00	0 07.2
14 00	3 50.0	38 00	1 14.5	86 00	0 04.1
14 30	3 42.0	39 00	1 11 9	89 00	0 01 0
15 00	3 34.4	40 00	1 09.4	90 00	0 00.0

THE SEXTANT.

THE Cut shows the details of construction of the Sextant. *ABC* is a light frame work of brass in the shape of a sector of 60 degrees, the limb *AB* having a graduated arc of silver (in some cases of gold) inlaid in the brass. It is held in the hand by a small handle at the back, either vertically to measure the altitude of an object, or in the plane passing through two objects, the angular distance of which is to be found. *CD* is a radius movable around *C*, where a small plain mirror of silvered plate glass is fixed perpendicular to the plane of the sextant and in the line *CD*. At *D* is a vernier read through a small lense, also a clamp and a tangent screw which enable the observer to give the arm *CD* a very slow motion within certain limits. At *E* is another mirror "the horizon glass." Also, perpendicular to the plane of the sextant and parallel to *CD*, *F* is a small telescope fixed across *CB*, parallel to the plane *CAB*, and pointed to the mirror *E*. Dark glasses can be placed outside *E* and between *E* and *C* when observing the sun.



As only the lower half of *E* is silvered, the observer can see the horizon in the telescope through the unsilvered half, while the light from the sun on a start *S* may be reflected from the "index glass" *C* to the silvered half of *E* and thence through *F* to the observer's eye. If *CD* has been moved so as to make the image of a star or of the limb of the sun coincide with that of the horizon, it is easy to see that the angle *SCH* (the altitude of the star or solar limb) is equal to twice the angle *BCD*.

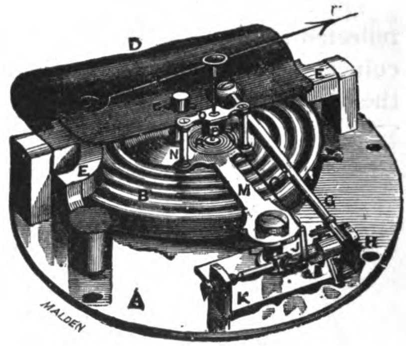
The limb *AB* is graduated so as to avoid the necessity of doubling the measured angle, a space marked as a degree on the limb, being in reality only 30′. The vernier should point to 0° 0′ 0″ when the two mirrors are parallel, or, in other words, when the direct and reflected images of a very distant object are seen to coincide.

When the sextant is used on land an artificial horizon is required. This is obtained by employing a basin of mercury protected by a roof of plate glass with perfectly parallel faces, which is levelled on three screws by spirit levels.

The telescope being directed to the image, the celestial object reflected from the artificial horizon and this image is made to coincide with that reflected from the object glass. In this case the angle *BCD* will be double the altitude of the star.

THE ANEROID BAROMETER.

THE word *Aneroid*, from the Greek privative *a*, and *neros* wet, suggests the character of this instrument, whose indications are obtained by the pressure of the atmosphere upon a delicate metal box, exhausted of air, instead of, as in the Mecurial Barometer, by the height of a fluid column.



Invented about the beginning of the present century, it was not until about 1848 that the difficulties involved in the construction of such an instrument were overcome, and the present serviceable form devised by M. Vidie.

Since that time, the Aneroid has continued substantially the same; improvements being rather in the direction of more perfect workmanship in its parts, and in the more perfect adaptation of its metals, than in any change of form.

As shown in the illustration, the Aneroid consists of a flat cylindrical vacuum box, the upper surface of which is corrugated, in order that it may yield more readily to external pressure. The lower surface of the vacuum chamber is firmly fixed at the center to a strong foundation plate, whilst at the center of the upper surface is a metallic pillar *C*, which acts upon a powerful steel spring *D*.

The varying atmospheric pressure causes the surface of the vacuum chamber to rise and fall; these movements are transmitted to the spring, and thence by two levers, *G* and *H*, to a metallic axis *I*. From the latter rises a lever *J*, to whose extremity a chain *Q* is attached, which turns a drum, the axis of which bears the index needle. A firm spiral spring keeps the chain constantly in proper tension. By this arrangement of multiplying levers, a very small movement of the surface of the vacuum chamber causes a large deviation of the needle; $\frac{1}{200}$ of an inch causing it to move through a space of 3 inches.

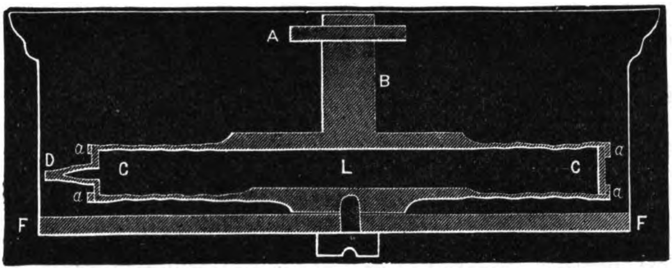


Fig. A.

Figure A shows a section of the vacuum box; *B* being the pillar to which the main-spring is attached; *L* the attachment to foundation plate; *D* the tube through which the box is exhausted, and *a*, *a*, *a*, *a*, the overlapping thin German silver corrugated plates.

