STANLEY'S SURVEYING INSTRUMENTS

Surveying

College Toronto with the Authors Compts.

SURVEYING AND LEVELLING INSTRUMENTS

THEORETICALLY AND PRACTICALLY DESCRIBED

FOR CONSTRUCTION, QUALITIES, SELECTION, PRESERVATION, ADJUSTMENTS, AND USES; WITH OTHER APPARATUS AND APPLIANCES USED BY CIVIL ENGINEERS AND SURVEYORS

BY

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LONDON: E. & F. N. SPON, 125 STRAND

NEW YORK: 446 BROOME STREET

AND OF THE AUTHOR, GREAT TURNSTILE, HOLBORN, LONDON, W.C.

1890

A. R. GOLDIE. AMERICAN PRINTER. GLASGOW

PREFACE

Notes were taken for many years before the production of this work of queries that came before the author for reply relative to functional parts of surveying instruments. These bore most frequently reference to optical and magnetical subjects and to the qualities and action of spirit level tubes, also occasionally to graduation and the qualities of clamp and tangent motions. It was therefore thought that it would be useful to give notes upon these subjects in detail as far as possible in early chapters. As the work proceeded it was found that this plan saved much space, in avoiding the necessity for separate descriptions when complex instruments were afterwards described.

To show the state of the art and render the work useful, it was necessary that the structure of surveying instruments should be given with sufficient detail to be worked out by the skilful manufacturer. Beyond this it was thought to be most important that the professional man, who must have limited experience of the qualities of workmanship, should be supplied with as many simple tests as possible for assuring the qualities of the instruments he might purchase or use, with details also of their adjustments. This matter is therefore carried into detail for one instrument at least of each class, as very little general information is to be found on the subject in our literature. In fact, large groups of instruments in extensive use, such as those for mining surveying, and subtense instruments, have remained heretofore nearly undescribed in our language.

The technical principles followed in working out details in these pages are given by illustrations of such parts of important instruments as present any difficulty of observation from an exterior view of the engraving of the entire instrument. The plans of construction thought to be the best are selected for illustration. Certain constructions that are liable to failure are pointed out. Many recent improvements in instruments are recognized and some are suggested, but no attempt has been made to record the little differences of construction, often meritorious, which give only a certain amount of style to the work of each country and of each individual. Upon this point it must occur that the work done in any shop must vary from other work according to the skill and judgment of the master. It is intended, therefore, that distinctly typical instruments only should be described, in a manner that details may be worked out therefrom. To make this matter as clear as possible, with few exceptions these pages were written in the presence of the instruments described, and the illustrations, when not taken directly from the instruments, were taken from workshop drawings to a reduced scale.

In practice it is found that instruments performing similar functions may be very much varied in construction, bearing reference frequently to the conditions under which they are to be used. The same may be said of the functional parts of instruments. We may also observe that English instruments differ in detail from foreign ones, and upon this point there is no doubt much may be learned by comparison of some details of English and foreign work, although our own is admitted to rank high. Comparisons are therefore freely made in the following pages, and suggestions offered after study abroad of foreign work and careful inspection of nearly the whole literature upon the subject, in which it is very observable that Continental books, treating of parts of the subject, are much in advance of our own.

The surveying instruments described in these pages are nearly limited to those used in the field. Instruments for plan drawing and calculation of areas, which the surveyor uses in the office, have been described in the author's work on drawing instruments (sixth edition), to which this is intended to be the complement of the subject.

To render the work as complete as possible it was thought to be necessary to give briefly the manner of using many instruments in practical surveying. This part of the subject, from the author's very limited experience in the field, is largely taken from inspection of the best works on surveying. The author, however, is very pleased to acknowledge the kindness of many professional friends for assistance on this and many other points, and for historical notes. For the description of the 36-inch theodolite, given in chapter VII., the author is indebted to the late Col. A. Strange, F.R.S., who gave every detail of his design and discussed many points. The author is also indebted to Mr. Thomas Cushing, F.R.A.S., Inspector of Scientific Instruments for India, who has given information and his opinions upon many subjects from his large practical experience. Also to Prof. George Fuller, C.E., who has kindly read proofs, examined formulæ, and made some technical points clearer. Also to Mr. W. N. Bakewell, M. Inst. C. E.; Major-General A. De Lisle, R.E.; Right Hon. Lord Rayleigh, F.R.S., for assistance on several technical points.

In this first edition, entirely from manuscript, there will no doubt be errors and omissions; therefore the author will feel obliged by the receipt of any notes that he may make use of for future corrections, should another edition be demanded.

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CHAPTER I.

HISTORICAL SKETCH—CLASSIFICATION OF THE SUBJECT—PURPOSES AND QUALITIES OF INSTRUMENTS—WORKMANSHIP—METALS—FRAMING—TOOLS—AXES OF INSTRUMENTS—SOLDERING—FINISHING—BRONZING—LACQUERING—GRADUATING—ENGRAVING—GLASS-WORK—WOOD-WORK—LUBRICATION—PRESERVATION OF INSTRUMENTS—PACKING.

1.—**Historical Sketch.**—Although the aim of this work is to show the state of the art it is intended to represent at the present period, derived from personal experience, a large amount of literature, ancient and modern, has been consulted for its production, principally with the object that the authorship, as far as possible, should be given of the instruments described which have come into general use. Many of these instruments have been brought to their present state of perfection by small consecutive improvements upon older forms. Therefore, it is hoped, a brief historical sketch of the literature of the subject may be thought to form a fit introduction.

Land surveying was possibly first practised in Egypt, where landmarks were liable to be washed away or displaced by the overflow of the Nile. That it was also used otherwise is shown in that there is extant in Turin a papyrus giving the plan of a gold mine of about 1400 B.C. The earliest surveying instrument of which we have record is probably the *diopter* of Hero of Alexandria, about 130 B.C. This instrument appears to have been a wooden cross, with sights to take right angles. In the *astrolabe* of Hipparchus, we have a divided quadrant of a circle sighted from the centre. In Tycho Brahe's "*Astronomica Instaurata Mechanica*," 1598, we have descriptions and engravings of the astrolabe of Hipparchus, Ptolemy, Alhazen, and his own instruments. These all embrace the principle of the quadrant, but the sighting of the star or object with the instrument by movable parts is effected in various ways. These instruments were made at first only for astronomical observations, but they appear, with slight modifications, to have been applied to topographical surveying.

In 1624, Edmund Gunter, to whom science is indebted for the invention of the slide rule, sector, and chain of 100 links, published a work giving descriptions of the cross-staff and modernized form of quadrant, with improvements on some other instruments. In 1686, we have the first treatise on mine surveying, the "*Geometria Subterranea*" of Nicholaus Voigtel, published in Leipzig, in which we have the *hanging compass*, still in use on the Continent, described. Beyond this, few improvements are recorded upon surveying instruments in the seventeenth century.

2.—Near the commencement of the eighteenth century we have a somewhat important work, published in Paris, written by J. B. Bion, "*Constructions des Instruments de Mathematique*," 1718. This treatise was translated into English by Edm. Stone, who made many additions, in 1723, forming an important work in its day, excellently illustrated. In this we find an account of the circumferenters, plane tables, magnetic compasses, and other instruments then in use. The next important work treating the subject is "Gardiner's Practical Surveyor," 1737. In this we have the theodolite introduced, then recently invented by Jonathan Sisson, which was not, however, perfected until the introduction of the achromatic telescope by John Dolland, about 1760. Gardiner gives also a careful consideration of the best instruments employed generally in the practice of surveying. Nothing from this time appears except transcriptions and incidental descriptions of instruments in works on surveying, until we have Geo. Adams' important "Geometrical and Graphical Essays, containing a Description of Mathematical Instruments," 1791. In this we have an able discussion of the best surveying instruments then in use. This work was much advanced in later editions by the descriptions of the great improvements made in the construction of this class of work by Jesse Ramsden, as also by the invention of the box-sextant and artificial horizon by Wm. Jones. The last edition carries the subject well up to date at the beginning of the present century (1803).

In the present century no original work appears on the subject till F. W. Simm's treatise on "Mathematical Instruments," 1834. This small work is limited to quite popular instruments for land surveying and levelling. It was probably called hurriedly into existence to supply a want at the commencement of the railway mania. Another small popular work, by the late J. F. Heather, 1849, appeared in "Weale's Scientific Series." This was almost entirely compiled, using old and even then obsolete engravings. No work in the English language, from an early date in the present century, is found to treat the subject comprehensively, or to bring it nearly up to the advanced work of our best opticians at the period it was written.

3.—In Germany we have recent works of an altogether higher order in "*Die Instrumente und Werkzeuge der höheren und niederen Messkunst, sowie der geometrischen Zeichnenkunst; ihre Theorie, Construction, Gebrauch und Prüfung*," by C. F. Schneitler, 1848; and a work upon the larger instruments, "*Die geometrischen Instrumente*," by Dr. Hunäus, 1864.

These works are original, and enter ably into constructive details. The authors, however, do not mention, nor were possibly acquainted with, many excellent instruments in the hand of the British surveyor. As regards reflecting instruments, which derive their first principles from Hadley's sextant, there is no work in which these are treated so ably as that of the Italian, Captain G. B. Magnaghi, in "*Gli Strumenti a Reflessione per Mesurare Angoli*," 1875. The consideration of these instruments is, however, in this work more in reference to astronomical and nautical observations than to surveying.

4.—The important class of subtense instruments, the use of which was first proposed by our countryman, Wm. Green, as early as 1778, since re-invented in Italy by J. Porro, 1823, of which we have a description in his work, "*La Tachéométrie, ou l'Art de lever les Plans et de faire les Nivellements*," 1858. This class of instrument, now in extensive use on the Continent, and to some extent in America, is scarcely known in this country except in Edgecombe's little-used stadiometer, of which we have descriptions, without any recognition of the optical correction always required to render this instrument practical; and in some descriptions of Eckhold's omnimeter, given generally with an illustration of an early abandoned form of instrument; until quite recently we have the subject of subtense instruments ably discussed in a paper by B. H. Brough, on "Tacheometry," as it is termed, read before the Inst. C. E.'s, 1887.

5.—**Classification**.—The surveying instruments necessary to be employed on any particular survey will depend, in a great measure, upon the nature of the work to be performed. Thus, if it is for a simple plan of an estate, the surveyor requires to ascertain the positions of buildings and important objects, the internal divisions of the land, and the surrounding boundaries of the estate, placing all parts in their true horizontal positions and bearings in relation to the points of the compass. If it is for a topographical survey of great extent, he requires these matters in less detail, but, in addition to the above, to give the true latitudes and longitudes, and the relative altitudes of the parts of his work. If it is for a railway or a canal, he requires to ascertain, besides the general horizontal plan, the altitudes especially of all parts of his work very exactly. If it is for coast survey, he requires, besides the bearings, the exact relative trigonometrical positions of all parts of the coast-line, as also the relative soundings on the sea-front. If it is for a mining survey, he requires to ascertain, besides the horizontal plan, sections showing the position and depths of strata, faults, veins, &c.; and, as the work is principally underground, it is necessary that he may take his observations by artificial light. It becomes, therefore, clear that special instruments can be adapted, more or less perfectly, to these various kinds of work without that amount of complication and of weight necessary to be personally carried about, which would be required in the use of any single instrument constructed to perform many of the functions named above.

6. — Taking the subject in a general way, the instrumental aid of the greatest importance in the work a surveyor has to perform, is such as will provide measurements and angles by which he may be enabled to make a horizontal plan or map of the ground he surveys to a measurable scale. The means employed to secure this object is by taking lineal measurements in certain lines to fixed positions, or *stations* as they are termed, and by taking angles from such stations to prominent points of view, which may be either natural or artificial objects. To obtain this end, he requires means of measuring such lines, and some instrument that will take angles of positions in the horizontal plane, or as it is termed in *azimuth*.

7.—The instruments used in practice for measuring the complete circle in angles of azimuth are the various kinds of theodolite, including transits, omnimeters, tacheometers, circumferenters, also mining - dials of various kinds, prismatic compasses, and plane-tables. Instruments limited to measuring angles upon the plane, within a segment of a circle, are sextants, box-sextants, and semi-circumferenters. Instruments adapted to take certain fixed angles only are the optical square (90°), the cross-staff (90° and 45°), the apomicometer (45° only). The theodolite being a universal instrument, is used for taking angles in altitude as well as in plane. The sextant is also adapted to this. Circumferenters and mining-dials are generally constructed to measure altitudes less exactly than the theodolite. In extensive surveys of countries a constant check is required by taking the latitude and longitude, in which a good transit instrument is required and a reliable chronometer.

8.—Practically for taking altitudes for railway, canal, road, and drainage survey, a telescopic level is used, either with or without a magnetic compass. For topographical work and measurements of great altitudes in extensive surveys, the theodolite, aneroid or mercurial barometer, or boiling-point thermometer is used. In important surveys of mountainous countries, all of these instruments are used, the one as a check upon the other. For taking merely angles of inclination of surface, angles of embankment or cutting, and dip of strata, a clinometer of some kind is used. Some general details of construction will be considered in this chapter before proceeding with the details of the instruments mentioned above, and some particulars also which it would be difficult to introduce hereafter.

9.—**Qualities of Work.**—The qualities that instruments should possess will be separately discussed with the description of each special instrument. It may be stated generally that much of the quality of surveying instruments depends upon the perfection of the tools used in their manufacture, but very much also depends upon the character of the man who produces them—not only upon his intellect, but whether his chief object is the perfection of his work, or the amount of profit he can obtain from it. It is generally known in all branches, as a rule, that the cheaper kinds of work, from the less care required in details, secure the greatest profits. In the author's and some other optical works, a completely-fitted engineer's shop is employed to keep tools in perfect order, make special tools, and produce the heavier class of work, for which the engineer is better adapted than the mathematical framer. It is also advantageous at all times to have one skilled engineer, who is styled *the engineer*, in a workshop where about 50 men are employed.

10.—**Metals.**—The alloys used in the construction of surveying instruments, to which alone it is necessary to direct attention, are brass, gun-metal, bell-metal, and occasionally electrum or German silver. These are required to possess certain qualities, and, where the magnetic needle is used, to be perfectly pure or free from iron. The certainty of metals being quite free from iron is one of the great troubles with which the manufacturer of magnetic instruments has to contend with when obtaining his castings from the ordinary commercial founder. This has led the author, and some others in his line of business, to cast their own metals as the only means of getting them pure. Where the metal is had from the ordinary founder, every part of the casting should be carefully brought within the influence of a delicately-suspended magnetic needle. If the slightest attraction be found in any part of the casting, it should be rejected.

11. — The general object to be obtained in the

distribution of metals to the various parts of an instrument is to get good wearing surface with solidity, and even balance of the moving parts with moderate lightness. In practice, such parts as can be thoroughly hammered, drawn, or rolled in a cold state will form stiff, elastic, and durable parts in brass. For the composition of this metal the author uses copper ·69, zinc ·30, tin ·01. The tin is used in place of the lead of the ordinary founder, and produces thereby a stiffer alloy. For such parts as require stiffness, where sufficient hammering is impossible, or the metal is in considerable mass, gun-metal should be used. The author has found the best practical mixture for this,—copper ·88, tin ·12. For centres requiring great rigidity, as those of the theodolite, level, or sextant, bell-metal is used by all the best makers. This should be of such composition that it cannot be permanently bent without immediate fracture. It should possess about the hardness and stiffness of untempered steel. The best alloy, the author has found for the bell-metal for these instruments is copper ·83, tin ·17. If very small castings are made with this alloy, they are somewhat brittle, probably from the rapid cooling of the surface in the mould, therefore, for small castings, a safer alloy is copper ·85, tin ·15.

In making all the above alloys, for the best results the metals are assumed to be commercially pure. The introduction of a little uncertain scrap, which the ordinary founder is so fond of using to make his metal run down, will often foul a pot of metal. In all cases the copper should be entirely melted before the addition of the zinc or tin, after which it should be thoroughly stirred with a charred stick or earthenware rod, and then be cast in small ingots to be re-melted and cast a second or, even better, a third time for the final castings.

12.—**Workmanship.**—It would be quite impossible, within the limits of this work, to give such particulars of the workmanship in surveying instruments as to enable a person to manufacture them without practical knowledge of the manipulation of the various branches of the art, but it is thought that a general sketch of the various operations entailed, which vary somewhat in different workshops, may be useful. Some of these particulars may be also useful to the surveyor, not only as general knowledge of the instruments he uses, but in some cases of accidents and emergencies, and for the sake of keeping his instruments in order when he is far away from the manufacturing optician.

13.—**Framing Work.**—The ordinary turning and filing of metals, and some knowledge of the workmanship of the business, are assumed to be understood by those who may use this work for special constructive details. The tools in a mathematical or philosophical instrument-maker's workshop, where high-class work is done, nearly resemble in every way a good engineer's shop, except that on an average the tools are much lighter, and run at a higher speed. Where the works are extensive, steam-power is used, or at least a gas engine. In small shops the foot lathe is the only important tool. There is a great advantage in using power for good work, as the oscillation of the tool, which is always caused by the action of the foot, produces what is termed a chatter upon the work. For turning brass and silver, a high speed is desirable with a lathe of sufficient rigidity to give no sensible vibration. A surface-cut speed of about 250 feet per minute should be aimed at. For turning gun-metal, German silver, and mild wrought-iron, about 100 feet per minute is required. For turning bell-metal and cast-steel, a very slow speed is required—about 16 feet per minute. The lathe should therefore possess means of insuring these differences by overhead motions or otherwise.

14.—**Tools.**—The lathe of the most suitable construction for surveying instruments has the upper surfaces of the bed, one side of **V** section, and the other flat, not both flat as in engineers' lathes. This insures the certainty that rests and other tools can be firmly clamped down without possibility of lateral shake. The slide-rest should have a broad base and be provided with perpendicular and rotary motions, with means of clamping the motive parts not in immediate use, as smooth cuts can only be obtained on copper alloys by perfect rigidity of all parts of the tools. The lathe should also possess a bed-screw and overhead motions suitable for applying flying cutters and milling-tools in every desired direction upon the piece of work when it is chucked in the lathe.

15.—*A universal shaping machine* and a milling machine generally replace the planing machine of the engineer. These tools are sufficient for producing the flat surfaces for all ordinary work. Even where power is generally used, small hand planing and shaping machines, worked with a lever, are very useful for working up single pieces and small parts. A circular saw and a good grindstone are also indispensable. With good tools, well applied, very little work is left for the rough or bastard file; on many instruments none whatever—only a little scraping, superfine filing, and stoning being required.