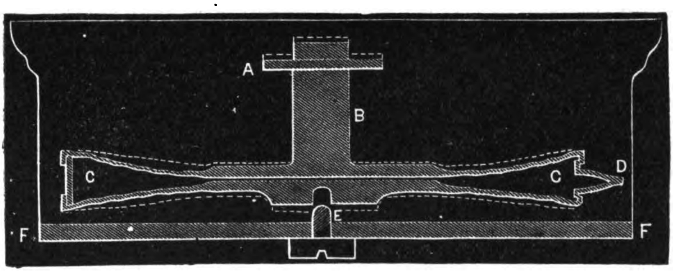


Fig. B.

In figure B, we have the chamber exhausted of air; the dotted lines showing the tension to which the instrument is brought, and enabling it to be understood how readily the instrument may respond to the varying atmospheric pressure. Compensation for temperature is effected, as in chronometers, by an adjustment of brass and steel in the main lever, by whose unequal expansion and contraction the liability to error from change of temperature is overcome.

The dial is graduated arbitrarily to correspond with the mercurial barometer, after the instrument is tested under the air-pump to find the range. It is apparent, therefore, that the Aneroid can never be used as an independent standard, but must be frequently compared with the mecurial barometer.

When so compared, however, and adjusted by a Mercurial Standard, the Aneroid possesses several advantages over the former. It is extremely portable and can be carried in any way, or subjected to any motion without danger of disturbance of its indications. It is not at all liable to get out of order—is not easily broken, and lastly, *it is very much more sensitive* than the Mecurial Barometer.

The late Admiral Fitzroy, Mr. Glaisher the æronaut, and many other authorities, testify to the extreme sensibility of the Aneroid; the former particularly noting "its quickness in showing the variations of atmospheric pressure." Even in observatories, therefore, where Mercurial Standards are in use, the Aneroid is most valuable in its capacity of giving earlier indications than can be obtained from the more sluggish mercurial column.

To the seaman, who has often extreme difficulty in using the barometer from the pumping of the mercury caused by the vessel's motion, the Aneroid is indispensable; and from its greater delicacy, he can often prepare for a change in weather a considerable time before the Mercurial Barometer gives evidence of an impending storm.

The value of the Aneroid in ascertaining differences of altitude, is obvious, and of this we speak more fully in the succeeding pages.

THE USE OF THE ANEROID FOR ALTITUDE.

From its portability, sensitiveness, and the ease with which approximate altitudes may be ascertained, the Aneroid Barometer is very valuable to the engineer. In preliminary surveys and reconnoissances it has been found extremely useful, and for these purposes it is largely employed. Carrying one of these little instruments, the size of which need not exceed two or three inches in diameter, the engineer, riding rapidly over a country, can speedily and with ease procure the data for the determination of the line of a survey. Holding an Aneroid in his hand, the traveller seated in the railroad car, can mark the changes of elevation as his train moves; the mountain climber can note, step by step, his gain in altitude; and the miner, with the new mining Aneroid, can measure his descent in single feet.

We have elsewhere explained the principle of the Aneroid, and the manner in which its indications are obtained, and have referred to the necessity of accurate workmanship in its construction, and of intelligence and skill in its examination and adjustment. For hypsometrical work, it is especially important that the Aneroid should be absolutely accurate; that its compensation for effect of temperature on the metallic works be perfect, and that its indications should be identical with those of the mercurial column. The importance of compensation, particularly for Pocket Aneroids, is evident when it is remembered that the change from a room to the external atmosphere may frequently involve a difference in temperature of from 30° to 50° F., a difference, which, without proper compensation, may move the needle through a space equal to one hundred or more feet. It is also neccssary that the Aneroid be tested for correspondence with the mercurial column. If the scale of the Aneroid be accurately divided and in accord with the instrument itself, the needle will move tenth by tenth, with the mercurial column, in perfect coincidence.

There are many good-working Aneroids in use, which do not thus correspond with the Mercurial Barometer, and whose constants of error being unknown, give inaccurate results. Such barometers could be used with satisfaction if their corrections were known; and all Aneroids require to be periodically tested—adjusted to accord with the Standard Mercurial Barometer, and their corrections, if any are necessary, ascertained.

CORRECTIONS DEPENDENT UPON PHYSICAL LAWS.

In strictly accurate observations, it is necessary that the Aneroid, as well as the Mercurial Barometer, should be used with formulas for various corrections. The corrections, however, for gravity, for temperature of the mercury, and for capillary attraction are of course unnecessary with the Aneroid; and, indeed, for all ordinary work, the only correction required is that for the temperature of the atmosphere, which need only be considered when the temperature is above or below 50° F.

It must of course be remembered, in using a barometer of any kind for the purpose of ascertaining the altitude of a place, that while the normal barometric pressure is assumed to be represented by a mercurial column of about 30 inches at sea-level, it is but occasionally that this is actually attained. The variations of atmospheric pressure are continual, the periodic fluctuations being considerable, and the nonperiodic oscillations so great and so irregular, that it is only by taking the mean of a long series of observations that the periodical variations can be ascertained. It follows, therefore, that a single reading of the barometer can never, save by the rarest chance, indicate an absolute elevation.

Aneroids for altitudes may be used with the ordinary scale of inches and tenths, or, as they are now more usually arranged, with a graduated circle of feet in addition.

TO MEASURE ALTITUDES WITH ANEROID BAROMETER,

Without Altitude Scale.

Roughly speaking, the barometer falls one inch for every 900 feet of ascent; or at mean atmospheric pressure in this latitude.

Above sea-level	
917 feet, the barometer falls	·1 inch.
1860 " " " "	2 inches.
2830 " " " "	3 "
3830 " " " "	4 "
4861 " " " "	5 "

TO FIND THE RELATIVE HEIGHT OF TWO GIVEN PLACES.

Take a reading of the Aneroid at first station; subtract from this the reading at the second station. The product multiplied by 9 will give the difference of altitude in feet, thus:

First Station, ...	30 20
Second Station, ...	29 99
	21
	9
Difference of altitude, . . .	189 feet.

This under ordinary pressures and with a temperature about 50° F. will give good results. If the temperature is over 70° F., multiply by 10.

The table prepared by Mr. Symons is more strictly accurate:

Mean Temperature.	30°	40°	50°	60°	70°	80°
Mean pressure, 27 inches.	9.7	9.9	10.1	10.3	10.5	10.8
" " 28 "	9.3	9.5	9.8	10.0	10.2	10.4
" " 29 "	9.0	9.2	9.4	9.6	9.8	10.
" " 30 "	8.7	8.9	9.1	9.3	9.5	9.7

The best results may, however, be obtained by the use of the table prepared by Sir G. Airy, late Astronomer-Royal of England.

TO USE AIRY'S TABLE,

With mean temperature at 50°.

Take the reading in inches of the barometer scale, at the lower and upper stations. Find in the table the heights in feet, corresponding to the barometer readings. Subtract them and the remainder will be the height required.

When the mean temperature is above or below 50° F., the following correction must be applied: add together the temperature of the upper and lower stations. If the sum is greater than 100° F., *increase* the height by $\frac{1}{1000}$th part for every degree of the excess above 100°; if the sum is less than 100°, *diminish* the height by $\frac{1}{1000}$th part for every degree less than 100°. The complete formula is:

$$D=(H-h)\left(1+\frac{T+t-100}{1000}\right)$$

T and t are the observed temperatures; H and h are the heights in feet taken from the table.

AIRY'S TABLE.

Arranged for temperature of 50° F.

Height in feet.	Aneroid or Corrected Barometer.	Height in feet.	Aneroid or Corrected Barometer.	Height in feet.	Aneroid or Corrected Barometer.	Height in feet.	Aneroid or Corrected Barometer.
ft.	in.	ft.	in.	ft.	in.	ft.	in.
0	31·000	1850	28·966	3700	27·065	5550	25·289
50	30·943	1900	28·913	3750	27·015	5600	25·242
100	30·886	1950	28·860	3800	26·966	5650	25·196
150	30·830	2000	28·807	3850	26·916	5700	25·150
200	30·773	2050	28·754	3900	26·867	5750	25·104
250	30·717	2100	28·701	3950	26·818	5800	25·058
300	30·661	2150	28·649	4000	26·769	5850	25·012
350	30·604	2200	28·596	4050	26·720	5900	24·966
400	30·548	2250	28·544	4100	26·671	5950	24·920
450	30·492	2300	28·491	4150	26·622	6000	24·875
500	30·436	2350	28·439	4200	26·573	6050	24·829
550	30·381	2400	28·387	4250	26·524	6100	24·784
600	30·325	2450	28·335	4300	26·476	6150	24·738
650	30·269	2500	28·283	4350	26·427	6200	24·693
700	30·214	2550	28·231	4400	26·379	6250	24·648
750	30·159	2600	28·180	4450	26·330	6300	24·602
800	30·103	2650	28·128	4500	26·282	6350	24·557
850	30·048	2700	28·076	4550	26·234	6400	24·512
900	29·993	2750	28·025	4600	26·186	6450	24·467
950	29·938	2800	27·973	4650	26·138	6500	24·423
1000	29·883	2850	27·922	4700	26·090	6550	24·378
1050	29·828	2900	27·871	4750	26·042	6600	24·333
1100	29·774	2950	27·820	4800	25·994	6650	24·288
1150	29·719	3000	27·769	4850	25·947	6700	24·244
1200	29·665	3050	27·718	4900	25·899	6750	24·200
1250	29·610	3100	27·667	4950	25·852	6800	24·155
1300	29·556	3150	27·616	5000	25·804	6850	24·111
1350	29·502	3200	27·566	5050	25·757	6900	24·067
1400	29·448	3250	27·515	5100	25·710	6950	24·023
1450	29·394	3300	27·465	5150	25·663	7000	23·979
1500	29·340	3350	27·415	5200	25·616	7050	23·935
1550	29·286	3400	27·364	5250	25·569	7100	23·891
1600	29·233	3450	27·314	5300	25·522	7150	23·847
1650	29·179	3500	27·264	5350	25·475	7200	23·803
1700	29·126	3550	27·214	5400	25·428	7250	23·760
1750	29·072	3600	27·164	5450	25·382	7300	23·716
1800	29·019	3650	27·115	5500	25·335	7350	23·673
1850	28·966	3700	27·065	5550	25·289	7400	23·629