16.—The greatest technical skill required in the manufacture of surveying instruments is in the principal axis of these instruments, particularly in theodolites, tacheometers, sextants, and some kinds of mining dials, wherein a class of work is demanded which must be performed by a skilful, experienced, and careful workman. The axis of these instruments, as already mentioned, should be formed of a casting of good bell-metal. This axis must be turned upon its own centres, which should be drilled up sufficiently to keep a steady bearing, so that the truth of the work is quite independent of any fault there may be in the lathe. The turning must be performed with a point-tool, the upper angle of which should be about 60°. This should be kept constantly sharp, and be allowed to take only the finest possible cut at a slow speed. The slide rest should be set to the exact angle of the taper of the axis. The socket, if it is not very stout, should be placed in a massive metal box and embedded in plaster of Paris, which must be allowed to set perfectly hard before use. The socket is turned out if possible, or otherwise it is roughed out with a hard steel fluted cutter, and finally cut up by another fluted cutter which has been carefully ground to the correct cone intended for the finished axis. The axis is chambered back in its central part, so that it may fit the socket for about half-an-inch or so, only at its extreme ends. After turning and boring as correctly as possible, the axis and socket are ground together with wash emery to true form. After this, the emery surface is turned, or scraped entirely off, with a sharp tool, and the axis is again fitted by rubbing contact only. It is most important to be sure that no grit remains embedded in the metal from the emery grinding, as this will be sure to work out and abrade the axis afterwards.

17. — The same care as is necessary to be bestowed upon the centres of instruments, is required for tangent motion screws. These should be made, if possible, of hard drawn wire. They should be turned on their own centres, the cut of the tool being extremely light to avoid flexure, all screws of over $\frac{1}{8}$-inch diameter should be cut direct in a light screw-cutting lathe, although it is advantageous to run a pair of dies lightly over them afterwards to make the thread smooth, and ensure a perfect fit in the nut.

18.—**Soldering**.—Besides the tubes of instruments, all parts which are difficult or impossible to be formed advantageously in a single casting, are *hard soldered* or brazed together where this will render the part of the instrument more rigid than by screw attachment. The pins of all screws should be made of drawn metal, to which the part to form the milled head may be a casting. Hard soldering in this country is now generally performed with one of Fletcher's gas blow-pipes, the parts of the instrument, if large, being embedded in a pan of charcoal. The author uses a pair of gas blow-pipes, taking the blast of a centrifugal blower driven by the steam engine. These blow-pipes are placed opposite each other, so that the pieces being soldered together, are entirely surrounded by the flame projected from opposite sides. The flames of the gas blow-pipe may, with this apparatus, be reduced to mere points for small pieces. The solder employed for ordinary work is fine spelter with a flux of ground borax. The most convenient method of using this is to put about a quarter of a pound of spelter and an ounce of ground borax in a saucer, and add sufficient water to cover it. The borax and spelter may then be taken up together with a small spoon and placed directly upon the clean part of the metal which is to be soldered. With deep or difficult joints it is well to soak the whole of the pieces an hour or so in a saturated solution of borax before commencing the soldering.

For soldering very small pieces, or for soldering steel to brass, silver solder is better than spelter; it appears to bite the steel more firmly and it runs at a lower heat (cherry-red).

19.—**Soft Soldering**, or what is termed in the trade *sweating*, should be resorted to as seldom as possible, It is necessary in making attachments to drawn tubes, as the heat of hard soldering would destroy the rigidity of the tube, which is due to the drawing processes. In this case, where soft solder is employed, the tube should be if possible surrounded by a band of solid metal, which forms a part of the attachment, or the attached part should be well secured with screws, tapped dry, before the soldering is done. Soft soldering on brass is generally very deceptive: the solder may form a glaze round the joint with no attachment within. Many surveyors will recognise this who may have had one of the slop-made soldered-up levels fall to pieces in their work by a simple jar accidentally given to the instrument.

20.—**Finishing** mathematical work: the surface as it leaves the superfine file is brought up by cutting it down to a *mat* with Water-of-Ayr stone, and finally clearing with soft grey slate-stone.

21.—**Polishing.**—Where brightness is desirable, particularly for steel work, wash-emery and French polishing paper are used. Heads of screws and small turned parts are better finished off with the burnisher direct on the lathe.

22.—**Optical Black.**—The interior parts of telescopes are painted over with a dull black paint, the object of which is to cut off the reflection of extraneous light entering the object glass obliquely. Optical black is made by finely grinding drop-black in turps or spirits upon a stone with a muller, this is afterwards strained through fine muslin, if it is ground in turps a little good gold-size is added, if it is ground in spirit, a little spirit varnish. The black should be tested. It should appear quite dull, and yet be sufficiently firm to bear the finger rubbing upon it without soiling. For eye-pieces, the dull black generally employed is due to oxydation obtained by burning off an acid solution of cuprous-nitrate in a gas flame.

23.—**Bronzing.**—For the protection of finished metal work in surveying instruments the surface is generally *bronzed* as it is termed, leaving bright only such parts as are required to be easily seen, such as milled-heads, heads of screws, &c. The dark green of the bronze is also much more pleasant to the eye than a bright surface, particularly out in the sunlight, so that bright instruments have gone nearly out of use.

The bronzing is effected by the application of a liquid that will corrode the metal and, at the same time, leave a dark pulverent deposit upon it. There are a great number of bronzes to be had, but that which the author has found to be the safest from after-corrosion is platinic-chloride, dissolved in sufficient water. The bronzes which are to be particularly avoided are those containing mercuric-dichloride. These are to be had very cheap, and they give a fine dark surface, but they are certain to rot the brass and produce a pitted or spotted appearance after the instrument has been much exposed. The bronze, whatever kind is used, is put on with a brush upon the surface of the metal, which must be quite clean to receive it. After the colour is well brought up by passing the brush over the work several times, the work is then thoroughly brushed over with a hard brush and fine black lead until every trace of free corrosive liquid is removed from the surface, and the work is quite dry in all parts. Some makers put a thin coat of ashphaltum, dissolved in turpentine, over this, which produces a light black surface. Some, to save trouble and expense, simply paint the instrument with black varnish. This looks very smart at first, but the black is very liable to chip off in use and make the instrument unsightly.

24. — **Lacquering.** — All parts of instruments intended to be left bright, as well as all properly bronzed parts, are separately covered with a thin coating of *lacquer*, the application of which is technically termed *varnishing*. The metal is raised to an equal temperature of about 200° Fahr., and the varnish is applied with a fine flat camel-hair brush. The process requires considerable skill, so that only a few workmen do it to perfection. Special varnishes are made for the philosophical and mathematical instrument trades, all of which have a base of fine shellac, dissolved in

absolute alcohol. The shellac answers very well by itself if it is clear and good.

25. — **Engraving** of figures, words, &c., where there is much repitition, is best done by the engraving engine—general work by the ordinary skilled engraver.

The method employed for the graduation of instruments will be considered further on in the discussion of instruments reading with a vernier scale.

26. — **Glasswork**. — The most important technical work, except perhaps the graduation in surveying instruments, is found in the optical parts, of which only a brief description can be given. The glass used for the lenses, particularly for the achromatics, is that manufactured by Messrs. Chance Bros. of Birmingham, or by M. Feil of Paris, both of which firms use the process discovered by Guinard of Solothurn, in Switzerland, which was afterwards much improved by Geo. Bontemps. This glass is nearly white and transparent, of uniform density, and free from veins and striæ. It is also perfectly annealed, which is important. The following kinds of glass are usually employed for the object-glasses of surveying instruments:—

	Density.	Index of Spectrum Lines.			
		C	D	F	G
Hard Crown,..........	2·485	1·5146	1·5172	1·5232	1·5280
Dense Flint,............	2·660	1·6175	1·6224	1·6348	1·6453

These particulars are given by the glass-makers, who supply the glass, which leaves the optician no necessity to test the special qualities.

The grinding and polishing of the surfaces of the glass require only a certain amount of mechanical skill necessary for the first approach towards achromatism, so that objectives of a low standard may be turned out very cheaply. Where the greatest amount of time is spent and considerable talent required is in the figuring. The various processes of working are:—

27.—1*st. Rough Grinding*, for which the glass is cemented upon a holder and held against a revolving tool, which is supplied with coarse emery and water until the approximate curve required is reached, which is found, on examination, by the use of a metal template, except for small glasses, which are ground down entirely by the next process.

28.—2*nd Process.* The *pair* of tools used for glass-grinding possess two spherical surfaces, one resembling a shallow basin and the other fitting into this. They are ground together in the making, and are kept in order by the same means. These tools may be of cast iron or brass. The working surface of the tool is, of course, of the reverse curvature to that of the glass ground in it, when the glass is ground by hand. Each tool possesses a screwed socket by which it can be screwed to a stump or post, fixed in the ground or firmly on a floor, or to a short knob-handle to be used as the upper tool by hand. For working a glass, or several glasses, it or they are cemented upon a hand tool or holder, which is of less curvature than the working tool. This has a boss or handle in its centre, provided as a means of moving it to the curvature of the working tool. The working is performed by rubbing in a straight alternately with a circular direction, with a certain stroke difficult to describe, at the same time walking round the post to reverse all positions. The grinding is continued over the spherical tool until the surface of the glass is brought up to its curvature being supplied at first with coarse emery, 40-*hole*, which is kept in a very moist state, and afterwards with finer emery, 60-hole, carefully washing off between the processes, and reserving the mud most carefully for wash-emery, which is used in completing the grinding. Where machinery is employed, hand motions are imitated as nearly as possible by the motion of the tools.

29.—*The Wash-emery* is formed of particles which are held suspended for a minute or so when the mud is stirred in a large vessel of water. This water is drawn off for final settlement to form the wash. The final grinding with the wash is continued until the emery appears jet black on the surface of the glass, which has then a semi-polished, almost metallic, lustre.

30.—*3rd Process—Polishing*. This is performed in various ways; some very fair results being obtained by what is termed the dry process, that is with polishing papers which are pasted in slips upon the surface of the grinding tool, sometimes moist cloth is placed over the tool. The more general and better way is to cover the polishing tool with patches of hard pitch, which are made to take the form of the hand tool by having the fellow tool to that used in working pressed upon the surface while the pitch is still warm, using a sheet of moist tissue paper to prevent adhesion. The polishing after the pitch is brought to the required curve is effected in the same manner as the grinding, but with Tripoli powder, rouge, or peroxide of tin (putty powder).

31.—As so very much of the quality of a lens depends upon the perfection of its polish it may be well here to note how this may be observed. Generally, if the reflections seen in the lens of any well-lighted object of angular form with straight lines appear sharp and clear at the edges, without any trace of *seediness*, the lens is fairly polished. Perhaps a better test is to throw the shadow of a thin object as that of a piece of wire upon the surface obliquely. This should show clear edges when the lens is changed to all positions for reflection. The test of polish is really only the test of brightness of the surface of the glass, which may be distinguished in many ways that will readily suggest themselves. The importance of the subject is that to which attention is desired to be drawn.

32. — *4th Process — Centring.* The finished crown glass is fixed on the nose of a tool capable of revolution similar to the hollow mandril of a lathe. The image of a small hole in a metal plate, illuminated by a gas-flame behind it, is then thrown through the lens upon a movable screen, which is brought up behind the tool to exact focus of the glass. The glass is then slowly revolved and shifted at the same time, until the point of light, which comes to focus on the screen, appears to remain quite stationary during a revolution. The glass, after it is set, is then marked with a diamond to size, and afterwards turned or ground off. The flint glass is cemented on the crown glass for centring. After turning, a second testing is required, as it is most important that the objectives of surveying instruments should be truly centred.

33.—*5th process—Figuring and Testing.*—The technical difficulties of figuring are too great to be discussed briefly in a work of this elementary class, much of this work is done by the skilled workman in the manner he works his tool and applies his grinding and polishing material, every stroke giving a slightly different figure. Some method, however, may be given of *testing*, which will be useful in estimating the quality of a lens, irrespective of its manufacture. To test in the best manner, the objective should be mounted in its telescope and focussed upon a star, or, more practically, the reflection of the sun as this is seen in the mercury of a small bulb of a thermometor placed conveniently on a black background at as great a distance as it is clearly visible in the telescope—a common distance is 20 feet. The objective is then partially covered with various discs and rings of opaque paper, leaving at each such covering first the centre of the lens only open, and then consecutively a narrow zone around the centre of about half-an-inch in width, and finally, the outer zone only. If the focus under these tests remains constant, so that the image of the sun appears sharp and without much colour, the objective is perfectly corrected. If any zone gives a more or less distant focus, which may be discovered by moving the objective towards or from its first position, it must be re-worked until it is correct. This error, if great, will require re-grinding, or, if small, be corrected by pitch polishing alone. The grinding action upon the glass is nearly proportional to the extent of grinding surface upon the tool, so that parts of the pitch which cover the tool may be carefully cut away where the surface grinding is intended to be missed in the figuring. After all possible skill, it must be borne in mind that a perfect achromatic lens has not yet been made. Therefore, it is only necessary to look for that fair amount of accuracy that is necessary for the special purpose for which the glass is to be used. Further information on this subject may be gained from a very important paper read by Sir Howard Grubb, the eminent optician, before the Royal Institution.*

34. — **The Woodwork of the Stands** of instruments made in this country is generally of straight grained Honduras mahogany. For occasional work the mahogany is better if seasoned for three or four years in boards which are cut to thicknesses increasing by quarter inches, so that about the thickness of the finished work in one dimension may be used. Where a number of stands of constant dimensions, as for ordinary theodolites and levels are required, it is better to cut the mahogany a little over finishing size directly from the fresh log, and then allow it to season three or four years. In this manner any natural warp of the wood takes place before it is worked up which causes it to stand well afterwards.

* Proc. Royal Institution, Vol. XI., page 413.

35.—**Lubrication of Instruments.**—For the lubrication of all screws, good watch oil should be used. Where this cannot be obtained, salad oil, filled up in its bottle with fresh-cut shavings of lead, will produce a perfect oil free from acidity. For working centres and collars, a grease is better—that extracted from pork fat, by leaving it in the sunshine, answers very well, but what the author has found the best for the purpose is pure vaseline. This keeps its greasiness, and appears to be perfectly non-corrosive. For the collars of tangent screws, a mixture of tallow, wax, and soap is employed. This mixture does not fret out to cause a bite upon the surfaces. As the instrument-maker leaves the working centres of instruments, these will generally perfectly maintain their lubrication for four or five years, and it is not well to disturb them; so that this note may be considered only for the restoration of old instruments to order, or for cleaning them up generally, which is best done by skilful hands.

36.—**Preservation of Instruments.**—Instruments that have by any accident become splashed, or dirty by exposure to rain and dust or otherwise, may be washed with damp wash-leather. If a piece of soft, dry leather be afterwards moistened with a little sweet oil, and this be rubbed over the instrument when it is quite dry, this will restore the original brightness, and tend to preserve it. For wiping object glasses some prefer a piece of clean old linen, some an old silk handkerchief, either will answer if kept quite clean. If the glasses are only dusty, the application of a soft camel hair brush is all that is necessary, and this is quite safe from carrying grit. If glasses are stained by slight corrosion, this can be partially removed by clean spirit. In replacing glasses, it is important to observe that the notch marks, if any, on the edges of the glass agree, and that the double-convex lens is placed outwards from the telescope.

37. — **Packing of Instruments.** — This is really a very important matter seldom estimated at its proper value. An instrument should lie or stand in its case in such a manner as its most solid parts only take the bearing surface, and thus perfectly secure it. When this is effected there should be no exceptional jar on any delicate part from the jolting of the conveyance of the instrument. Great care should be taken to note how the parts of the instrument were originally arranged by the packer, and this arrangement should always be followed in replacing the instrument in its case to its position, into which it should fall with perfect ease. Instruments are frequently strained by being placed wrongly in their cases. Even with all these precautions, particularly in tropical climates, the wood of the case may shrink or warp to a certain extent, so that the instrument may be exposed to external pressure from closing the case or otherwise, so as to injure it or to spoil its adjustment. In such cases it is better to examine the packing occasionally, and, if the case does not easily and perfectly close, there is risk that the instrument is being strained. If this is the case, assuming the instrument is in its correct position, the bearing surfaces should be lowered with the pen-knife or other tool, so that it is just free but will not shake. It is better to have a piece of cork under the bearing surface, this gives a certain amount of elasticity, with sufficient rigidity for support, to preserve the instruments from injurious jar. If the cork is originally placed on the bearing surfaces, it may be afterwards cut away more easily with the pen-knife than the wood.

38.—With complicated instruments there are always a number of loose pieces which are used occasionally upon or with the instrument. These, for compactness of packing, are often placed one above the other, and are liable to get astray. It is very desirable that complete parts should be arranged, as far as possible, to go into their cases in any state of adjustment,—this is, however, not always possible. As a rule, before putting an instrument or any of its parts by, all movable parts, such as the telescope, cap-pieces, etc., should be closed to their closest form. Parallel plates should be left square to the instrument, with the screws loose. Generally, the packer leaves little liberty. Instruments are often packed so that they will go into their cases only just in one state of adjustment, and in one position of the movable parts. In this case, great care must be taken at first in examining the position in which the instrument and its parts arrive from the maker. The late M. Gavard, of Paris, who was celebrated for his delicate pentagraphic instruments, to whom the writer owes many useful hints, put initial letters on the parts of his instruments, and placed printed labels on the parts of the cases where these should go. Mr. Hennessey, First Assistant in the Great Trigonometrical Survey of India, gives some excellent notes upon the subject of packing in his "Topographical Instructions" for the use of the Survey Department. He recommends upon opening a case that a sketch should be made of the contents as they lie, and all possible particulars should be recorded; but his most useful hint is, always to replace an instrument gently, and in no case to use force if the instrument will not fall into its place. Unless there is something very wrong in the packing, there is sure to be a displacement of some of the parts of the piece, which must be carefully looked into to avoid injury.

39.—**Over Leather Cases.**—For instruments for use in the field, it is better to have a solid leather case over the ordinary mahogany case. This acts as a kind of buffer, and takes off the effect of an accidental blow to the case, which might otherwise injure the instrument. It also protects the mahogany case from the warping effect of direct sunshine and rain, and closes the meeting-joint to keep out the dust.

Solid leather cases are also general for all light instruments, rendering a stiff case of wood or paste-board unnecessary. These admit most perfectly of straps being placed conveniently to adapt them to the person for carrying.

CHAPTER II.

THE TELESCOPE AS A PART OF A SURVEYING INSTRUMENT — GENERAL DESCRIPTION — QUALITIES — OPTICAL PRINCIPLES—REFRACTION OF GLASS—LIMIT OF REFRACTION—REFLECTION—PRISMS—LENSES, CONVEX AND CONCAVE—ABERRATION — FORMATION OF IMAGES — DISPERSION — ACHROMATISM—CURVATURE OF LENSES—TELESCOPES—EYE PIECES—POWERS—DYNAMETER—CONSTRUCTION OF THE TELESCOPE, DIAPHRAGM—WEBS—PARALLAX—EXAMINATION AND ADJUSTMENT.

40.—**General Description of the Telescope.**—This instrument forms part of the theodolite level, some kinds of miner's dials, sextants, plane tables, and other surveying instruments. For this purpose it is made of similar construction to the refracting telescope used for astronomical purposes. The great object desirable in the telescope when used as a part of a surveying instrument is, that it shall assist vision in obtaining the true direction, or pointing to the position of an object in a manner that the telescope can be employed to ascertain the angular position of two or more objects in relation to the position of the centre of the instrument, also to obtain relative altitude to this centre in relation to a distant station by the reading of a divided measure or staff placed thereon.

41.—The qualities desirable in a surveying telescope are, that sufficient rays of light may be collected from the object observed that it may be clearly seen as a whole, and in some cases that sufficient magnifying power should be available, that details or divisions painted upon a staff may be sharply defined. The amount of light received by the eye which is effective in producing distinct vision is in proportion to the extent of active surface of the object glass conveying the rays. The magnifying power is regulated by the sum of the convexities of the lenses of the eye piece upon principles to be explained. The surveying telescope is required to possess only a very limited field of view, but very great focal range, so that objects may be seen at any great distance or quite near.

By the necessary optical arrangement of the telescope which will be further described, the object observed is generally seen *inverted*. This inversion of the *image* as it is termed, at first presents a little difficulty to the learner, but in practice it soon becomes so familiar as not to be recognised mentally.

42.—**Optical Principles involved in a Telescope.** —To commence with the optical construction of the telescope, that this may be thoroughly understood, it is necessary to give brief details of some first principles upon which it is constructed, assuming optics has not been made a special subject of study.

43.—**Refraction of Glass.**—The properties of a lens depend entirely upon the fact that a ray of light passing from air obliquely into the surface of a dense transparent medium (in this case of glass) and equally from the glass into air is bent, or as it is termed *refracted*, to a certain angle at the surface of contact of the air and glass. The ray of light entering the glass is termed the *incident ray*, that proceeding from is the *emergent ray.*

44.—There is no known medium, glass or other, which refracts a ray of white light to one uniform angle. The white ray is universally separated upon refraction, or *dispersed*, as it is termed, into rays of all colours of the rainbow. In considering refraction, therefore, in its simpler aspect we are compelled to take the refraction of one uniform ray which is distinguished by a colour, that forms a part of the white ray, as for instance the red, yellow, green, or blue, that is, for a *monochromatic ray*, as it is termed, and which gives a sharp refraction of its own coloured light, only in this ray. Incandescent soda produces monochromatic rays, but in practice, an intense flame behind any bright coloured glass will answer the same purpose, as the coloured glass absorbs all, or nearly all, parts of the white ray except that of its own colour.

45.—Every transparent medium has a special quality of refraction. Therefore, different kinds of glass refract in different degrees within certain limited angles which will be hereafter considered. The refraction is uniformly in the *plane containing the incident ray, and the perpendicular to the surface separating the two media.* Every medium refracts monochromatic light equally according to the following law for any angle of refraction :—

Whatever the obliquity of the incident ray may be, when it passes from a rarer to a denser medium the ratio which the sine of the angle of incidence bears to the sine of the angle of refraction is constant for any two transparent media.

46.—The natural law by which the power of refraction of any medium may be shown and consequently the magnifying power of a lens in the ratio of its curvative through this refraction may be exemplified, is given in the following diagram (Fig. 1) :—

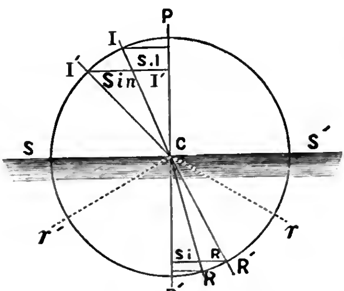


FIG. 1.—*Diagram of Refraction and Reflection.*

PP′, a line perpendicular to the surface of the plane of the medium (glass) with air above it, a ray of light would pass directly P to P' through the glass surface S S' without refraction, and so for all perpendicular incidences or emergencies. To this perpendicular line PP', termed the *normal*, all refractions are measured. The incident ray I to C is refracted to R. Then if we call the angle ICP I, and the angle RCP' R, it is found by experiment that the perpendicular from I on PP' (or sin I) bears a certain proportion to the perpendicular from R on PP' (or sin R) according to the density of the glass. This proportion is generally expressed by the formula—$\sin I = \mu \sin R$. Another incident ray I' to C would be refracted to R', and using similar notation to the above we have $\sin I' = \mu \sin R'$, and from this it follows that $\frac{\sin I}{\sin R} = \frac{\sin I'}{\sin R'}$ 2μ, which is called the *index of refraction*. Thus, if in a certain glass the sine of I measures 3 equal parts on any scale of length, and the sine R 2 parts on the same scale, the *index of refraction* of this glass would be 3 divided by 2 or 1·5, expressed technically as 1·500.

47.—If the above process be reversed and the ray of light R be refracted on passing *from* the glass to the air, it will be projected to I in the emergent ray, and follow the same law as that given above.

48.—**Limit of Refraction—Reflection.**—The sines to the angles ICP and $I'C'P'$ being constantly greater in proportion to the obliquity in the case of glass we are considering by $\frac{1}{3}$ than the sine of the angles RCP' and $R'CP'$ of the rays of incidence thrown upward upon the surface SS'. It will be seen that at a certain angle or that in which the sine is $\frac{2}{3}$ the radius, namely, 41°.48′.37″, the equation given above makes $\sin I = 1$ its maximum value; therefore, at any angle of incidence greater than this, the sine of refraction to continue in proportion would exceed the radius—an impossibility. The refraction, if possible, would carry the ray into the substance of the glass. This is therefore called the *critical angle*. At this point we may consider what must happen. By our rule, refraction must cease at the angle refraction becomes impossible by increase of sine, and as light cannot be extinguished in a transparent medium it must be *reflected.* Thus the ray *r* cannot be refracted in the proportion according to the rule given for sine *I* to sine *R*, as this would exceed the greatest sine, that is, *SC* the radius, this ray will therefore be *reflected* at the surface from the point *C*, and pass in the direction r'. This property of refraction, continuing, as it were, into reflection, is made use of in many instruments.

It may be worthy of repeating, as it is a mistake occasionally made by persons designing instruments for special purposes (as telemeters), that the refractions are not equal for varying angles of incidence, but only as before stated in the ratio of the sines. Thus there is no refraction *P* to P', a certain refraction *I* to *R*, and a greater refraction I' to R', the refraction constantly increasing with the angle of incidence.

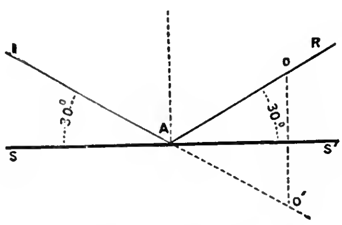


FIG. 2.—*Diagram reflections from a plane.*

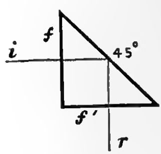


FIG. 3.—*Reflection from a prism.*

49.—*The Reflection of Light* follows a very simple law, which is that:—*The angle of reflection of a ray of light from a reflecting surface is equal and opposite to the angle of incidence upon it.* Thus, in Fig. 2, let a ray of light *IA* fall upon the reflecting surface SS' at 30° of inclination to this surface, then this ray will be reflected from

A to R at the angle RAS', which is also 30°. If an object be at O, and the eye at I, then the object will appear as though it were at O', as the eye only recognises the object in the direction from which it actually receives the light. The apparent angle $S'AO'$ is equal to IAS, so that the point of a mirror, from which an object reflected is received, is in direct line between the eye and the apparent object. This observation will be found useful in placing mirrors.

50.—*Prismatic Reflection.* The same law, as given above, applies to internal reflection from glass. Let Fig. 3 represent the section of a prism ff', two plain surfaces of glass at right angles to each other, and the third side making an angle of 45° with each of the other two. The ray i will therefore pass perpendicularly through the plane f without refraction to meet the plane 45°, and the angle of refraction, being equal to the angle of incidence, will leave this plane at 45°, and reach r. The angle of glass here given of 45° being greater than 41° 49, its extreme angle of refraction, therefore, the internal reflection will be perfect.

51.—*Prismatic Reflection*, as this is termed, is largely used in optics in preference, where practicable, to open reflecting surface, from the certainty of keeping the reflecting surface clean; as dirt exterior to the reflecting surface of the prism does not affect the internal reflection in any degree.

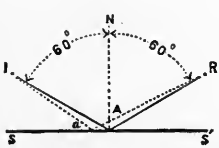


FIG. 4.—*Measurement of angle of reflection in optics.*

52.—The reflection is shown for clearness from the plane (Fig. 2) as it actually occurs, or as it is measurable, independent of theory. In optics it is found much more convenient to take the reflection in relation to an imaginary line drawn perpendicular to the plane. In Fig. 4, *NA* is termed the *normal.* Taking the angles as before as 30° to the plane, the optical expression of this would be 60° to the normal, and the reflection of the incident ray *IA* to *R* would be in the angle *IAR* 60° + 60° = 120°, the amount the incident ray is deflected from its former course. This method is important to be understood in the construction of the sextant and other reflecting instruments. In reflection the ray is found to follow the shortest path,—that is, the path *I* to *R* by reflection is shorter in the lines *IAR*, placed at equal angles to the normal, than it would be by any other possible path. As, for instance, it is shorter than *IaR*, shown by dotted lines.

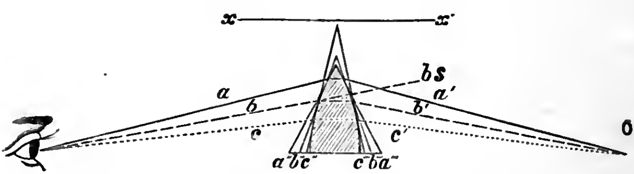


FIG. 5.—*Diagram illustrating the principle of the lens.*

53.—*Passage of a Ray of Light through a Prism or a Lens — Convex Refraction.* If we comprehend the law of refraction exemplified above, art. 45, the path of a monochromatic ray through a prism or a lens is easily determined, taking into consideration the refraction index of the glass. Let Fig. 5 *a''a'''* be the base of an equilateral prism, which base may also represent the axis of a lens lineal or parallel with the direction from the centre of the eye to *O.* Now, if a ray of light passes from a small luminous object at *O* in the path *a'* to the prism, we may assume all other parts of the prism covered, and the refraction of the glass be such that the ray will pass through it from this position in a horizontal direction, or that parallel to the assumed axis $a''a'''$, then the same ray will pass through the prism to equal distance from the centre of the prism,—that is, to the position of the eye shown by the ray continuing in the path *a*, the angles to or from the prism being equal; so that, if we cover up all parts of this prism except a line parallel with its base joining the ends of the lines aa', where it is shown passing through the prism, any ray of light from *O*, under the conditions given, will appear as a spot of light on the plane parallel to the base of the prism; or if we place our eye at the position shown, we shall see the image of the light *O*. If we take a prism of the same kind of glass, but of less angle, whose base is $b''b'''$, the refraction would then be less (that is in the ratio of the sines), so that the ray Ob' would pass through horizontally as before, and emerge from the prism in the path *b*, also with equally less refraction, so that the ray would reach the eye at the same point as the more refracted ray. In like manner, if the prism were of still less angle with base $c''c'''$, the refraction would be proportionally less, and therefore reach the eye at the same point.

If we take the half lens shown in section in the figure, this may be considered to touch the surface of the prisms described tangentially in the lines $a''a'''$, $b''b'''$, and $c''c'''$, where the angles of contact of *O*, *a*, *b*, or *c* upon the prism would be equal to those upon the lens for an infinitely small extent of surface. Therefore, if we make the lens of such form that a ray of light may pass from any single point upon the line of its axis, and be refracted by every point of the surface of the lens to a single point or focus on the opposite side of the axis, such form would be a perfect lens. For simplicity of demonstration, the refractions given above are made parallel with the axis of the lens. This parallelism could only occur with the object and the eye at equal distance from the centre of the lens, and with this distance also proportional to the amount of refraction of the glass for the construction. If the rays were all parallel to each other upon incidence, they would still be bent in the same ratio (to the sines of the angles of contact or departure), and this would bring the focus nearer to the glass; but it is evident the same principles would hold.

54.—As regards the action of the eye in this matter, it can possibly only recognise the direction from which it receives the light, and not the processes the rays may have undergone before reaching it. Therefore the rays proceeding from *O* in the path *b'*, passing through the lens or prism and emerging in the path *b*, is recognised by the eye as the ray *b* only. So that the point of light *O* appears visually as proceeding from the direction *bs*, and this convergence or expansion of the point *O*, with its coincidence from the opposite side of the lens, produces the effect of magnification of the object represented by *O*.

55.—**Concave Refraction.**—In Fig. 6 a convex lens is shown in which the parallel rays *L* are shown drawn to a focus at *F* upon principles just demonstrated. If the lens were made *concave* as shown in section Fig. 7, by the same principles of refraction, it is evident that the rays would *diverge*, as the refraction bends the ray uniformly towards the thickest section of the glass. If two lenses are brought together, one with convex face, and one of the same radius of curvature, but with concave face, the rays in passing through would not be refracted. In this case the lens would be said to be *corrected*. A convex lens has a *focus* where the rays converge. A concave lens is said to have a *negative focus*, equal to the focus of the convex lens, that will correct it, or make it equal, as regards refraction, to plain parallel glass.

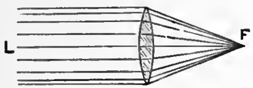


FIG. 6.—*Diagram convex lens.*

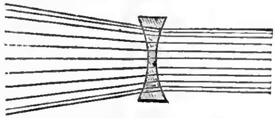


FIG. 7.—*Diagram concave lens.*

56.—*Spherical Aberration.*—If the surfaces of convex lenses are truly spherical, it is found, by an analysis too complex for this work, that the rays that pass through at different distances from the axis converge to slightly different points of distance. This subject was at one time seriously discussed for the proper formation of objectives for telescopes; but at present it is entirely neglected by the optician, as it is found practically to be as difficult to make a lens truly spherical as one of the convergent or divergent form required under the special conditions present. The spherical form, as it is approximately produced from the grinding in spherical tools, being always nearly correct, the correct forms of object-glasses are made by *figuring*, which has been already referred to art. 33. In eye-pieces the spherical aberration would cause some confusion were the glasses not adjusted in such a manner as largely to prevent this.

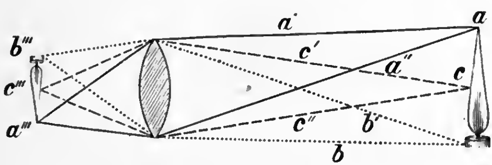


FIG. 8.—*Diagram of the convergence of rays of light.*

57.—*The Formation of Images by Refraction from a Convex Lens.*—If we take any double convex lens, as that shown in section Fig. 6, we find, if it is held towards the sun at a certain distance from a solid surface, we form a burning-glass,—that is, we produce an *image* of the sun where his rays of light and heat are refracted by the whole of the surfaces of the glass. The distance from the centre of the lens to the point of greatest light is called the *solar focus* of the lens,—that is, the point at which it concentrates or converges parallel rays, and forms the image of the sun. With parallel rays from the sun, the distance of focus is less than if these rays were divergent in any degree. Consequently the *solar focus* is less than that subtended by any object on the earth.

In the diagram Fig. 8, a candle-flame at *acb* forms its focus at $a'''c'''b'''$, where all rays converge to form an image in the following manner:—Every point of the candle throws its light upon every point of the surface of the lens, and, therefore, throws the image of each point to its focal position behind the lens, according to the direction of its refractions; so that, if we take all the separate points of light thrown from the candle, we then have a perfect image of it formed by the immense number of separate focal points, and as the rays by their direction necessarily cross over the axis, the image is in an *inverted position*.

The whole of these lines would form a confusion if shown in a diagram. We may, therefore, take for illustration the exterior of a cone of rays proceeding from three points only. Thus the *clear* lines aa' and aa'' from the point of the flame would refract to the lower part of the image a'''. The *dotted* lines bb' would proceed to the upper part of the image, as shown by the continuation of the *dotted* lines to b''', whereas the central *dash* lines $c'c''$ would form their images in the centre following the *dash* lines to c''', and thus, from the number of luminous points, the whole image of the candle would be produced at the focii $b'''c'''a'''$ in an inverted position.

58.—*Dispersion of Light.*—The conditions stated above for refraction of monochromatic light would not answer for perfect vision, which is only possible in clear white light. It therefore becomes necessary in practice to correct the quality of *dispersion*, which light suffers in refraction through any dense medium. The evidence of dispersion by glass may be shown by a prism, as in the following diagram :—

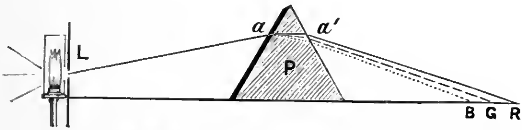


Fig. 9.—*Diagram showing chromatism of light by the prism.*

Let Fig. 9 *P* represent the section of a prism of glass, covered except at the narrow opening *a*. Let a strong light, as shown, be covered, except from a narrow slit, then the ray from the light, refracted from *a* towards *a'* in the prism, will be dispersed or split up at *a* into the colours of the rainbow, shading from blue, green, and yellow, to red, within the prism. Upon emergent refraction at *a'* this dispersion will increase so that an image of the slot near the light, if thrown on a plane proceeding from the base of the prism to the right, will be represented at *BGR* by a prismatic or *chromatic spectrum*, as it is termed, shading off from blue to green, to yellow, to red.