AIRY'S TABLE—*Continued.*

Height in feet.	Aneroid or Corrected Barometer.	Height in feet.	Aneroid or Corrected Barometer.	Height in feet.	Aneroid or Corrected Barometer.	Height in feet.	Aneroid or Corrected Barometer.
ft.	in.	ft.	in.	ft.	in.	ft.	in.
7400	23·629	8550	22·653	9700	21·717	10850	20·820
7450	23·586	8600	22·611	9750	21·677	10900	20·782
7500	23·543	8650	22·570	9800	21·638	10950	20·744
7550	23·500	8700	22·529	9850	21·598	11000	20·706
7600	23·457	8750	22·487	9900	21·558	11050	20·668
7650	23·414	8800	22·446	9950	21·519	11100	20·630
7700	23·371	8850	22·405	10000	21·479	11150	20·592
7750	23·328	8900	22·364	10050	21·440	11200	20·554
7800	23·285	8950	22·323	10100	21·401	11250	20·517
7850	23·242	9000	22·282	10150	21·361	11300	20·479
7900	23·200	9050	22·241	10200	21·322	11350	20·441
7950	23·157	9100	22·200	10250	21·283	11400	20·404
8000	23·115	9150	22·160	10300	21.244	11450	20·367
8050	23·072	9200	22·119	10350	21.205	11500	20·329
8100	23·030	9250	22·079	10400	21.166	11550	20·292
8150	22·988	9300	22·038	10450	21.128	11600	20·255
8200	22·946	9350	21·998	10500	21.089	11650	20·218
8250	22·904	9400	21·957	10550	21.050	11700	20·181
8300	22·862	9450	21·917	10600	21.012	11750	20·144
8350	22·820	9500	21·877	10650	20.973	11800	20·107
8400	22·778	9550	21·837	10700	20.935	11850	20·070
8450	22·736	9600	21·797	10750	20.896	11900	20·033
8500	22·695	9650	21·757	10800	20.858	11950	19·996
8550	22·653	9700	21·717	10850	20.820	12000	19·959

MOUNTAIN ANEROIDS.

The majority of Mountain Aneroids now have Airy's table engraved around the dial, the circle bearing the scale of feet being generally movable. This movable circle, as its zero can be turned to correspond with the barometer reading for the time, is convenient for approximate work, as the elevation can be read directly off. The barometer scale, however, being a diminishing one, this mode of use would lead to grave inaccuracies. It is better, therefore, that the zero point be set at 31 inches of pressure and the two readings of feet subtracted to get the difference in height.

TO USE THE ANEROID, WITH ALTITUDE SCALE.

Find the height in feet at first station and subtract this from the height in feet at second station. If the mean temperature is greater or less than 50° F., apply correction for temperature as before given.

Example:

Aneroid at Station A,	1,800 feet.	Thermometer,	50°.
" " " B,	800 "	"	70°.

The approximate height is 1,000 feet. The sum of the temperature is 120. A correction of +20 is therefore applied. This is 20 feet.

The difference of elevation is therefore 1,000+20=1,020 feet.

SIZE OF THE ANEROID.

Aneroids are graduated from 3,000 to 20,000 feet, from 1¾ inches diameter to 5 inches diameter. The larger sizes of course permit the use of more open scale, and are consequently more easily read. The smaller sizes are, however, extremely accurate, and their portability is a strong recommendation.

POSITION OF THE ANEROID IN USE.

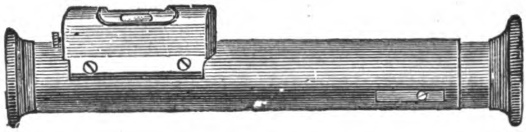
It should be borne in mind that all Aneroids vary in their readings with the position in which they are held, reading somewhat higher in a horizontal position with face up than when vertical. As they are tested and adjusted in a horizontal position, it is better that they should be uniformly read from the horizontal dial.

Before a reading is taken, the face should be tapped slightly with the finger to bring the needle fairly into equilibrium.

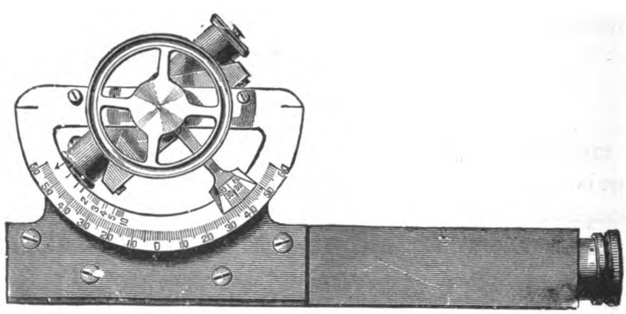
ATMOSPHERIC DISTURBANCE.

As there may be considerable atmospheric variation if any great interval of time elapses between two observations, engineers are now accustomed to use two matched barometers, one of which is kept in camp, where observations are taken at stated intervals, whilst the other is observed at corresponding times in the field. A correction can thus be applied for atmospheric oscillation. Where one barometer only is used, observations may be made repeatedly and the mean taken, or where it is inconvenient to take the higher elevation more than once, the lower reading can be taken *after* as well as before the higher, by which method a partial correction may be obtained.

LOCKE'S HAND LEVEL.