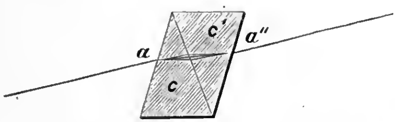


Fig. 10.—*Diagram perfect achromatism.*

59.—*Achromatism of the Prism in the same Quality of Glass.*—Taking the prism Fig. 10 *C* as before and applying a second exactly similar prism *C'* reversed upon the face of the first—then at every part of the process of dispersion from a point of white light under diffraction into the first prism, will by equal diffraction, in passing through the second prism, be brought *to a point*, where it will issue a white ray at the point *a''*, as it entered at the point *a*; or, practically, the emergent ray will be achromatised. This principle must be followed in the manufacture of achromatic lenses, although under various indices of refraction and dispersion from differences in the qualities of glasses. It is made use of in the achromatism of eye-pieces, and in combinations, and assures the achromatism of parallel glasses used for sextants under different angles of incidence.

60.—**The Achromatic Lens.**—The achromatism of a pair of lenses by which a large amount of refraction of pure white light is obtained, depends upon differences in the qualities of glasses which are due to their density and chemical composition, so that in one glass a less amount of dispersion is produced at an angle which gives an equal amount of refraction than in another. The combinations of glasses in use are crown and flint, as already described art. 26, the crown being a light glass of soda and silica, the flint being a heavier glass containing potash and lead. In a certain kind of flint glass used for optical purposes for a prism giving only slightly greater refraction to one of crown glass, the dispersion is about double. Therefore, we may combine a pair of glasses so that we obtain a desired amount of refraction from the combination, if we make the crown glass refract something over double the amount we require for the perfected lens or prism, and diminish this quantity by the reverse refraction of the flint glass, thereby entirely correcting the dispersion, as may be shown by the diagram on next page.

Let Fig. 11 *C* be a prism of crown glass giving over double the amount of refraction to a prism of flint glass *F*; but only of equal total dispersion to the thicker crown glass. The compound white ray of light *a* will then be dispersed upon refraction at the meeting faces of the two prisms, a certain quantity represented by the cone of rays shown, and again converge at *a′*, an equal

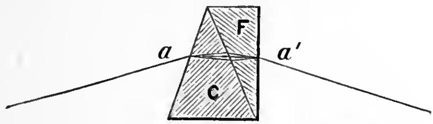


FIG. 11.—*Showing principles of achromatism.*

quantity on emergence from the exterior surface of the flint prism, so as to issue again a white ray, of which this system of prisms has refracted, but not dispersed, the light.

61.—That the same principles given above for the prism will hold in the achromatic compound lens, is already demonstrated by the comparison of lenses and prisms shown in Fig. 2; but for the sake of clearness, it may be again shown diagrammatically in Fig. 12 for an

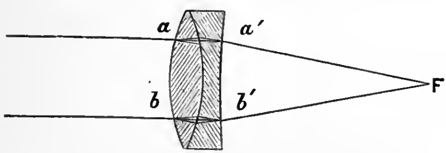


FIG. 12.—*Showing achromatic objective.*

actual objective, wherein the parallel rays *a b*, proceeding from a distant object or star, are shown refracted to *a′ b′*, and coming to a focus at *F*, although dispersed at the meeting surfaces of the two glasses, as shown diagrammatically, by the internal cone of rays.

62.—Practically, the matter is not quite so simple as it would appear to be, theoretically, by the above-described conditions, as we actually find the spectrum of a prism of flint glass of equal dispersion to one of crown glass does not give exactly similar extent of separate colours within its spectrum, the medium ray of the spectrum in the flint glass being nearer the blue than in the crown. Thus, this compound lens does not perfectly correct by inversion as it does in the perfect case discussed, and shown in Fig. 10. For this reason better definition is found by slight displacement and slight difference of total extent of dispersion of one of the spectra in coincidence on the *meeting planes* between the lenses, leaving in all cases a certain amount of residual colour, blue or red uncorrected, by making the glass *under* or *over corrected*, as it is termed, which does not, however, seriously impair distinct vision. It is quite possible that, by some future improvements in the chemical constitution of the glass, this defect may be remedied. English glass-workers prefer to *over-correct*. German and French glasses are more often *under-corrected*.

63.—The measurements of refraction and dispersion being both in one direction, may be taken together within certain angular limits in one term in the construction of a lens as *the ratio of dispersive powers*, the indices being certain dark lines which are observed uniformly in the spectrum of the sun projected from a narrow slit. These lines or bands in the sun's spectra are known to be due to metallic vapours which are present in his atmosphere, and can therefore be reproduced by the deflagration of like metals on a small scale. To certain of these lines letters of the alphabet have been applied. Of these letters, a pair of lines due to sodium vapour marked D, and three lines due to hydrogen, marked C, F, and G, are commonly taken for reference of dispersion. Achromatism is generally considered duly corrected when the lines C and G are united. The middle of the spectrum between these lines is about E; and chromatic dispersion of optical flint and crown may be taken to be fairly corrected, if the spectra are coincident in colour at this line.

64.—*Curvatures in the Achromatic Lens.*—A large amount of mathematical power has been expended upon this matter, but the perplexity of the subject is due to small differences of the material; and the impossibility of working even, absolutely true, spherical curves, has rendered this work of little practical value to the optician who still resorts to the formulæ of Dollond and Tully. Those who care to follow the subject beyond the scope of this work will find numerous papers in the *Phil. Trans.*, and in the works of Herschel, Barlow, Coddington, Robinson, and Stokes, wherein, what is known theoretical of the subject is fully investigated and discussed.

65.—For all small achromatics, such as are employed in surveying instruments with Chance's hard crown and dense flint, the following simple formula is commonly employed, expressed in terms of the radius of the curved surface into f, the total focus of the finished objective, for first working before trial:—

1st.—Outside	surface,	$\frac{f}{2}$	convex,	crown.
2nd.—Inside	,,	$\frac{f}{3}$	,,	
3rd.—Outside	,,	$\frac{f}{3}$	concave,	flint.
4th.—Inside	,,	$4f$	convex,	

By different makers the surfaces are changed as far as reversing the curvature of the front glass, and indeed very good glasses are made with the 1st, 2nd, and 3rd $= \left(\frac{f}{2\cdot5}\right)$. In all cases true convergence of the white ray is only obtained by correction of the outer and inner surfaces, or by *figuring*, as it is technically termed, in which the curvature is not only made greater or less, but its character is altered generally in the direction from circular to elliptical section. Excellent information upon this subject was given in a lecture before the Royal Institution, by the eminent optician, Sir Howard Grubb, of Dublin.*

* Proc. Royal Inst., May 1886.

66.—*Optical Arrangements of the Telescope.*—The earliest form of telescope is that of Kepler Fig. 13. In this the

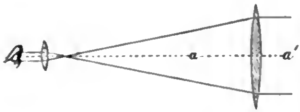


FIG. 13.—*Kepler's telescope.*

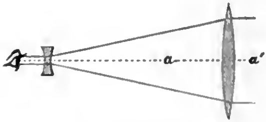


FIG. 14.—*Galileo's telescope.*

rays from the object-glass cross in front of the eye-glass; consequently, the image is inverted. This form is at present little used except in combination with a separate eye-piece.

Galileo's Telescope, Fig. 14.—In this the eye-piece is a concave glass. This glass is placed inside the focal distance, so that the rays from the object-glass are bent to less convergence, that they may enter the pupil of the eye in a direction possible to reach the retina. The image in this telescope is maintained erect. This principle is used entirely for field and opera glasses, also for sextants and some other instruments where it is desirable to keep the image erect, and small power is required, sufficient only to obtain more distinct vision. The lines *a a'* in Figs. 13, 14 are termed the axis of the telescope.

67.—*Optical Arrangement of the Huygenian Telescope.*—In surveying instruments, where angles and directions are

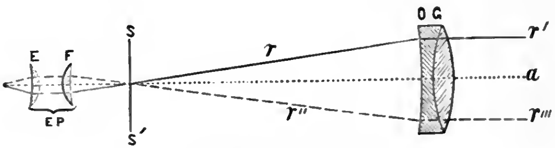


FIG. 15.—*Diagram of arrangement of lenses.*

not taken by coincidence of direct and reflected images, it is necessary that the direction of the axis of the telescope should be clearly indicated. In this case the focus of a distant object is projected upon a plane, termed the *diaphragm* Fig. 15 SS', upon which a visible object or index is placed, the position of which is picked up by a secondary telescopic arrangement, or *eye-piece* as it is technically termed.

68. — The arrangement of lenses in a surveying telescope is shown in the illustration above, where OG is the *object-glass* or *objective*, E the *eye-glass*, F the *field-glass*. The two lenses, E and F, in their mountings form the *eye-piece EP*. The dotted line a is the *axis* of the telescope, SS' is the *focal plane* of the object-glass, where a metal disc is placed with an opening in its centre—this is termed the diaphragm, or, technically, the *index-stop*. Across the opening in the disc, spiders' webs or other fine visible objects are placed, to be described further on.

69.—Both the object-glass and the eye-piece are fitted in sliding tubes, which will be described presently, in such a manner as they may be made to approach or recede from the focal plane SS'. The nearest distance of the object-glass to this plane being the solar focus, or the distance at which a sharp image of the sun or a star placed in the axial line would be formed. The greatest distance of the object-glass from the focal plane in most instruments is such that a clear image will be given on this plane SS' of an object placed at about twenty feet from it.

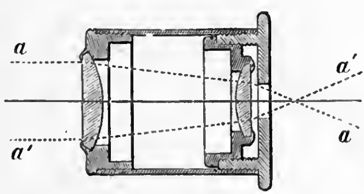


FIG. 16.—*Ramsden eye-piece.*

70.—**The Ramsden Eye-piece**, the optical arrangement of which is shown Fig. 16, is also known as positive eye-piece. It consists of two plano-convex lenses, the convex surfaces of which are turned towards each other. They are separated by a distance equal to two-thirds the focal length of either glass, and placed at one-fourth this focal length from the field-glass to the image given by the objective on the diaphragm.

71.—This eye-piece is considered not to be quite so achromatic as another form known as the Huyghenian eye-piece, but its spherical aberration is less than any other, and it gives what is necessary in all measuring instruments—a flat field of view, requiring no change of position to see the centre and border of the field with equal distinctness.

72.—*The Field of View* should be as bright as possible. To ensure this, the field of the object-glass which is taken by the eye-piece at the position of the front of the eye should not be larger than the pupil. If the whole field of light enters the eye as it should do, the brightness will then vary directly as the square of the diameter of the object-glass, and inversely as the square of the magnifying power. The directions of the rays are shown by dotted lines as *a a* and *a′ a′* for the Ramsden eye-piece in Fig. 16. This eye-piece is sometimes called an *inverting eye-piece*. It is not really so: the object-glass *inverts* its image and the eye-piece picks up the image in its inverted position. Two or three eye-pieces of this kind, of different magnifying powers, are commonly supplied with one surveying instrument. The same form of eye-piece being also a simple microscope, is used to read the division on the divided circles of theodolites, sextants, and other instruments, and for such purposes it is often desirable to ascertain its focal length.

73.—*The Focal Length* of the positive or Ramsden eye-piece is found by dividing the quotient of the focal lengths of the two lenses by their sum, diminished by the distance between them. Thus, if the focal length of each of the lenses be 1·5 inches, the distance between them 1 inch:—

$$\frac{1·5 \times 1·5}{3 - 1} = 1·125 \text{ inches.}$$

74.—*The Magnifying Power of the Telescope.*—The focal length of the objective divided by that of the eye-piece gives the power of the telescope. Thus, a 14-inch telescope with the above eye-piece would have a power,

$$\frac{14}{1·125} = 12·444 \text{ or } 12\tfrac{1}{2} \text{ nearly,}$$

a very general lowest-power eye-piece with telescopes of this focus.

75.—**Dynameter.**—The magnifying power of a telescope may be ascertained, without any knowledge of the focus of the glasses used in its construction, by the use of a dynameter. This instrument Fig. 17 consists of a compound microscope in which a finely-divided

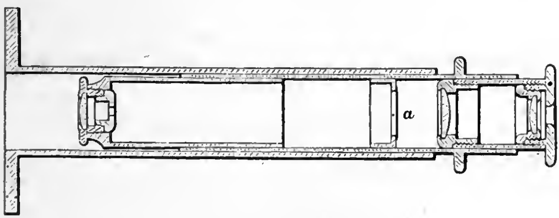


FIG. 17.—*Dynameter.*

transparent scale is placed in the mutual focus of its object-glass and of the eye-piece at *a*. The divisions of the scale may be ·01, ·02, or ·001 inches apart, adjusted so that a disc ·1 inch diameter at the exterior focus of the eye-piece may read a given quantity upon the scale. To use this apparatus, the flanged face is placed in front of the eye-piece of the telescope, previously set at solar focus. The telescope throws a circular image of its object-glass through the eye-piece, where it is picked up by the object-glass of the dynameter and brought to focus on the scale *a*, where it appears as a circular disc of light. If this image be measured by the scale, and the diameter of the object-glass be divided by this measure, the quotient will be the magnifying power of the telescope. There are several other forms of dynameter.

76.—**The Erecting Eye-piece**, generally supplied with theodolites and occasionally with other instruments, is the ordinary eye-piece of the common telescope Fig. 18. The glasses are so arranged as the image brought to the focus of the telescope inverted is again erected, so that objects appear in their natural position. The complete eye-piece is of the same optical arrangement as that of a compound microscope. The arrangement of lenses is shown in the engraving below.

FIG. 18.—*Optical arrangement of erecting eye-piece.*

A object lens, B amplifying lens, C field lens, D eye lens. Stops are placed at *d* and *d'* to cut out extreme rays. The image is formed by the objective at *O*, and the light passes in the direction shown by fine lines, being thrown from side to side of the lenses. The ray is achromatised proportionally to its dispersion by the separate lenses, upon principles discussed art. 59 and shown Fig. 10, as independently of the small amount of opacity of the lenses' extreme rays are cut off, so that central portions only are used. This eye-piece suffers loss of light at each of the four lenses; therefore, a telescope with it, for equally distinct vision to that obtained by using the Ramsden eye-piece previously described, would require a much larger objective.

77.—**The Diagonal Eye-piece** is used upon transit instruments, theodolites, and occasionally upon mining-dials Fig. 19. It permits the telescope to be used by the observer looking at right angles to its axis. Thus,

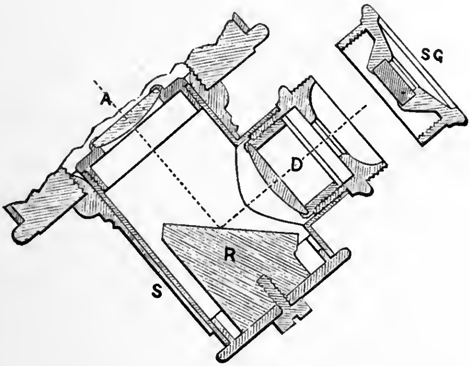


FIG. 19.—*Diagonal eye-piece, full size; S G sun-glass.*

by the natural direction of the eye, stars or the sun may be observed to near the zenith, or the direction of a line cut by two lights at the bottom of a shaft may be observed from above by a theodolite on its ordinary stand, to check the magnetic bearing of the needle if this is assumed to be subject to local disturbance. The socket of this eye-piece screws upon the telescope and has a free inner tube for rotation, so that the 90° to the axis of the telescope may be placed to any angle to the axis of its cylindrical circumference; as for instance, instead of being used vertically or for zenith stars, it may be used horizontally where precipitous ground would not permit direct axial vision through the telescope. The reflecting arrangement of this eye-piece may be adapted either to the Ramsden or the *erecting* form. In either case the reflector is placed in the central portion of the eye-piece. In surveying instruments the reflector is generally a piece of polished speculum metal for portable instruments, but a prism of glass for larger fixed instruments. The general arrangement is shown in the section of a diagonal Ramsden eye-piece on page 45, full size. *A* object lens, *D* adjustable for distance from the reflector *R*, *S* outer casing which permits adjustment to the diaphragm placed in front of *A*.

When a rectangular prism is used for the reflector, it is worked with one plane 45°, as previously discussed art. 51, Fig. 3. In place of one or both the 90° faces these surfaces are sometimes worked convex so as to form a magnifier dispensing with one of the convex lenses of the eye-piece. A long diagonal eye-piece is necessary, where stars towards the zenith are to be observed, to prevent interference of the limb of a theodolite with the face of the observer.

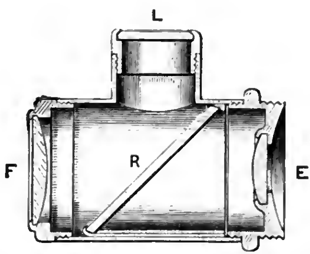


FIG. 20.—*Reflector in eye-piece to illuminate the front of diaphragm.*

78.—**Reflecting Eye-piece**, to illuminate the front of the webs in the diaphragm, is often required to observe small stars, as the circumpolar stars of the southern hemisphere, where a light thrown down the telescope from a reflector to illuminate the webs, would tend to dim the effect of blackness of the sky and render these stars indistinct. In the eye-piece Fig. 20, a piece of plain parallel glass is placed at an angle of 45° to the axis. This permits the webs to be clearly observed through the glass at the same time that it throws light from a lamp placed at a distance from the glazed aperture *L* by reflection of the surface of *R* sufficient for front illumination. The amount of light required is regulated by the distance of the lamp from *L*. This eye-piece is made to fit into the diagonal eye-piece casing, as *S* Fig. 19, *E* Fig. 20 being the position of the eye, *F* object lens.

79. — **Sun-glass.** — Sextants and theodolites are supplied with a very dark glass or a combination of dark glasses fixed in a rim to form an eye-piece front, which screws or fits on in front of any eye-piece, to take observations of the sun for longitude or bearing, Fig. 19, *S G*. It needs no description, but is necessary to be mentioned to complete the *optical* arrangements of a telescope, as it is sometimes used for surveying purposes.