THIS Instrument is made in three form, brass, nickel and German silver. The tube is 6 inches long, having, as shown in illustration, the small level on top and near the object end. There is an opening in the tube beneath, through which the bubble can be seen,and is reflected by a prism immediately under the level. Bothends are closed by disks of plain glass to exclude the dust. There is at the inner end of the sliding eye-tube a semi-circular convex lens which magnifies the level bubble and the cross wires beneath, and allows the object to be clearly seen through the open half of the tube. The cross wire is fastened to a small frame moving in the level tube and adjusted to its place by the small screw shown on the end of the level case. The level of any object in line with the eye of the observer is determined by sighting upon it through the tube, and bringing the bubble of the level into a position where it is bisected by the cross wire.



The Abney Level and Clinometer, as show by the above illustration, combines the features of the Locke's Hand Level, with an excellent clinometer. The arc is divided to 90 degrees each side of zero. When the level bubble is brought to the middle, by setting the vernier arm to zero on the dividing scale, the bubble is seen through the eye piece and the level is ascertained the same as with the Locke's Level. As the main tube is square it can be applied to any surface, the inclination of which is ascertained by bringing the level bubble into the middle and reading off the angle to 5 minutes by the vernier and arc.

The inner and shorter arc indicates the lines of different degrees of slope, the left hand end of the vernier being applied to the lines and the bubble being brought into the middle as usual.

THE ABNEY LEVEL WITH COMPASS.

The attachment of bar needle compass to the regular Abney Level makes the instrument practically a Pocket Autometer. This instrument is sometimes made with Jacob Staff Mountings so that it can be used on a staff.

Directions for use of Abney Level and Clinometer and Abney Level with Compass Attachment.

When the height of any object is required to be taken, a distance should be correctly measured from the object, say 100 feet, this forms the base line, and at which point the observer would stand; then, direct his vision through the tube of the level and elevate it until the highest point of the object is seen bisected by the horizontal edge of the reflector within the tube. While holding it steadily in this position, the spirit level which is attached to the axis of the arc should be turned upon its center until the bubble is seen reflected in the mirror, and also bisected by the horizontal edge of reflector, the alignment is then complete, and the height of object obtained by reading off the index of the arc.

The arc has two graduated scales upon it, one giving the angular measurement by degrees, and subdivided by the vernier division on the index. The other scale is figured one to ten with their subdivisions, representing $\frac{1}{10}$, $\frac{1}{5}$, $\frac{1}{3}$, etc., of the length of the measured base, and is read off by the fiducial edge at the side of the index. If, therefore, the edge coincides with division 4, the height of the object would be $\frac{1}{4}$ of the base line, or 25 feet.

In using the Angle reading scale on arc the following tables may be referred to:

Angle	1°	gradient	1	in	57.	Angle	12°	gradient	1	in	4.7
"	1° 30′	"	1	"	38.	"	14°	"	1	"	4.
"	2°	"	1	"	28.6	"	16°	"	1	"	3.4
"	2° 30′	"	1	"	22.8	"	18°	"	1	"	3.
"	3°	"	1	"	19.	"	20°	"	1	"	2.7
"	3° 30′	"	1	"	16.2	"	22°	"	1	"	2.4
"	4°	"	1	"	14.3	"	24°	"	1	"	2.2
"	4° 30′	"	1	"	12.6	"	26°	"	1	"	2.
"	5°	"	1	"	11.4	"	28°	"	1	"	1.88
"	6°	"	1	"	9.5	"	30°	"	1	"	1.73
"	8°	"	1	"	7.1	"	35°	"	1	"	1.40
"	10°	"	1	"	5.6	"	40°	"	1	"	1.20
						"	45°	"	1	"	1.1

When a slope or gradient is required to be set out to any given angle, the index of arc should be set by reference to the above tables, and the instrument placed upon the object to be inclined; this should then be raised or lowered until the bubble is seen in the center of spirit level, the required gradient being thus given.

CHAINS AND TAPES.

THE **ordinary** Gunter's or Surveyor's Chain consists of 100 pieces of wire called links, bent into rings at the end and connected one to the other by two rings and provided with a tally at the end of every 10 links. A link in measurement includes a ring at each end and is 7.92 long.

The iron chains are made of Nos. 7, 8 and 9 wire, varying from $\frac{5}{32}$ of an inch in diameter to nearly $\frac{1}{8}$ of an inch.

Steel chains are made generally of No. 12 wire, which is about $\frac{7}{64}$ of an inch in diameter.

In the iron chains the rings are oval and are cut square so that when closed the danger of stretching apart and kinking is greatly reduced.

The steel chains are made of the best tempered steel wire with all joints, rings and links brazed which prevents their opening and allowing the chain to lengthen.

The Engineer's Chain is made in the same manner as the Gunter's or Surveyor's Chain of both iron and steel wire, and the difference is that it is 100 feet long, each link being 12 inches in length. It is preferred to the Gunter's or Surveyor's Chain on railroads or canal work as it enables the engineer to work more rapidly and more accurately.

In the chains, when folded up, the links should not be parallel to each other, but should be crossed at such an angle as to cross each other in the middle. This prevents the opening of the links in strapping the chain together.

The handles of all chains are of brass and form part of the end links to which they are connected by a short link and jam-nut, by which the length of the chain is adjusted.

The tallies also are of brass and have 1, 2, 3 or 4 notches as they mark 10, 20, 30 or 40 feet from each end. The 50th link is marked by a round tally to distinguish it from the others.

Chains are often made with steel snaps in the middle and at one handle so that the chain can be separated, and, one handle being removed and transferred to the 49th link, a chain of half the length is obtained.

In using the chain the lengths must be taken from the extreme ends and the marking pins placed on the inside of the handles; it must be drawn straight and taut and carefully examined before each measurement is taken to detect any kink or other cause of inaccuracy.

As all chains will be lengthened more or less after use in the field, it is advisible for the surveyor to carefully mark on a level surface, where there is no danger of its being erased or destroyed, the exact length of the chain when new. By taking this precaution a standard measure is established, so that the chain can be adjusted from time to time and always be used with perfect confidence.

STEEL TAPES.

Steel tapes are now made in any length up to 1000 feet without joint from end to end. The width varies from 1/8 of an inch to 1/2 inch, and in thickness from 1-100 to 4-100 of an inch. For tapes of a length not exceeding 100 feet the general width is 1/4 of an inch and 2-100 of an inch in thickness.

The three finishes generally preferred are the blued, nickel-plated and aluminium plated. The latter has the special advantage of not rusting.

In tapes of over 100 feet in length, the narrow steel ribbon is best as it can be dragged through brush or used in all field work without danger of kinking or breaking.

The divisions of the tapes are generally marked in two ways, viz.: No. 1, the numbers and graduation marks are stamped on a piece of brass which is soldered on the top; the 10ths and 12ths divisions are marked by single rivets; the 1, 5 and 10 foot divisions by a brass strip which is soldered on the top and has the numbers stamped in plain figures. No. 2, the face of the tape is etched with acid, so that the division marks and figures stand out in relief, while the etched surface appears dull. Method No. 2 is generally used in tapes of lengths not over 100 feet, where fine and accurate measurements are required.

LINEN TAPES.

Accurate work cannot be done with this form of tape as it will contract in wet weather and expand in dry, and can be easily lengthened by over-straining. They are, however, useful on inside work or marking measurements with angles, as they are pliable and can be closely fitted into corners.

METALLIC TAPES.

Metallic Tapes possess the advantage over the ordinary linen tapes of having fine brass wire interwoven through their entire length, and are not liable to over-straining, and the danger of contracting and expanding in wet or dry weather to which the linen tapes are subject.

The Cases and Reels on all tapes vary to such an extent that an accurate description would consume a great deal of time and space. Steel, linen and metallic tapes of 100 feet or less are generally put up in leather and nickeled cases as it makes them compact and easily carried in the pocket. Tapes of greater length are invariably put on reels, as they are more easily handled, and the reels being open gives the tape a chance to dry without the danger of rusting, which so frequently occurs with the leather cases.

THE LEVELING ROD.

The Leveling Rod is used to measure the distance between the horizontal line of sight and the bench mark.

There are three general classes, Self-Reading or Speaking, Target or Plain and Metric Rods. The Self-Reading or Speaking Rod has a graduation such that the point on the rod which lies in the line of sight can be easily read with the telescope. With the self-reading rod the only duty of the rod man is to hold the rod in a vertical position. The observer notes and records the readings.

A Target Rod is furnished with a sliding target which is moved in the plane of sight by the rod man in response to signals from the observer and the position accurately read by means of a vernier.

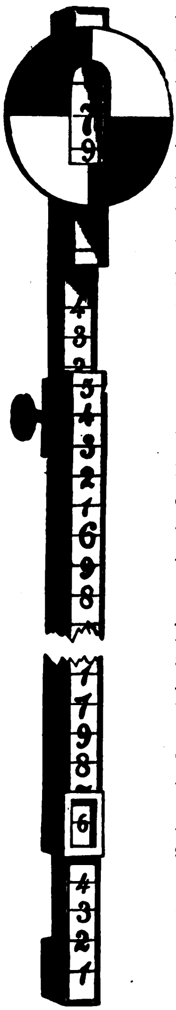
A Metric Rod is similar to the Target Rod, only instead of the graduations reading feet and decimals of a foot as in the above rods, the graduations are in meters and centimeters.

PHILADELPHIA RODS.

These are made in three forms, Self-Reading or Speaking, Target or Plain and Metric Rods as above description.

The rod is made of two strips of Spanish Cedar each ¾ inch thick by 1½ inches wide, and 7 feet long, connected by two metal collars. The upper one has a clamping screw for holding the two parts together when the rod is extended for a greater reading than 7 feet; also is fitted with a vernier or divided scale for taking readings on the double rod.

Both sides of the back strips and one side of the front are recessed $\frac{1}{16}$ of an inch below the edges. These depressed surfaces are painted white and divided into feet, tenths and hundredths of a foot, and the feet figured in red, and tenths in black. All the graduations and figures are stamped in from



steel dies, and hand painted, thus greatly increasing their durability. All the edges of the rod and the corners of the brass mountings are rounded, which makes the handling more comfortable.

The front piece is graduated from the bottom upwards to 7 feet, and the front surface of the rear half from 7 to 13 feet; also from the bottom upwards, so that when the rod is extended to full length it becomes a self-reading rod 13 feet long. The back surface of the rear half is figured from 7 to 13 feet, reading from the top down.