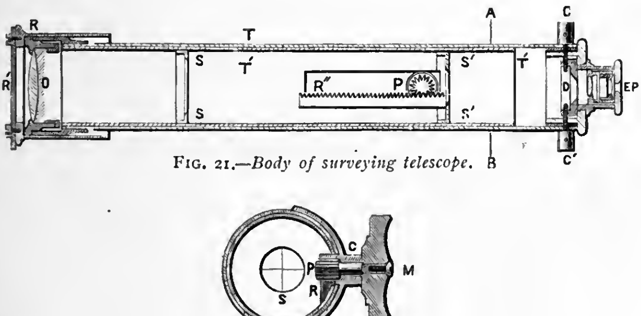


FIG. 21.—*Body of surveying telescope.* B

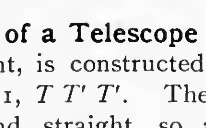


FIG. 22.—*Section Fig. 21, A to B.*

80.—**The Body of a Telescope** that forms part of a surveying instrument, is constructed of a pair of *triblet* drawn tubes Fig. 21, *T T′ T′*. These tubes should be truly cylindrical and straight, so as to fit smoothly together, the one within the other, and slide in and out quite freely but without any play. The inner tube should be as long as practicable, so as to remain steady when drawn out to the full extent required to sight near objects.

The object end *R* is generally enlarged so as to take the cell in which the objective *O* is placed, without cutting off any part of the light, or entailing the weight of larger tubes than is necessary to make use of the full field of the objective. The objective is generally held in its cell by an internally-fitting screwed ring with milled edge, so that the glasses may be taken out and separated to be cleaned, and be easily replaced. Two notches or grooves are commonly made in the edges of the glasses, one of which is deep enough to take a small brass pin which is soldered to the edge of the cell, and the second notch indicates relative position, so as to secure the glasses being replaced properly. In all cases the double convex crown glass is placed outwards from the telescope. A glass of large size should have a loose ring within the cell, to act as a spring to save distortion of the objective from shrinkage of the metal; but this is not necessary in ordinary surveying instruments. In some small telescopes the object-glass is burnished into its cell, in which case the glasses of the objective cannot be separated for cleaning.

81.—*Stops.*—Within the inner tube two thin metal rings, termed technically *stops* *SS* and *S'S'* are placed to cut off any extraneous light which may enter the telescope obliquely, and which, if not stopped off, would produce a fogginess over the whole field of view. It is important that these stops should not cut out any part of the full aperture of the object-glass if it is a good one. In the manufacture of the telescope this is easily seen by looking in at the eye-piece of the unglazed telescope to see if the stops clear the objective cell. In the finished glazed telescope another method will be discussed further on.

The inner tube of the body of the telescope is generally slid toward or from the objective for focussing by means of a *rack* *R''* and *pinion* *P*. The rack is soldered to the inner tube and the pinion fitted in a *cock-piece*, as shown Fig. 22 *C*, on the outer tube. The pinion is moved by a large milled head M. This fitting should be made with care. The pinion should be very free, so that it does not lift the body at any tooth, and at the same time there should be no shake on the gearing. It needs considerable practice to rack a telescope properly.

82.—The outward part of the object end of the telescope is generally turned to fit the interior of a separate short tube, shown at R, which is placed over it. The outer end is closed by a ring to the size of the aperture of the objective. This is termed a *ray-shade* or sometimes a *dew-cap*. The ray-shade is extended when the telescope is directed to such an angle that the sun's rays may fall upon any part of the objective, and thereby cause internal reflections. A swivel shutter Fig. 21 R' is placed upon the outward end of the ray-shade, which, when closed, as shown in the cut, forms a cap to the telescope. The eye-piece EP before described art. 70, Fig. 16, is placed in a tube constructed upon the end of the telescope, in which it slides freely, to focus upon the diaphragm to be presently described. The telescope is mounted sometimes solidly upon a transverse axis, or it is mounted in turned bearings, or it has two collars placed round it which are turned quite equal and true, and are mounted in V's which will be hereafter described.

83.—*Mechanical Adjustment of the Eye-piece.*—In some large instruments the eye-pieces are racked for adjustment in the same manner as the object-glass already described. A better plan is to have an inner tube to the socket tube cut with a screw into this, and provided with a milled edge, so that the eye-piece may be screwed gently to the focus upon the webs of the diaphragm.

84. — **The Diaphragm of the Telescope** is so constructed that it gives displacement of spiders' webs fixed in it in any direction at right angles to the axis of the telescope, or in the vertical only in the dumpy level

to be described, the object in all cases being to adjust the crossing of the webs to the axis of the telescope. It will be convenient here to discuss a general form of diaphragm applicable to theodolites, mining-dials, and plane-tables only, which gives movement in two directions at right angles to each other.

85.—The diaphragm Fig. 23, is formed of a stout disc of brass having a centre hole of about .30 inch diameter. Upon the side which is placed next the eye-piece, the hole is brought to a thin edge by an internal bevel or *countersink*, which leaves the hole much larger at its off surface Fig. 24 *P*. The disc is held in its place and adjusted by four capstan-headed screws, termed *collimating screws*, two of which are shown in section as

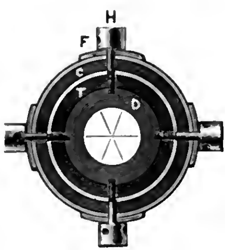


FIG. 23.—*Elevation of diaphragm.*

FIG. 24.—*Section of diaphragm.*

CC', the points of which are tapped into the rim of the diaphragm frame *P*. The screws are placed through a stout collar. The diaphragm has generally three spiders' webs crossed in the manner shown in the centre of Fig. 23. The eye-piece is screwed into the thick plate Fig. 24 *TT'* and adjusts to the focus of the webs.

86.—**Webs.**—It is a somewhat delicate process to web a diaphragm, but it is necessary that every surveyor abroad, out of the reach of an optician, should understand the method. The webs are taken from a rather small or young garden spider. The best webs are taken when the spider has first commenced spinning. To wind off the web a fork is bent up out of a piece of thin brass wire. A long hair-pin will answer for this purpose very well, or even a fork formed of a thin branching twig of a shrub; but if this last be used it should be thoroughly dry, or the webs will be broken or be baggy by its warping in drying.

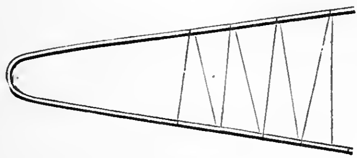


FIG. 25.—*Webs wound off for use.*

The web in connection with the spider is first attached to one prong of the fork by looping or by any sticky matter, if the web is not sufficiently sticky naturally. The spider is then suspended from the fork and jerked down a foot or so and the web is wound off as shown in Fig. 25. The last length of web being attached by gum. A dozen or so of forks may be taken from the same spider before she is exhausted. The webs are then gummed or varnished to the sides of the fork and are ready for use at any future time. They are most carefully preserved if placed in an air-tight box, which may have slots in an internal fitting to hold them. The small amount of spring given by the fork keeps the webs always taut. Where a living spider cannot be found, the open ties of an old web may be taken; but in this case, after the web is wound on a fork, it should be carefully washed by immersing it in clean water, and if necessary, brushing it gently under water with a light camel-hair brush, examining it occasionally with a magnifier to see that it is sufficiently clean and free from knots for its purpose.

87.—*To Fix the Webs*, lines are drawn on the diaphragm, into which the webs are to fall. It is then varnished over the divided side with Canada balsam, laudanum, or other quick-drying, sticky varnish—at a pinch, sealing-wax dissolved in strong brandy will answer. The outer, or the unused web upon the fork is lowered carefully over one of the most nearly vertical lines and lightly pressed down to assure its perfect adhesion to the varnish. It is then either broken off or cut loose. The second nearly vertical line is then webbed in the same manner and the horizontal line finally, being sure that this last cuts the intersection of the others. The diaphragm should then be placed in a warm place to be allowed to thoroughly set without disturbance before it is placed in the telescope.

88.—**Platinum Wires** are sometimes used in place of webs. These wires are made by drawing a piece of fine platinum wire, which has been previously soldered into a silver tube, to the greatest fineness possible with the draw-plate, and afterwards dissolving the silver off the platinum by nitric acid. The platinum wire is thus produced of less than ·001 inch diameter. For a time these wires were very popular, and it was thought that they would supersede the use of webs, but they do not appear to entirely answer expectation. The platinum drawn in this manner appears to lose some part of its elasticity. It is not easily fixed, that is, it is liable to shift from its fixing, possibly from its contraction and expansion with change of temperature, not being of the same metal as the diaphragm. It appears to become dewy more readily than the web, from moisture condensing in the telescope. It also oxidizes a little or becomes in some way corroded in use out of doors. It appears to answer better for astronomical telescopes. It is convenient to be taken abroad for use in case of accident where a suitable spider cannot be found or where webs are known not to stand very well. Where platinum wire is to be used, four small flat-headed screws should be placed on the diaphragm, towards its outer edge, to hold the platinum under their heads. If platinum is used to replace webs, the varnish used for fixing the webs should be cleared well off with spirits, so that the wires may lie in the divided lines.

89.—*Position of the Diaphragm in the Telescope.*—If the objective is accurately centred and its mounting true, the intersections of the webs should come exactly in the axis of the telescope; but it would never do to accept this without critical examination. Therefore the webs may be placed approximately in the centre and adjustments be made true with the axis of the objective and the telescope by what is technically termed *collimation.* The first point, however, to be studied in this adjustment is to get the eye-piece and the objective accurately in focus with the webs. The same description of focussing which answers for collimation will answer also for ordinary use of the telescope.

90.—*Adjustment of the Eye-piece to the Webs* is effected by pushing in or drawing out the eye-piece in its tube with a slight screwing motion until the webs appear most distinctly. To prevent confusion from the sighting of objects, it is better to take off the ray-shade to point the telescope to the distance in opposition to the direction of the sun, and to keep the telescope rack fully extended, so that it is quite out of focus. When the light is not very bright a sheet of note-paper or an envelope may be placed obliquely in front of the object-glass to obtain a soft reflection from the sky. This method is always employed by some observers.

91.—*Adjustment to Focus of the Objective—Parallax.*—The eye-piece remaining in focus, the telescope is racked out until the object desired to be brought in view, either for the collimation or for ordinary reading, is sighted. After this the milled head is moved as slowly as possible until what is thought to be the exact focus is obtained. The certainty of exact focus is not easily obtained by direct observation, but it may be obtained by what is termed *observation for parallax*, which must be taken in all cases when adjustment is required for collimation. Thus, having obtained the nearest possible adjustment by sights of a small object or a division upon the staff, bring the object to read exactly in a line above the horizontal web in the centre of the stop or the corner against a vertical web. If now the eye be moved up and down as far as the range of the eye-piece will permit vision of the centre of the webs, and the object sighted appears fixed at the same position to the webs, the focus is perfect. If, in moving the eye, the object sighted appears to follow its motion about the intersection of webs, the focus of the telescope lies beyond the webs; the objective must therefore be moved slightly nearer the webs by turning the milled head very gently in a left-handed direction. If, on the other hand, the object sighted moves in the opposite direction to the eye about the intersection of the webs, the focus of the telescope is towards the eye-piece, and the telescope requires slightly racking outwards by moving the milled head in a right-handed direction.

92.—*Collimation*—the adjustment of the crossing of the webs of the diaphragm to the axis of the telescope and its object-glass. This is effected by adjustment of the opposite collimating screws, Fig. 24 *CC'*, in two directions at right angles to each other. Where the telescope is placed in Y's or collars, this adjustment is made by placing the webs in focus of the eye-piece and the telescope in focus upon a small distant object. Then if the telescope is rotated in all directions and the small distant object cuts the crossing of the webs in all positions, it is said to be truly *collimated*. It is necessary to discuss the structure of various instruments to show the methods of collimating in special cases; therefore this subject will be again brought forward.

93.—*The Qualities of a Telescope* of a surveying instrument are best ascertained by its performance. The general method is to place a staff at the full range, 10 to 15 chains, and to see if the ·01 foot in fine bright weather is read clearly and sharply. This out-door observation is not always possible, particularly in large towns, but it may very well be supplanted by reading at a short distance. The author made for the late Colonel Strange, F.R.S., whose knowledge of scientific instruments was of the highest order, a test-card for the Lambeth observatory, to be placed at 25 feet from the instrument. This card had on one part fine lines ruled ·01 inch apart. A 14-inch telescope was considered sufficiently good if these lines could be clearly separated at this distance by the telescope when it was in correct focus. The dial of a watch, or an ivory scale answers very well as a test object, as sharpness of outline is the point to be ascertained.

A more refined technical method than that described above, which also tests the general accuracy of the optical arrangement of the telescope, is to fix a small disc of white writing-paper, say $\frac{1}{8}$ inch diameter, cut out with the point of a pair of compasses with sharp outline, on a black surface of a board, paper, or cloth. If this be placed as before, 30 feet or more distant in a good light, and be correctly focussed in the telescope, a sharp image of it should be obtained. This focal position of the telescope may be temporarily marked upon the inner tube with a fine soft black-lead pencil. If now the object-glass be racked outwards or inwards from this line, say for about a twelfth of an inch, and the image appears to be surrounded with a uniform haze, the objective may be considered to be correctly formed, or to be free from spherical aberration as it is termed, and the combination to be correctly centred. If the haze appears more on one side than the other the centring is defective. If the object remains fairly sharp when out of exact focus, the curves of the lens are defective, as the shorter the range of focus the more perfect is the correction from spherical aberration.

94.—If the curves are not sufficiently correct to throw the image from all parts of the objective to a focus, such incorrect parts are useless, and a good glass of smaller size would be better. The fault is generally found in the marginal portion of the objective which requires the greatest skill of the glass-worker. Therefore, a very good test to find if the whole of the aperture of the objective is in effective use, is to cut out a piece of card of the size of this aperture and to cut a second piece out of the centre of this, of half the diameter, so as to form a disc and a ring. If the objective be now covered by the ring and accurately focussed upon a test object, and this be then removed and replaced by the disc fixed over the centre of the objective, and the focus remains equally sharp, the curves may be said to be, practically, correctly worked.

As the central part of an objective is more easily got to correct curvature than the marginal parts, it is not uncommon in inferior instruments to make the aperture of the central stop of the telescope cut off the margin of the objective. This renders it only equal to a smaller glass.

95.—Whether the full aperture of a telescope is used may be discovered by employing a second eye-piece—outside the regular eye-piece that is placed in the telescope—to pick up the image of the object-glass formed through the eye-piece which is placed against the telescope in the manner of using a dynameter art. 75. With the ordinary surveyor's level, two eye-pieces are usually sold; one of these may be placed in the telescope, and the other used to pick up the image of the object-glass. With a theodolite, one eye-piece may be placed in the telescope, and one of the readers used to magnify the divisions of the limb may be used to pick up the image. The best manner of proceeding is to fix with water or thin gum two or three small pieces of paper, say $\frac{1}{20}$, $\frac{1}{10}$, and $\frac{1}{7}$ inch square, close against the edge of the cell upon the face of the objective. Then focus the telescope on an object at some distance, say a chain or two. Now use the second eye-piece in front of the one in the telescope, and an image of the object-glass will be seen; and if the aperture is fully open, all the pieces of paper in their places will be clearly distinguishable. If one or other piece is invisible, the margin of the glass is cut off to this extent. If the objects in front of the telescope tend to confuse, a piece of white paper may be placed obliquely to reflect the light of the sky into the telescope, which will at the same time fully illuminate the objective.

The discussion of the principle of the anallatic telescope, used only with the tacheometer, is deferred to chapter XII., where subtense instruments are described.

CHAPTER III.

THE MAGNETIC COMPASS AS A PART OF A SURVEYING INSTRUMENT OR SEPARATELY—BROAD AND EDGE-BAR NEEDLES—MANUFACTURE OF THE NEEDLE—MAGNETIZATION—SUSPENSION—DIP AND ADJUSTMENT—LIFTING—INCLINATION — DECLINATION — VARIATION —CORRECTION — COMPASS-BOXES — PRESERVATION OF MAGNETISM — DESCRIPTION OF COMPASSES—RING COMPASSES—TROUGH COMPASSES—PRISMATIC COMPASSES—STAND—SURVEYING WITH COMPASS—POCKET COMPASSES.

96.—**The Magnetic Needle**, which forms part of a great many surveying instruments, is made of the form adapted to the special purposes of the instrument in which it is placed. There are two prevailing forms commonly in use—one in which the needle is made pointed at one or both ends to read directly upon a divided circle fixed upon the instrument, and the other form in which it is made to carry and to direct a divided circle by its magnetic force.

97.—The magnetism which gives directive force to the needle has been found by experiment to reside in every

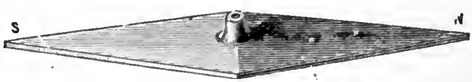


FIG. 26.—*Broad needle.*

FIG. 27.—*Edge-bar needle.*

separate part of the magnet, that is, it is assumed to be a *molecular* force. Therefore, it would not appear to be very important, within certain limits, of what form the magnetic needle is made, and this is found by experiment to be to a large extent true. The only important conditions appear to be, that the needle shall be of such form that the inducing magnet, to be described, which is used for magnetizing may be brought into contact upon every part of its surface, and that the molecular continuity of the parts should mutually support the general directive influence of the magnetism longitudinally in parallel lines.

98.—Magnetic needles are generally made in the form of flat bars, which are balanced upon a standing-point falling into a cup which forms the centre. When the greatest section of the bar is placed horizontally it is termed a *broad needle*, as shown Fig. 26. This may be made of the lozenge form shown or be parallel throughout. When the greatest section is placed vertically it is termed an *edge-bar* needle, as shown Fig. 27. The north pointing end of the broad needle is commonly tempered dark blue if the needle is left open. This is not necessary if it carries a ring. The edge-bar is generally used where it is required to read into a fixed circle of division, in which case its ends are brought to fine knife-edges.

From the difficulty of reading a sharp point in bright metal against the black line of a divided circle, the author occasionally makes the needle with one point of a broad

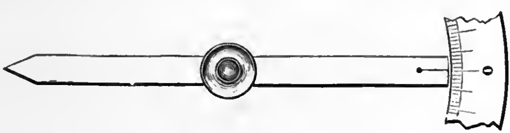


FIG. 28.—*Author's plan of needle reading.*

needle sawn vertically for a short distance, so as to form a kind of *split* which is closed at the end, so that it presents to appearance a fine black line of the same character as the divisions into which it reads. With this as shown Fig. 28, the reading is found to be much more easy. The point is also more easily adjusted by grinding, as the end of the needle being broad requires less care to be taken that it is not reduced so much that it leaves the interior of the circle short where it reads into the divisions. This form of needle is not adapted to mining instruments which have often to be read in an oblique direction.