When used as a target rod the target carries a scale (not a vernier) $\frac{1}{10}$ of a foot, being divided to hundredths and half-hundredths of a foot, by which the rod is read to half-hundredths of a foot. In taking readings of less than 7 feet the target is moved up and down the front piece, and for readings greater than 7 feet the target is set at 7 feet and the back piece is run up, the readings being obtained by a scale attached to the upper collar of the front piece.

When used as a self-reading rod the 10ths of feet are subdivided on the face of the rod into 100ths. The target then carries a vernier graduated 10 spaces, which equal 9 on the rod, so that readings can be taken to 100ths of a foot by the rod man, or if read direct, from the transit, the observer notes from the telescope the point of the rod covered by the cross hair.

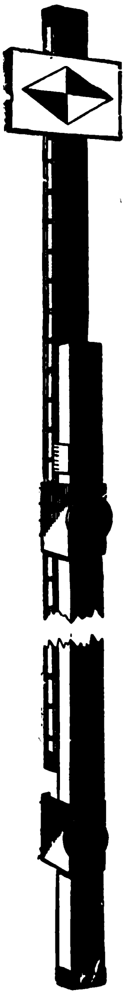
NEW YORK ROD.

This rod consists of two pieces of maple or satinwood sliding one upon the other, the same end always held on the ground, and the graduations starting from that point.

The graduations are made to tenths and hundredths of a foot, the tenth figures being marked with a black figure and the feet with a larger red figure. The front piece carries a target sliding in a groove. The target has a vernier so that readings can be made to thousandths of a foot. The front surface reads to 6.5 feet. When a greater height is required the horizontal line of the target is fixed at 6.5 feet, and the upper half of the rod carrying the target, is run upward, and the readings are then obtained by a vernier on the side of the lower half of the rod. When the rod is extended it is held in place by means of a clamp at the lower end of the upper piece.

This rod is frequently made in three and sometimes in four pieces. The special advantage of these forms is that it gives a rod of greater length, at the same time making it more compact and portable.

In both three and four piece rods, the divisions, verniers and reading are the same as those on the two part rod. The three piece rod is 5 feet long when closed and 14 feet long when fully extended. The four piece rod when closed is 5 feet long and when extended to its full lengts is 16 feet long.

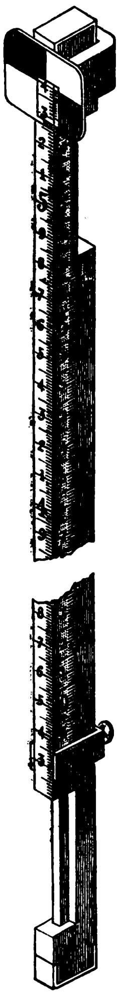


BOSTON ROD.

This rod is formed of two pieces of mahogany, each about six feet long and sliding easily by each other in either direction. One piece is furnished with a clamp and small vernier at each end; the other or front piece carries the target, and has on each edge an inlaid strip of satinwood upon which divisions of feet, tenths and hundredths are marked and figured.

The target is a rectangle of wood fastened on the front half, and is painted red and white, its middle line being just three-tenths of a foot from the end of the rod. Each tenth of the rod is figured decimally in three figures, or to hundredths of a foot, and read by the vernier to thousandths.

The target being permanent to the rod, when a reading of less than six feet is desired, the rod is placed target end down, and the piece carrying the target is raised. When a reading of more than six feet is desired, the rod is placed target end up and the piece carrying the target is raised. The reading being taken from the other vernier.



THE ARCHITECTS' ROD.

This rod is made of maple and is very light. It is a simple sliding rod in two equal parts. When closed it measures five feet six inches, when extended ten feet.

There are two forms of graduations used on this rod. For architects use the divisions are in feet, inches and sixteenths, and no vernier is required. For engineers use the front piece is divided on two sides to feet, tenths and hundredths, reading by verniers on the target and side to thousandths of a foot.

The target is the same as on the Philadelphia Rod, and it slides on the closed rod when readings of less than five and four-tenths feet are to be taken. When a greater reading is required, the target is clamped at the highest divisions on the front half, the rod is then run up and the readings are taken from the graduation on the side, to any point up to ten feet.

THE TELEMETER ROD.

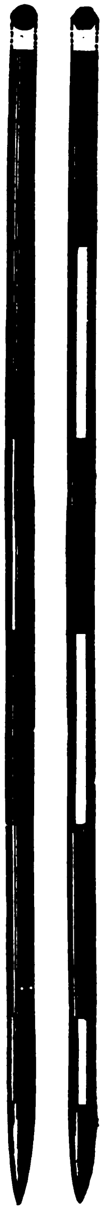
This rod is made of two pieces of best straight grained white pine, each three and one-half inches in width, seven-eighths of an inch thick and six feet long. The inner surfaces of the rod are recessed to protect the divided surfaces and painted white, with divisions in black, to feet, tenths and hundredths the feet figured in red and tenths in black. The two pieces are connected by strong brass hinges and holes for transportation. When in use they are opened flat and jointed directly in line by a wooden bar about twenty-four inches long, held to each piece by two strong brass thumb screws which enter into maple centres screwed on each part of the rod. When opened the rod is self-reading and is often used in connection with stadia wires to ascertain distances by simple observation in the same manner as the Philadelphia Rod.