99.—*In the Manufacture of the Needle*, it should be made of the finest cutler's cast steel, or, better still, of steel containing 3 per cent. of tungsten. If not left in a parallel strip as it is drawn or rolled, it should be brought as nearly to its form as possible by forging at a low heat. The steel should not be over-heated for hardening, and should be hardened in cold water or oil, and be tempered afterwards down to a very pale straw colour—in fact, the temper colour should only just appear. Long needles may have the temper sufficiently lowered at the centre to set them approximately straight during the tempering; but the temper should not be lowered even there below a pale blue, spring temper. After tempering, the setting and working up to balance is best done by grinding, and for the final adjustment, by stoning with Water-of-Ayr stone.

100.—*Magnetization of the Needle* may be performed in many ways by means of a permanent magnet or an electro-magnet, or by a solenoid. When the magnetism is induced from another magnet it is only important that the properly hardened needle should be regularly and equally magnetized over its surface by pressure upon it of the proper poles of the inducing magnet—that is, that the north pole of the magnet should induce magnetism in the southern half of the needle only, and the south pole in the northern half only.

101.—*Method of Single-touch.*—This method is more generally applied to touching up needles than magnetizing them at first. The northern pole of a strong permanent magnet is stroked down the southern end of the needle from its centre to its end three times on one side of the needle. The needle is then turned round, and the northern end is stroked down in like manner with the southern pole. The needle is then turned over and the process is repeated on the other side. This may be done a second time and the edges of the needle be stroked down also.

102.—*Method of Double-touch.*—In this process the needle is held down firmly with pegs on a board, and a strong horse-shoe magnet with rather close poles is laid on the bare needle without its cap in a manner that both terminals press upon it. It is then drawn backwards and forwards from end to end of the needle several times, lifting the magnet finally from about the centre. The process is then repeated on the opposite side of the needle and its edges.

103.—*Method of Divided-touch* is a somewhat quicker process, which does not entail removing the cap, the general plan of which is shown in the engraving below. The poles of the magnets, or one of them is marked. Two good straight bar magnets are used. The needle is fixed down on a board and the poles of the two

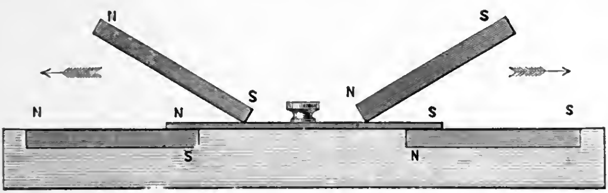


FIG. 29.—*Divided-touch magnetization.*

magnets are laid upon it at an angle of about 30°, applying one north or marked pole, and one south or unmarked pole. The magnets are then drawn apart in a horizontal direction along the needle with constant pressure upon it, so as to reach the opposite ends of the needle simultaneously, and then again pressed back to the centre. After this operation is performed three or four times on one side of the needle, the needle is turned over and the process is repeated on the other side, being careful as before to use the same ends of the magnets upon the same ends of the needle. The operation may be repeated several times to be sure of saturation of the needle. It is better to lift the magnets off at the termination of the operation at the centre of the needle.

It is found that the needle is magnetized a little more quickly if it is laid upon a strong magnetized bar during magnetizing, or upon the ends of two bars as shown in the engraving Fig. 29, or on the two ends of a wide horse-shoe magnet.

Two needles may be magnetized at the same time by two horse-shoe magnets placed at their ends, so as to connect up a magnetic circuit, and then further magnetizing the needles by the same divided-touch system as that just described, but with two horse-shoe magnets striding from one needle to the other.

104.—Needles may be magnetized electrically by placing them in a solenoid or coil of stout insulated copper wire through which a strong current is passing, or be magnetized by a strong electro-magnet. But the divided-touch system above described is generally preferred, as being at all times ready to hand, and sufficient to ensure saturation if carefully done.

105.—With every care in the manufacture of the needle there remains a little difference in the qualities of needles which are apparently otherwise identical. Little local differences in the quality of the steel, or slight over-crystallization from over-heating in hardening, or unequal tempering, or unequal magnetizing, is liable to form weak parts or even what are termed *consequent points*. These are points in which the magnet possesses a reversal of its general longitudinal polarity. This can be made quite evident by experiment, as it is quite possible to make a needle not only with poles at each end, but with intermediate poles which are easily detected by sifting iron filings over it. The filings are found to adhere strongly at other local points than near the ends where a good magnet is alone strongly attractive.

106.—To get the best permanent effects from bar magnets used for magnetizing, they should always be returned to their cases directly after use, taking care that they are properly placed on their keepers, *N* to *S* always in the same way.

107.—*Mounting of the Needle.*—The needle for a surveying instrument has a female centre upon which it is suspended. The centre, termed technically *cap*, is generally formed of a hard precious stone, agate, chrysolite, ruby, or sapphire, the latter being best, simply from the high polish it attains in grinding out with diamond dust. Rubies and sapphires are like minerals, except in the colour which varies very much, the *off-colour* stones, which are of small value, only being used for scientific purposes. The cap is mounted in a brass cell made as light as possible for sufficient stability.

The needle is supported upon a hardened steel needle point, upon which it is perfectly balanced. The base of the point is tempered down to a low temper to admit a certain amount of bending to counteract the slight warping which generally occurs in hardening the point.

108.—*Correction of Errors.*—The needle, after it is mounted, although in balance may not have the steel placed symmetrical about its axis through slight curvature, unequal thickness about the cap, or otherwise, so that the magnetic direction is not perfectly lineal between the points and the centre. If the points and centre are not magnetically lineal, the correction for declination, which will be presently considered, cannot be made accurately. For this reason it is better for the manufacturer to mount the needle on a slate bed upon which there are two sliding heads that may be brought up to the points of the needle. The heads have upon their upper surfaces lines drawn perfectly lineal with the centre point of suspension of the needle, and a few lateral divisions to these lines for determining errors. On this bed the needle is placed to be examined how nearly its points are true with the axis. The error being recorded, the needle is demagnetized, and remagnetized end for end, and is again examined. Corrections are then made by grinding or stoning from observations of bisections of the points cut in the separate readings, until the needle is made symmetrical and invariable whichever end is magnetized for the north or south.

109.—*Lifting the Needle.*—The needle of a surveying instrument should never be suspended on its centre except for the time it is in use for observation, as a fine steel point against a hard stone must, by any jar in conveyance from place to place, receive a certain amount of abrasion that will make the point duller. For this reason a *lift* for the needle is always provided in scientific instruments. In the engraving Fig. 30, an edge-bar needle is shown in section

FIG. 30.—*Section of mounted needle.*

with its lift. The lift is made in the form of a bent lever, whose fulcrum is upon the bottom of the box. On the left-hand side of the broken line at *B* the needle is shown lifted. On the right-hand side *A* the needle is shown at its position for use, floating just slightly above the divided circle *D*. The pressure of the milled-head screw *C* depresses the bent lever or lift on the bottom of the box and thereby raises the point under the centre of the needle. This point has a hollow cone formed upon it which fits over the standing-point to keep the lift in position. The cone fits externally into the cap to lift the needle vertically. The screw *C* should always be clamped down when the needle is out of use. In place of the screw a wedge-shaped sliding piece is sometimes fixed inside the compass-box, which is moved by a stud projecting through the outer case. Another plan of raising the lift is by cam, or what is technically termed a *kidney-piece*, applied to the exterior part of the lift. Either of these plans answer, but the screw first described, being the gentler motion, jars the needle less. A screw is occasionally used longitudinally to the needle connected with a cam lift, the object in all cases being to lift the cap entirely clear of the standing-point.

110.—*The Inclination or Dip of the Needle* is the position a needle balanced level upon a free centre *before* magnetization takes in the vertical plane *after* magnetization. This inclination or dip varies in different parts of the globe, and at different times. At the present time (1889) at Greenwich, the angle is about 67° 23′ from the horizon. It is uniformly nearly *nil* at the equator, and increases until over one of the magnetic poles, where it becomes vertical. There are two magnetic poles in the northern hemisphere active in directing the needle, one in Siberia, but the most active is about Melville Island; also two in the southern hemisphere which are supposed to be nearly together, of which the exact position is not ascertained. As we require only the horizontal component, and not the dip, it is necessary to balance the needle in opposition to the direction of the dip until it keeps in a horizontal position. This may be done by making the needle lighter on the dip side—that is, the northern in this hemisphere. But the plan adopted in all scientific instruments is to place a rider over the needle, as shown Fig. 30 at *R*. This clips the needle sufficiently to hold firmly to its place, and yet is sufficiently loose to be moved by the fingers to balance. The rider has to be shifted when the instrument is taken into a country where the dip is different. Where a needle is taken abroad without any rider, it may be balanced by means of a little sealing-wax placed upon its uptending end.

To get at the needle for suppression of dip when it is placed in the compass-box, it is necessary to raise the spring ring, which is placed over the glass to keep it down, by inserting the point of a pocket-knife between the ring and the glass, moving the knife entirely round it and using a little twist upon it if necessary until the ring is free. This must be done gently or the glass will break. After the needle is adjusted to read correctly to the plane of the divided circle and it is replaced in its box, the glass is then replaced and the spring ring is pressed down by passing the finger firmly round it until it is tight upon the glass. This sometimes needs a little extra pressure by a hard body, but this must be done with care or the glass will be broken.

111.—*The Declination of the Needle*, that is, its pointing in a northernly and a southernly direction, is necessary to be known and considered by the surveyor where the needle is used, both in relation to the locality and to the time, as this declination does not only vary in different countries, but it varies from year to year. For instance this year (1889) in England. The needle points 17° westward of true north, from a point a little east of Cromer on the Norfolk coast to a little east of Hastings. It points 18° westward from Grimsby to a little west of Newport in the Isle of Wight; 19° westward from Hartlepool passing through Leeds and west of Bristol to Exmouth; 20° from Dunbar, east of Carlisle, Portmadoc, Tenby to west of Land's-end, these lines of declination all being curved slightly to eastward. This will give a general idea of the necessary correction for bearing when working with the compass, particularly for underground work where the needle has to be depended upon. The following chart

Fig. 31 gives the declination variation for 1887. The whole system of declination lines are now moving westward at the rate of about seven minutes per annum, but the rate varies locally and from year to year. These lines, however,

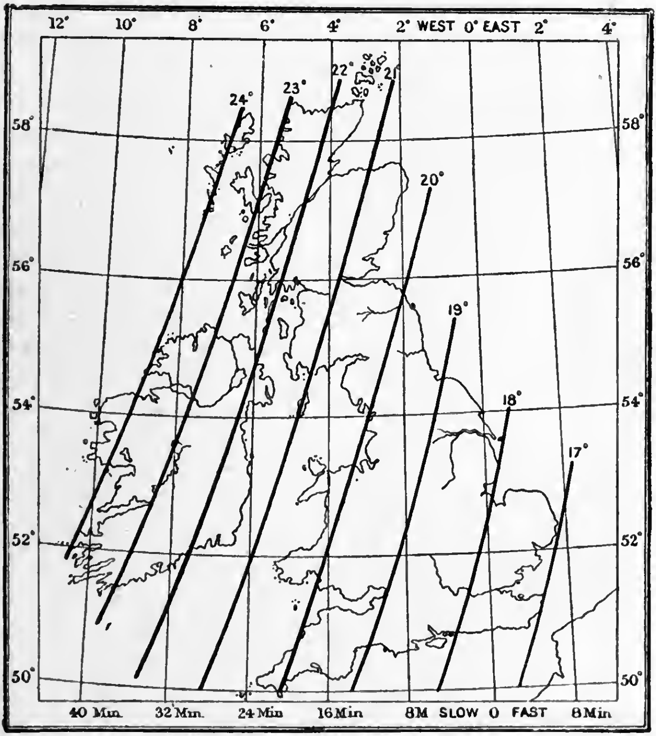


FIG. 31.—*Magnetic chart for Great Britain*, 1887.

independent of correction which will be presently considered, may not be truly represented by the symmetrically curved lines shown in the figure. There are local deflections from the theoretical curves here given, which are permanent and need local consideration when using the needle for obtaining correct bearing. These have been ably considered by Professor Rücker and Dr. Thorp, but the subject is too complicated to be entered upon here, except for this note of observation.*

112.—For new countries, where the needle often becomes most important from the impossibility of tying up lines by direct observation through forests and other obstructions, reference must be had to magnetic charts which give systems of lines which are easily worked through by symmetry, even for unexplored countries. At present the declination is west in Europe and in Africa; east in Asia and the greater part of North and South America.

113.—*The Magnetic Variation of Declination in Time*, becomes important in reference to old plans in which the magnetic north of the period has been plotted for the true north very much to the pecuniary advantage of the legal profession engaged upon disputed boundaries. The following table gives an idea of the variation in declination for London approximately for a few dates:—

Year 1580,	Dec.—	11° 36 E.	Year 1860,	Dec.—	20° 40 W.
„ 1663,	„	0	„ 1870,	„	20° 19′
„ 1700,	„	8° 20 W.	„ 1880,	„	18° 58′
„ 1818,	„	25° 41 W.	„ 1888,	„	17° 33′
„ 1850,	„	19° 31 W.	„ 1890,	„	17° 9′

It will be seen by the above table that the needle pointed due north in 1663, and that it attained its greatest western declination in 1818, and that it is now losing westerly declination somewhat rapidly.

114.—*Annual Variation.*—The declination is subject also to a small annual variation which is greatest about spring time, diminishes towards the summer solstice, and increases again during the following nine months. It varies at different periods and seldom exceeds 16′ of arc.

* See articles, "Underground Mountains," Prof. A. W. Rücker—*Good Words*, Jan., Feb., Mar., 1890.

115.—*Declination Correction* to true north may be made for the compass by observation in this hemisphere of the pole star, which is practically due north in January at 6 p.m., February at 4 a.m., March at 2 a.m., April at midnight, May at 10 p.m., August at 4 a.m., September at 2 a.m., October at midnight, November at 10 p.m., December at 8 p.m. Many surveying instruments are not made convenient for this observation, except the transit theodolite and some kinds of mining-dials. More generally observations of the position of the sun may be made where a sun-glass is provided to the telescope of the theodolite, Fig. 19 *SG*, with the aid of a chronometer or a good watch. For this observation we may remember that the sun is true south at twelve o'clock on the 16th April, 15th June, 31st September, and 25th December. The following table may be useful for some intermediate times to show how much the chronometer (mean time) is faster or slower than the sun's southing approximately at noon:—

Jan. 1	...	subtract 4 min.	July 15	...	subtract 6 min.
,, 16	...	,, 10 ,,	,, 30	...	,, 6 ,,
,, 31	...	,, 14 ,,	Aug. 14	...	,, 4 ,,
Feb. 15	...	,, 14 ,,	Sept. 13	...	...add 4 ,,
Mar. 2	...	,, 12 ,,	,, 28	...	... ,, 9 ,,
,, 17	...	,, 8 ,,	Oct. 13	...	... ,, 14 ,,
April 1	...	,, 4 ,,	,, 28	...	... ,, 16 ,,
May 1	...	... add 3 ,,	Nov. 12	...	... ,, 16 ,,
,, 16	...	... ,, 4 ,,	,, 27	...	... ,, 12 ,,
,, 31	...	... ,, 3 ,,	Dec. 12	...	... ,, 6 ,,
June 30	...	subtract 3 ,,	,, 31	...	subtract 3 ,,

As variation in time of southing is from fourteen minutes fast to sixteen slow, or a difference of thirty minutes, correction becomes important as the sun passes over $7\frac{1}{2}^\circ$ in this period. In these observations the webs must bisect the sun's disc. This is done more exactly by taking the position of the mean position of the sun's eastern and western limbs or its semi-diameter, which is given for every day of the year in the *Nautical Almanac*.

116.—*The Compass-box.*—The needle, as it is generally mounted for the theodolite, mining-dial, and many other instruments, reads into a divided circle of 360°. The circle is raised up from the bottom of the compass-box to the height of the top of the needle, as shown in section Fig. 30 *D*. It is generally silver-plated. The bottom of the compass-box is sometimes divided with a *compass-rose* giving the points N. E. S. W. The E. and W. in some cases are reversed from their natural directive position from the centre of the box, so as to read the letter indicating the point nearest to the division instead of the opposite to it. In modern surveying instruments, however, no regard is paid to the points of the compass, north being 0°, east 90°, south 180°, west 270°.

117.—In the manufacture of the compass-box very great care should be taken that the metal is quite free from iron, and that no iron comes near it. On this point the maker cannot be too guarded. The author has in several instances found the compass-box of perfectly free metal; but a single foul screw made of commercial brass wire, being used to fix the ring or the rose plate, has by its influence entirely destroyed the value of the compass.

118.—In the construction of the compass-box, the author has found the most certain method of getting the divisions correct with the centre, is to make the division directly from the standing-point of compass, and not to try to get this point correct to the divisions afterwards. The standing-point may be fixed directly to the box by screwing or be attached to a brass plate before fixing. It is adjusted to the compass-box by bending the standing-point until the needle turns freely, but at the same time nearly touching the circle. The needle is then removed and the circle is divided with the point as its centre. Where the divisions read to the point of the needle, or to a line upon it without a magnifier, the divisions of the circle may be made directly upon the lathe by a lever to the slide-rest if the lathe has a well-divided head-stock. When the divisions are magnified and require great accuracy, or where a floating ring is used upon the needle, the circle should be divided upon the dividing engine, which will be described further on, the centre used being still the point or *pivot* on the bottom of the case, from which the divisions are made radially.

119.—*Preservation of the Magnetism in Needles.*—It is most important that the magnetism of the needle, particularly in mining-dials where so much depends upon it, should be preserved to nearly saturation to secure certain direction in opposition to the friction of the centre necessarily always present. This is often much neglected from carelessness or want of knowledge of the principles of magnetic action. In the first place we know that a bar of soft iron, possessing no evident magnetism, if it be placed in the magnetic meridian with proper dip, will after a time manifest strong magnetic properties. Thus, such a bar in London placed due north and south, with a dip of 67° to the north, becomes a weak magnet. From this we may also infer and this experiment shows that a needle placed in this position will not lose its magnetism. But what is most important to observe is that if the needle is placed in a *contrary direction*, as, for instance, with its northern end towards the south, it is in constant opposition to the influences of terrestrial magnetism and will certainly become weaker. Therefore, although it is necessary to lift the needle when carrying the instrument, which must necessarily place its poles in all directions, it is not at all necessary that the needle should be lifted when the instrument is put by out of use. Indeed magnetism is *materially preserved* by releasing the lift to let the needle take its true bearing. This does not at all injure the standing-point, as there is no movement upon it to cause wear. Of course if the needle is at first magnetized beyond its permanent condition it will lose this surplus magnetism, but the residual magnetism in this position will remain nearly constant. A further precaution for needles in constant wear, is occasionally, say twice a year, or much oftener if used in a dusty mine, to take the needle out of its box and wipe out the cap with the point of a small sable brush. The standing-point may at the same time be sharpened if necessary by gently rubbing it all round with a slip of oiled Arkansas stone. The sharpness of a needle is easily ascertained by sliding the thumb nail over the point at an angle of about 30° to it. If the point sticks and holds the nail, it is sharp; if it glides upon it, it is dull. The author has often had compasses of various kinds sent to him for remagnetization whose only fault has been dulness of centre.

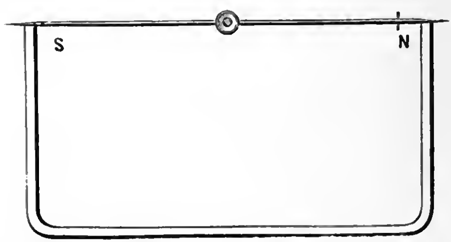


FIG. 32.—*Permanent magnet for preservation of magnetism in a needle.*

120.—*Magnetic Keeper.*—For the certainty of preserving the magnetism of needles, the author has constructed a peculiar-shaped permanent magnet, on the poles of which the needle is placed whenever it is out of use, thus maintaining the needle in a state of perfect saturation at all times. This is shown Fig. 32. There are two grooves in the poles of the magnet which hold the needle. The magnet is sunk in a block of wood and the needle has a cross pin at its north end corresponding with a groove in the block, which secures it being always placed to the right pole of the keeper when put by, as it will not lie otherwise. This magnetic keeper in its wooden sheath is attached to the box containing the mining-dial by dowels, so that it can be taken out and left at home if desirable when the dial is in use. By the use of this keeper weak or badly made needles become much strengthened. To enable the needle to be taken out easily, the compass covering glass is fixed in a spring cap. Care should be taken at all times when removing a needle for any purpose to replace it upon its point very gently. A slight concussion spoils a good point. Where the needle has to be entirely depended upon, a spare needle may be kept on its keeper. But if there is any variation in the two needles this must be noted.

121.—**Ring Compasses.**—In modern levels and prismatic compasses the magnetic needle carries a light divided circle which is now generally made of aluminium, on account of the extreme lightness of this metal. A broad needle is used of about $\frac{1}{4}$ inch in width and $\frac{1}{18}$ inch in thickness. There is considerable difficulty in mounting the circle to get it truly concentric and correct for bearing, therefore ring compasses are often found to be inaccurate. The author has followed two methods of construction, either of which answers fairly well:—The one is to leave a bar across the compass when cutting out the compass ring from a plate of aluminium. In this case, when the outer edge of the ring is chucked to be turned, a centre hole is also made in the cross-bar which exactly fits over the cap of the needle, so that the adjustment for centre is practically secured, and attention is only necessary to get the adjustment correct for bearing—that is, the 0° at true magnetic north to the axis of the needle. Another method, which was suggested to the author by Mr. Thos. Cushing of the India Office, answers perfectly and only entails a little extra trouble in setting for dividing. This is to permanently mount the ring on the needle without any means of after-adjustment, and to divide the circle from a point placed in the axis of the dividing engine, upon which the ruby centre is placed, being of course particular that the zero line 0° cuts the magnetic axis true north in the graduation.

122.—**Mariners' Compasses,** and an inexpensive class of prismatic compasses, are made with a paper disc in place of the ring above described answering the same purposes. The paper disc is generally made in two thicknesses with a thin sheet of talc placed between them. Mariners' compasses have frequently the divisions painted directly upon talc for transparency in lighting from beneath, also for general lightness combined with stiffness.

123.—The reading of mariners' compasses, and the compasses on levels where the needle carries a divided ring, is taken from a line drawn vertically up the inside of the box. This *lead* line in the mariner's compass gives the direction of the head of the vessel; a similar line in the level compass gives a direction in line with the axis of the telescope.

124.—**Trough Compass**, sometimes termed a *long compass.* Where an instrument possesses a double vertical axis and a divided circle, as the theodolite, the division of the circle may take the place of the divided ring of the compass and save the repetition of the graduation, at the same time the needle may often be made longer, as the bulk of the compass-box is proportionately less. In fact in all cases where the magnetic north only is required the trough compass is better. The ordinary construction of this compass is a narrow box representing in plan a parallel section taken through the ordinary compass-box,

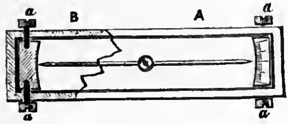


FIG. 33.—*Trough compass for attachment to an instrument.*

north to south Fig. 33 of about 10° to 20°, graduated on each side of the meridian line.

125.—**Magnification of Reading.**—With the trough compass it is very common to have some form of microscope for reading the needle more exactly. This may be done by a Ramsden eye-piece being placed directly over the needle, as is common in some German instruments. A much more convenient plan for certain instruments is to read the needle longitudinally. This is generally done by means of a transparent scale being placed across the end of the needle which is divided upon glass or horn. This may read to either the near or distant point of the needle. A very good form of needle reading is found in some French instruments. This is shown Fig. 34, where

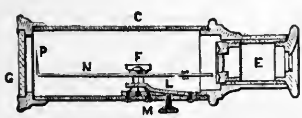


FIG. 34.—*Needle with reader.*

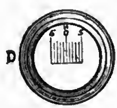
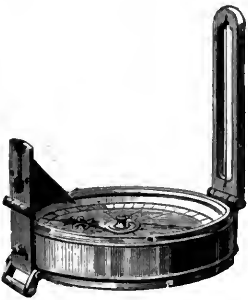


FIG. 35.—*Scale at G.*

the compass is shown entirely enclosed in a tube *C* which protects it from dust. The needle *N* has a vertical point fixed upon its end at *P* which reads pretty closely to a scale of 20° divided upon glass at *G* by the eye-piece *E*. It has a lift *L* pressed up by a milled-head screw *M*. Fig. 35 shows the graduated glass. This compass is attached beneath the limb of a theodolite or to any other convenient position upon any instrument. The author has placed a compass constructed upon this principle in a telescope, in a manner that the needle may be read with the eye-piece, so as to cut a line with a distant object coincident with the line cut by the principal telescope of the instrument as 0° of its graduation. This plan will be more fully explained with tacheometers, chapter XII.



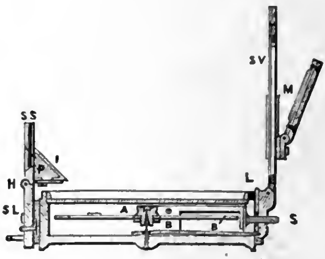


FIG. 36.—*Ordinary prismatic compass.* FIG. 37.—*Section of the same, but with mirror.*

126.—**The Prismatic Compass**, shown Fig. 36, was invented by Captain Henry Kater about 1814. It is the most convenient portable instrument for reading magnetic bearing. Angles may be taken with great rapidity within about 15′ of arc by holding the instrument in the hand, or perhaps within 5′ if the instrument is of 4 to 6 inches diameter and placed on a stand. It is a most valuable instrument for filling in close details, such as may occur among buildings, trees, etc., after the principal points have been laid down from observations taken with the theodolite. The principles of the reflection of a prism were discussed art. 50, Fig. 3.

127.—*Prismatic Compasses* are made from 2½ to 6 inches in diameter. The compass needle sometimes is made to carry a card dial for the 2½-inch size; for larger sizes the ring is uniformly of aluminium. The reading of the compass ring is effected by means of a glass prism

Fig. 37 P, which is cut to 45° upon one face and 90° for the two others, the 90° faces being worked convex, so as to give magnifying power simultaneously with reflection of the ring at right angles, so that the reading of the compass appears to stand erect before the user of the instrument and to be considerably magnified. As the reading is made on the side of the ring nearest the observer, the figures on the ring are engraved right to left. The prism is placed in a box which has a vertical sight slit SS over it which cuts a line with the centre of the top of the prism. The box with its prism moves upwards or downwards in a sliding fitting SL by means of a *thumb-nail* stud, which adjusts the prism until it is in exact focus with the divisions on the ring. The back of the prism-box has a hinge H, so that this box may be closed down to the level of the compass-box to render it portable when out of use. On the opposite side of the compass-box to that upon which the prism is placed, a long vertical window SV is attached, which has a central hair placed so as to cut a direct line from the slit SS in the prism-box across the axis of the needle. This window piece is jointed to turn down upon the face of the compass-box and simultaneously to lift the compass needle off its centre by a part of it pressing the outer end of the lifting lever L. To prevent too great a continuity of the oscillation of the compass needle and the ring, through unsteadiness of the hand in holding it, a pin is placed at S, through the compass-box under the window, which carries a light spring B that just touches the ring lightly when the pin is pressed in, and thereby brings the compass ring to rest, or fixes it for reading with some degree of certainty. An open ring under the prism-box is sometimes used for placing a piece of ribbon through, to attach it to some part of the person to save dropping the compass accidentally when it is used in the hand. When the instrument is out of use a brass cap is provided to protect the glass. The instrument is uniformly carried in a leather case with strap to pass over the shoulder.

128.—**Additional Parts** commonly provided with the prismatic compass are a mirror and sunshades, shown only in section Fig. 37. The mirror *M* is carried in a frame attached with a sliding piece to the window, upon which it can be placed either upwards or downwards. It is jointed with a hinge so as to be set at any angle. By reflection from the mirror, bearings in azimuth are taken much above or below the horizontal plane. Sun-glasses are also provided in front of the prism, which are used for taking the sun's place either with or without the mirror, a single sun-glass being also used very comfortably for working towards the sun at all times. The sun-glasses, which are simply small, dark-coloured, glass circles in frames, are not shown in the engraving.

129.—*To Prepare to take Observations with the Prismatic Compass*, after the window and prism are opened out, the prism is adjusted to read the divided ring sharply when the compass is about level, by raising or lowering the prism *P* by pressure of the thumb and forefinger of the right hand upon the stud placed upon the prism slide fitting, shown below *SL*.

130.—*In Using the Prismatic Compass*, the compass-box is held with the thumb of the right hand under the prism at *SL* and the forefinger upon the stud *S*. The object is sighted, of which observation is required, through the slit *SS*, cutting the left-hand side of the hair in the window *SV*, while the division which comes opposite the reading point at its edge is noted by the reflection from the prism. The ring when free oscillates for a time, but the oscillation is easily brought to rest for reading by gently pressing the pin *S* upon which the forefinger is placed.

Where objects are observed for taking their bearings above the horizontal plane, the length of the window will be sufficient to take in a vertical angle of 20° to 30°; but for such altitudes it is necessary to take as great care as is possible that the compass is level, to get magnetic angles even approximately true. Below the horizon, angles can be obtained with somewhat greater certainty by means of reflections from the mirror. Altogether, except for taking nearly horizontal angles or for very close work in filling in after the theodolite, it is much better to have the prismatic compass mounted upon a tripod stand. With a stand, where the angle in azimuth is much above or below the horizontal plane, it is better to have a small glass level, described further on art. 156, to place across the compass when setting it up. If the compass ring is very carefully balanced across 90° to 270° two bright wire points may be placed inside the compass-box, level with the compass ring, which will answer for the cross levelling.

131.—**Stands.**—The author has made a very simple inexpensive tripod stand for the prismatic compass, the

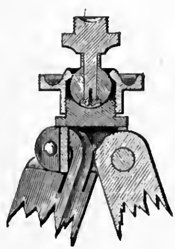


FIG. 38.—*Improved prismatic compass stand.*

head of which consists of a ball and socket only, clamped by a large milled-head screw. An axis through the ball permits horizontal adjustment, shown in section Fig. 38.

132.—**Hutchinson's Prismatic Compass** Fig. 39 is now very generally used by military men. In this compass the metal cover is fixed on the top of the compass-box, and a glazed opening is placed in the cover, occupying about one-eighth of its area, near the prism. This opening gives sufficient light to the compass

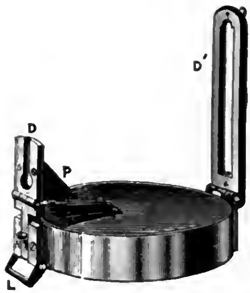


FIG. 39.—*Hutchinson's prismatic compass.*

card to permit it to be easily read, and the loose cover is dispensed with, besides which, the cover being fixed, this, as well as the whole instrument, may be made much lighter, retaining equal rigidity for wear. This compass is not fitted with shade and mirror arrangements as before described. Size, $2\frac{1}{2}$ inches diameter, $\frac{3}{4}$ inch in thickness; weight, only $8\frac{1}{2}$ ozs.

133.—**Captain Burnier's Military Compass.**—This portable compass is more generally used on the Continent than other forms. It is generally combined with a clinometer, therefore the illustration is deferred, *ante* with clinometers. The compass ring is set up vertical to the plane of the needle and is read by an index point by means of a cylindrical lens. There are a pair of sights formed of a slit near the eye-piece and a hair in the window as in the prismatic. When this instrument is held horizontally, at about a foot distance from the eye, the sight line and the index line read distinctly into the graduations of the ring. A lift is provided to raise the compass off its centre, as with the prismatic compass, and a spring clutch to prevent continuity of oscillation.

It is adapted to be set up on a plain rod stand, the socket fitting to which is held in the hand when it is used as a hand instrument.

134.—*Surveying with the Compass only.*—In modern practice very little surveying is performed with the compass only for taking angles in azimuth, except for sketch or exploring maps and filling in details, wherein the prismatic compass is used. The magnetic needle was formerly much used for surface work and depended upon almost entirely for underground work; but this has been found practically in many cases unsafe, from the uncertainty of magnetic variations, local and other, in the district surveyed. Mining compasses, or *dials* as they are termed, are now in modern practice made with means of taking angles with the compass or independently of it. This subject will therefore be deferred to a future chapter, wherein these instruments are discussed.

135.—*In Plotting Military Sketch Surveys* from angles taken with the prismatic compass, the paper employed is ruled lightly all over with parallel lines an inch or less apart. The angles taken with the prismatic compass from 0° to 360° (northern zero) are set off with an ivory military protractor, which has lines corresponding with latitudinal lines drawn over its face at 90° to its base, so that the protractor may be placed transverse to the lines drawn on the paper with its centre in any position. Particulars of this method are given in every detail in Major Jackson's "Course of Military Surveying."

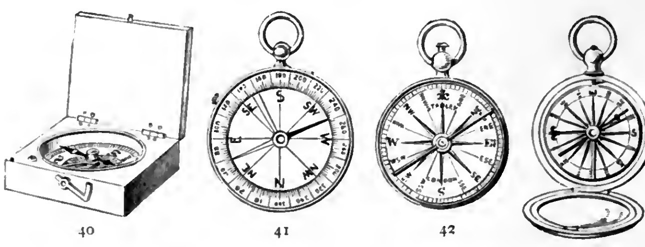
136.—For making a sketch plan with the prismatic compass, a very convenient way is to use the tee-square, the upper edge of the blade of which represents magnetic east to west, the upper end of the board magnetic north and the lower end south, according to the reading of the compass. The bearings taken from any starting-point are set off on the plot by a semicircular protractor with its base along the tee-square.

The northern angles are raised from the square from the left-hand side of the board and the southern from the right. The distances from the stations for all bearings are measured and set off by scale.

137.—It is indifferent how many stations are taken by the prismatic compass. The measurements in any direction may continue all round an estate, and will be found fairly correct if carefully made, as the small personal errors in reading the prismatic, which may be *plus* or *minus*, tend to correct each other on the whole and to tie up.

138.—The rolling parallel rule may replace the tee-square, if it is thought desirable to place the plan in another direction than that erect to magnetic north with the paper, or that it is inconvenient to use the tee-square. In this case a few parallel lines may be at first drawn correctly across the paper, at about equal distances, with a sharp pencil E. to W. for references to reset the parallel rule at any position desired.

139.—**Pocket Compasses**.—The subject of compasses will scarcely be complete without mention of the small



40 41 42 43

FIGS. 40, 41, 42, 43.—*Pocket magnetic compasses.*

pocket compasses which are so useful and universal. Several well-known forms are shown in the illustration above. The square form shown first Fig. 40 will be found the most useful for very rough sketching. The edges may be sighted for the direction of roads, etc., or the box may be placed against a wall for taking the magnetic direction of a building. In like manner also the compass-box may be laid on a drawing and lines drawn along by the edges of the box to the magnetic directions taken. This in most cases is sufficiently accurate for architectural work, in which the exact direction is not generally thought to be important. Fig. 41 is a French form of compass with step reading level with the upper surface of the needle. Fig. 42 is an old English form with enamelled dial, with lift under the bow of the handle. Fig. 43 is the same make in hunter case. In this the lift rises upon closing the case.

140.—The author has made a small pocket magnetic compass, which is represented full size in the illustration below. The needle is placed in a long box: it has a

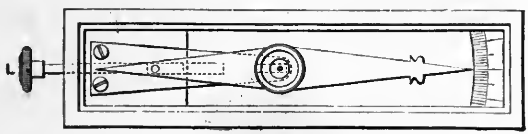


FIG. 44.—*Trough form of pocket compass.*

shaped head or single line section for north, which reads at its point into a single line when the needle is exactly parallel with the sides of the box. The variation of the needle is corrected by means of a thin slide fixed on the bottom of the box, shown Fig. 45. This slide moves out just the amount of magnetic variation, the stud *S* being made concentric for this adjustment. The needle is lifted off its centre in closing the slide. If the box be made of ivory a few useful scales may be divided upon it. The compass slips into a light leather case and is the most portable for its length of needle of any compass made. The edges of the box are used as directing lines, as above described for the square form.

The illustrations show a compass made for Great Britain, but a similar instrument is also made universal. In this

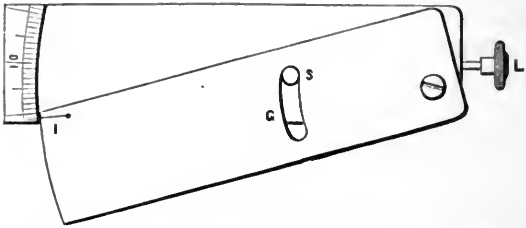


FIG. 45.—*The author's under slide for setting off variation.*

case the box is a little wider, with the centre of the slide in the middle, so that the magnetic variation can be set off west or east. A rider also on the needle enables it to be balanced in southern latitudes.