THE TELESCOPIC ROD.

The rod is made of maple and is in three parts. The two smaller upper parts slide out of the larger lower part which answers as a case. When closed the rod is five feet long and extends to fourteen feet. It is divided on recessed surfaces to feet, tenths and hundredths, the divisions being painted and figured like those of the Philadelphia Rod.

THE CROSS SECTION ROD.

This rod is made of well seasoned white pine and is ten feet long, four feet in middle, where there is a an opening which acts as a handle. It tapers to both ends where it is 1½ inches square. Both sides are graduated on recessed white surfaces, the divisions being painted black like those of the Leveling Rod, but figured on each side from reverse ends. There are two adjustable spirit levels mounted, one at each end.

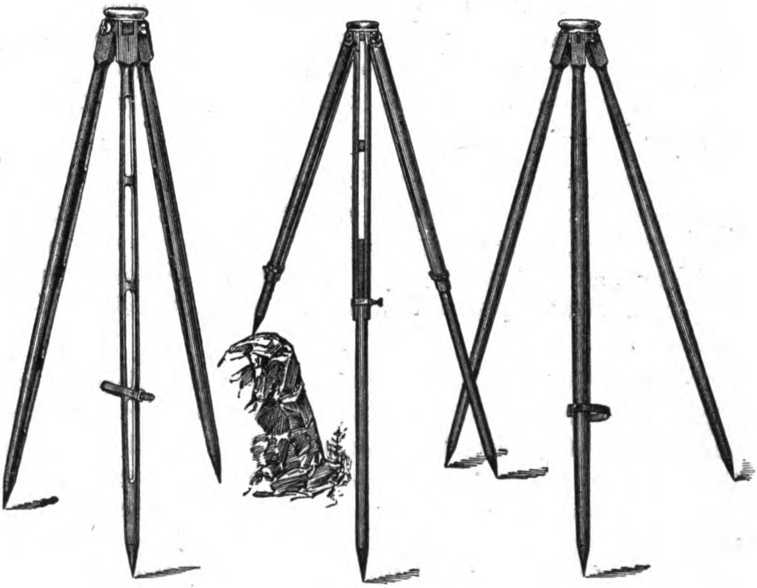


RANGING POLES.

These are made of well seasoned white pine octagonal in shape, tapering from the bottom to the top, in lengths of 6, 8 and 10 feet, The bottom has a steel shoe, and the graduations are in feet painted red and white alternately. This rod is also made flat, about two inches wide by one inch long at the bottom, tapering at the top where it is one inch by three-fourths.

There is also a convenient form of ranging pole made of iron tubing eleven-sixteenths inch in diameter, hung in gimbels so that it can be readily set from a given point. Similar iron poles are made without gimbels in lengths of 6, 8 and 10 feet the same as the wooden pole,

TRIPODS.



The three best and most commonly used forms of tripods are the Plain or Solid Leg, the Split Leg and the Extension or Adjustable Leg.

The tripod heads on all three forms are made of the best bell metal, and the tennons and upper parts are cast in one piece and firmly braced together.

The method of attaching the instrument to the tripod head varies according to the construction of the instrument. The two most commonly used are the screw head and the bevelled clamp head. In the screw head the threads are cut on the outside of the plate and are deep and large, so that the instrument when tightly screwed down is very rigid and the danger of the threads stripping is avoided. The clamp head, which is the quickest way of attaching the instrument to the tripod, consists of three bevelled clamps, one of which is adjustable. The lower plate on the transit is bevelled so that when it is fitted in the tripod head it is only necessary to tighten the adjustable clamp.

The points or shoes consist of tapered brass ferrules with iron ends and are firmly screwed and riveted to the wood. The wooden leg has a slot at the top which fits in the lug cast around the tripod head. There are washers on the inside and outside of the slot part of the tripod leg which prevents the wearing of the woodwork, A long bolt with an anchor pin runs through the woodwork to the tripod head lug, and is tightened by a thumb screw and check nut which prevents any looseness.

The Solid Leg Tripod is made about 4 feet 8 inches long from head to point and tapers in each direction between the head and shoe. The diameter is about 1¾" at the swell; 1⅜" at the top and 1⅛" at the point. This tripod is generally used on the heavier engineer's transits, surveyor's transits and Y levels.

The Improved Split Leg Tripod is the same as the solid leg tripod, but has the centre cut out which reduces the weight and improves the general appearance. This tripod is used on the lighter Engineering Transits and Levels. The increased strength given by the arch form compensates for the wood cut out. The latest improved form of split leg tripod is made of two strips of rounded wood firmly clamped at the top, centre and point. This is unquestionably the strongest and most rigid tripod made.

The Extension Tripod. The illustration shows the latest improved form of extension tripod, and is a decided improvement over the old form, as it is stronger, more rigid and is more compact when closed for carrying. The construction of the side pieces allows the middle piece, which is round and slides in rings, to be clamped firmly with a single band and screw. Slight changes in length can be made by releasing the clamp screw and twisting the middle piece up or down.

The three best woods to be used in tripods are cherry, straight grained ash and white maple. The wood should be straight grained and thoroughly seasoned, so that when it is necessary for an engineer to force the point through rocky or frozen ground, in order to secure a firm foundation, his entire weight can be thrown on the leg without danger of its springing or breaking.