141.—**Barker's Luminous Compass** with floating dial of mother-of-pearl, with one half of this engraved

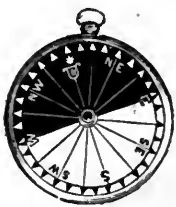


FIG. 46.—*Barker's luminous compass.*

with black figures and the other half painted black with the figures left white, permits magnetic direction to be observed in the dusk and by moonlight. These compasses are much used by travellers—Fig. 46. Mr. Francis Barker has also designed a compass in which the needle carries a paper bar painted with luminous paint.

CHAPTER IV.

LEVELS — METHODS OF ASCERTAINING — LEVEL TUBES — MANUFACTURE—CURVATURE—SENSITIVENESS—TESTING—READING — SURVEYORS' LEVELS — Y-LEVEL — PARALLEL PLATES — ADJUSTMENTS OF Y-LEVELS — SUGGESTED IMPROVEMENTS—DUMPY LEVEL—TRIPOD STANDS—ADJUSTMENT OF DUMPY—COLLIMATOR—IMPROVEMENTS IN DUMPY LEVEL—TRIBRACH HEAD—DIAPHRAGMS—CUSHING'S LEVEL —COOKE'S LEVEL—CHEAP FORMS OF LEVEL.

142.—*A Level Plane* is understood technically to be a plane truly tangent to the theoretical spheroidal surface of the earth, as represented by any spot upon the mean surface of the ocean or of still water free from local attraction. The importance of having the means of constructing efficient instruments that can be conveniently employed to obtain the correct relative altitudes of points or stations on the earth's surface, in relation to such a plane or *datum*, can scarcely be overrated. Such instruments are not only used for topographical surveys of countries, but also in designing and carrying out public works adapted to the local conditions of natural inclination of the land surface, for railways, drainage, irrigation, canals, water-works, and other constructions.

The force constantly at our command to enable us to ascertain relative altitudes and to form mentally or graphically local level lines on the earth, is that of *gravity;* and it is only a question in any case how the action of this force shall be employed. There are four principles which we may accept as data for employing gravity, each depending upon a natural phenomenon:—(1) The open upper surface of a liquid unaffected by currents of air, or the influence of solid objects in close proximity causing capillary action, or local attraction of solid masses, represents a level plane. (2) The line of a plummet unaffected by currents or lateral attractions forms a vertical line to which the level plane is everywhere at right angles. (3) The atmospheric pressure, from the approximated equality of its density due to its weight into its height over limited areas, gives pressure according to its gravity—therefore altitude or difference of level relatively to minus pressure compared with a lower datum. This pressure is measurable with a barometer or other form of pressure gauge. (4) The resistance to ebullition in a liquid is inversely proportional to the weight or pressure of the aerial fluid resting upon its surface. This is measurable by the temperature at which liquids boil under varying atmospheric pressures. Various instrumental refinements have been discovered to render these natural phenomena available in practical use for ascertaining difference of height. The first method employed for this purpose, by means of the liquid plane, will be considered in this chapter. The other methods will be deferred to later pages.

143.—In taking the level of a liquid surface contained in a vessel, we have, as just stated, to keep this surface free from the disturbing influence of air currents and to surround the surface with equal conditions of capillary attractions, or to make these attractions equal in the direction in which we desire to ascertain our level. This is found practically to be best performed by means of an arched, sealed, glass tube, in which by gravitation the liquid will naturally occupy the lower place, and any air or lighter fluid contained therein, the space above this.

144.—**Level Tubes**, *or Bubble Tubes* as they are technically termed, are used in nearly all important surveying instruments. One of these is represented Fig. 47. The glass for the construction of these tubes is drawn at the glass-houses in lengths of about 6 feet, and may be ordered of any desired size and substance. The tubes are drawn as nearly straight and of as equal bore as possible; but they are found to be, when examined after annealing, curved more or less in various directions at different parts of the length. They are found also generally to be slightly tapering from end to end and of slightly unequal substance. In the manufacture of level tubes parts of the tube are selected with approximately regular longitudinal curvature, and these parts are cut off into the required lengths, by a triangular file dipped in spirits of turpentine, to be ready for the future operations of grinding, sealing, and dividing.

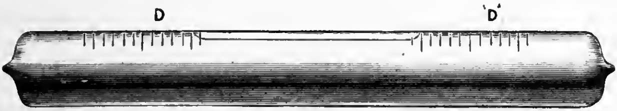


FIG. 47.—*Level tube (bubble).*

After the tube is cut off and carefully examined to get its most concave internal surface upwards, this is then marked by a *test mark*, with the flat of a file, near one end for future work and reference. The grinding of the inside of the glass tube to true curvature is performed by passing it over a brass mandrel or *core*, which is employed to grind the glass by means of fine emery. The *core* is turned slightly barrel-form to the longitudinal curvature intended for the upper surface of the finished tube. It is made of full three-quarters the diameter of the interior of the tube and a little longer than the entire tube. This core is attached by its ends to two stiff but flexible wires of brass, about 8 B.W.G. for a tube of ·7 diameter, and these wires are held firmly by their ends in two vices, so that the core is slung, as it were, to permit a certain amount of flexibility under the pressure of the hand used in grinding. Some good makers do not use a mandrel core, but only a strip of brass on the mandrel, extending about 60° of the circumference. In this case the strip has to be corrected for curvature during the grinding, which plan is sometimes preferred for certainty. The grinding of a tube cannot be commenced with coarse emery, such as is used in the grinding of lenses, as the cut of a coarse emery will quickly split the tube. After the glaze is removed there is not so much risk, so that a little time may be saved by passing a current of hydro-fluoric acid gas through the tube; but more careful testing is required afterwards, as the cut of the grinding of the tool is not so evident at sight if the glazed surface is removed.

145.—The operation of grinding is very much the same as that described for lenses art. 28. The surface is required to be traversed in every direction longitudinally and transversely, which is effected as far as possible by a twist of the hand alternately to the right and left. The tube should also be frequently taken off and turned end for end. Slight variations of curvature are readily made by differences of pressure of the hand on parts of the tube; and a little *coaxing* is allowed to get the centre of the tube *quick* where the tube is to be used for levelling only, and not for measuring small angles, so that in this case the finished tube is slightly parabolical. The finishing touch is produced with wash emery. The inside should be left smooth but not polished, as the slight roughness of a fine ground surface assists the capillary action by causing better adhesion of the spirit to give a quicker run to the bubble. Where the tubes are required of a given radius they are tested frequently, during the grinding, upon the *bubble trier*, by placing two corks in the ends of the tube which is nearly filled first with water for rough trial, and then with spirit for final correction.

146.—**The Bubble Trier** is a bar or bed 12 to 20 inches long, with two extended feet ending in points at one end, and a micrometer screw, the point of which forms a resting foot, at the other end, thereby forming a tripod. This stands on a cast-iron or slate surface plate. The micrometer screw has a fine thread, and a large head with divisions upon it to read seconds of arc. The tube is supported on the bar by two Y's, which are adjustable for distance apart, according to the length of the tubes to be tried.

147.—*The Sensitiveness of a Level Tube*, the upper curvature and ground surface being equal, depends very much upon the capillary action due to the size of the tube, the larger tube, from the freedom of restraint by capillarity, being the more active. As regards the ultimate settling to gravitation equilibrium, perhaps there is no difference, but small tubes are sluggish and take time to work. The following are about the usual dimensions of the interior of sensitive tubes—8 inches × 1 inch diameter, 7 inches × ·9, 6 inches × ·8, 5 inches × ·7, 4 inches × ·6, 3 inches × ·5, $2\frac{1}{2}$ inches × ·45, 2 inches × ·4, $1\frac{1}{2}$ inches × ·35, 1 inch × ·3. The larger the volume the greater the expansion of liquid with heat; the longer the tube the less torsion it is liable to suffer from sealing, so that if possible, as expansion is a serious defect, it would be better to have short tubes, if these could be sealed without disturbance of curvature. Much shorter tubes are used in America than in Great Britain.

148.—*The Curvature of a Level Tube* is worked to radius according to the delicacy of the work to be performed with it afterwards. The radii of curvature of different level tubes used for scientific purposes varies from about 30 feet to 1,000 feet or more. The radius of any curve may be conveniently measured by the relation of its versed sine to its chord of arc, the chord being the length of the tube. If this is first calculated out, a piece of shellac may be attached by melting it down upon the centre of the edge of a parallel glass straight-edge, to represent by its thickness the versed sine. The spot of shellac may be brought to the exact height required from the straight-edge by filing and stoning, at the same time taking its protuberance by a calliper gauge provided with vernier or micrometer to read ·001 inch. The versed sine of a given radius is formed for a given chord—

$$\textit{versed sine} = \textit{rad} - \sqrt{\textit{rad}^2 - (\tfrac{1}{2}\,\textit{cho})^2}$$

149.—The general instruction however, given to the maker is the distance of run of the bubble that is required to give seconds or minutes of arc; and perhaps this is after all the best test for accuracy of the tube which, like all other articles in glass submitted to the process of grinding, is subject to a certain amount of local error. By this method the local error is discovered by testing with the bubble trier. When the run is given, the radius of the curve of the tube may be found if desired by the use of a common multiplier, as follows, very approximately.

Arc equal to radius expressed in minutes, 3437·74677
„ „ „ *seconds*, 206264·80625

The run of a good sensitive tube is frequently made $\frac{1}{30}$ inch to the second, here omitting decimals—

arc sec (206264·8) × $\frac{1}{30}$ inch = 573 feet radius nearly.

For scientific purposes a millimeter run per second is commonly used, then—

arc sec (206264·8) × ·001 meter = 206·264 meters radius or 680 feet nearly.

For an ordinary 12-inch dumpy level the tube is divided into minutes at about $\frac{1}{20}$ inch apart, radius 14 to 15 feet; for a sensitive 14-inch Y-level of good construction the same divisions may represent 5 seconds, radius of bubble tube about 170 feet.

150.—*The Divisions upon Ordinary Level Tubes* are made after the tube is finished, but with the highly sensitive ones the divisions are made before the tube is finished. The run is taken for ten to thirty divisions on each side of the centre of the tube, where it is lightly marked with a marking diamond. These spaces are then equally subdivided and etched in with hydro-fluoric acid or marked with a hard steel edge dipped in turps. If further refinement is required, the errors of run in relation to the divisions are tabulated from the testing of the tube with the bubble trier. In many high-class instruments the level tube is left undivided and an independent metal scale is mounted over it.

151.—Level tubes are generally filled with pure alcohol for ordinary purposes; for trade purposes with methylic alcohol, which is much cheaper. For very delicate tubes sulphuric ether or chloroform is used. The sensitiveness of the bubble depends very greatly upon the mobility of the liquid with which it is filled, and of the quality of adhesion of the liquid to the glass. The relative mobility of the above-mentioned liquids is found by delicate tests with the bubble trier for small distances under the microscope at a temperature of 60° Fahr. Taking water as 100:—we find commercial methylic alcohol 22, absolute alcohol 13, sulphuric ether 5, chloroform 3,—that is, for equal small runs taken in 15 seconds of time. All bubbles appear to be more or less affected by temperature, particularly where the spirit is not nearly absolute. In the higher temperatures the bubbles are more active. The objection to chloroform, where it is likely to be subject to great changes of temperature, and where there is no provision made for regulating the size of the bubble—the means of doing which will be presently discussed, is that its expansion with heat is so great that it is very liable to burst its tube. It can therefore only be used with ordinary sealed tubes where these are small and strong. Sulphuric ether has the same fault but in a less degree.

152.—The sealing of ground tubes requires the skill of a very experienced glass-blower, and is a technical matter on which no written instructions would be of value under any conditions. A little strain is unavoidably put upon the tube in sealing with the blow-pipe, so that the curvature to which it is worked is more or less disturbed. For this reason level tubes required to be of the highest degree of accuracy are sometimes left as they are ground, and closed at the ends by small discs of glass grooved to the end surfaces. These are fixed on with glue, and when the glue is set are bound over with silk and finally varnished; but this plan is much too delicate for instruments for use in the field.

153.—**Colonel Strange's Level Tube.**—These tubes are blown with an outward bead at each end of the tube, two outwardly screwed collars being first placed over the tube before the blowing. The tube is then ground to curvature. A plug is formed for each end of the tube from a plano-convex lens which is ground to a bevel on the plano side, and also ground into the end

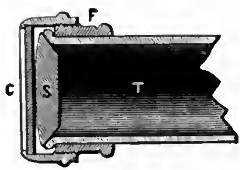


FIG. 48.—*Colonel Strange's level tube.*

of the tube as a stopper. A cap is screwed over the end upon the collar. The springiness of the cap keeps the stopper always tight. As there is no blow-pipe used after the grinding, the tube remains constant as it is ground, or it can be adjusted by grinding to any desired sensitiveness. This cap for security is better covered with silk tied over it and afterwards well varnished.

154.—As the run of bubbles varies slightly with its size, for exact purposes and extreme climates it is very desirable to be able to adjust the size of the bubble to the surrounding temperature, so that it shall be kept at about equal dimensions for all measurements with it. This becomes particularly important where chloroform is used, from the expansion being very great. A general way of doing this is to have a stopper ground into one end of the tube, which is itself a small bottle, on the under

FIG. 49.—*Bubble with supplemental air-chamber.*

side of which a hole is ground, so that by turning the tube over and raising it more or less, any amount of air may be taken to form the bubble that is desired. The stopper is fixed with thin glue. The general construction is shown above Fig. 49. Of course where such a tube is used there must be means of tipping and turning the instrument over in which it is fixed, or the bubble itself must have separate fixings. The portability of a surveyor's level admits readily of the necessary tipping—with theodolite levels upon the vernier plate it would be very awkward.

155.—**Extra Strong Level Tubes.**—Colonel Scott's very ingenious device of enclosing a level tube within another tube of thoroughly annealed glass, will be found

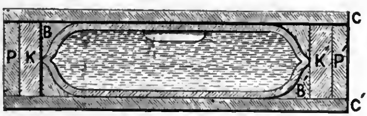


FIG. 50.—*Colonel Scott's protected bubble.*

valuable in all cases where the tube is much exposed, or where it is difficult to procure a new tube in case of accident. These tubes are at present only made by the author for Scott's telescopic gun sights which are nearly like little theodolites. The level tube Fig. 50 is made as stout as it can be soundly sealed after filling. It is then enclosed in an annealed tube of about ·08 to ·12 inch in thickness $C\,C'$, the interspace between the two tubes being filled with Canada balsam. It is then plugged with elastic marine glue $K\,K'$ and cemented over $P\,P'$. The annealed tube is of great strength, so that the complete naked tube thus formed will bear dropping on the ground, and also when attached to a large gun will bear the violent vibration of firing without injury.

156.—*The Level Tube may form a Complete Instrument in Itself.* In this case the lower surface is ground to a flat plane to rest on any plain surface. This level is

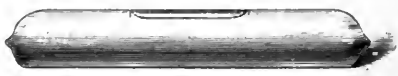


FIG. 51.—*Artificial horizon level.*

generally contained in a small pocket case and is most convenient for adjusting instruments to level. It is commonly used with the black glass artificial horizon.

157.—**Mounting Tubes**.—Level tubes when applied to instruments are generally mounted in brass covering tubes. Small level tubes under 2½ inches are conveniently mounted in such tubes with a fixing of slaked plaster of Paris inserted at each end of the brass tube. Larger level tubes should be bound round with thin paper pasted round the ends, which is allowed to get quite dry, to be afterwards fitted to the brass tube with a file. Fitted in this manner the tubes admit of adjustment to the difference of expansion of the metal and glass by change of temperature without distortion. There is no objection, however, to thoroughly fix one end of the tube with plaster if the other is left free, and this is perhaps advisable for portable instruments.

It is convenient in mounting level tubes to place white glazed paper under the bubble to reflect the light that passes through it.

158.—*In Fixing Undivided Level Tubes*, or replacing such tubes in instruments, it is important to observe that the *test mark*, which is a small ground facet, should be placed on the *upper side*.

159.—*In the Use of Level Tubes* generally, it is not well to have the tube of greater sensitiveness than the general construction of the instrument upon which it is placed permits. Thus the centre of a surveyor's level that may be under constant strain from the unavoidable inequality of the pressure of parallel plate screws, will appear never to reverse properly if it has a very sensitive bubble, the cause of the irregularity being entirely due to the distortion from the strain on the vertical axis of the instrument. The same amount of irregularity occurs in a less degree with the Y's of a theodolite, where these and the collars become corroded by exposure. The optician often gets credit in a wrong direction for setting such instruments in good order by merely replacing the sensitive bubble by a dull one—that is, by doing what is really in this case the best for the instrument.

160.—When an instrument is to be used abroad that depends entirely upon the level for its possible working, one extra tube should be taken, as the level tube is very generally more exposed and is more delicate than any other part of the instrument. The tube is not only fractured with a slight blow, but even the heat of the sun's rays will sometimes burst it.

161.—*Reading the Bubble.*—The exact position of the capillary concave surface of the spirit in the tube is liable to deceive the observer by the difference of refraction and reflection it gives, whether the light is towards the right or left hand. To avoid this cause of error it is better in sunlight to hold a piece of white paper at a short distance over the end of the bubble during the observation taken of its terminal reading into the divided scale on the tube. It is also important to note that the observer should stand at right angles to the tube to see the position exactly where the upper capillary line of the spirit cuts, as the tube itself refracts the light unconformably. It is not at all difficult to read the bubble if the observer stands over it; but generally, as it is mounted upon an instrument, it is at the height of the eye. In this position the hollow surface round the bubble, caused by the adhesion of the liquid to the sides of the glass tube, reflects the light in a manner

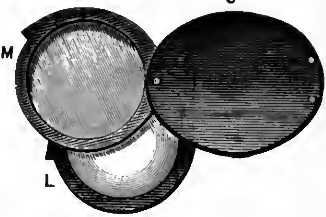


FIG. 52.—*Pocket lens and mirror.*

that the hollow may be taken for the end of the bubble and a false reading made. It is better if possible to take the convenient side reading first, and afterwards get a glance at the upper surface reading for certainty. In some cases this may be much assisted by the employment of a small mirror of about the size of a spectacle eye, which is carried open in the pocket, or, as the author has made it, it may close in a horn case with a pocket lens as in the Fig. 52 shown above. *C* sheath, *M* mirror, *L* lens.

162.—**Surveyors' Levels**, of which there are several forms, consist essentially of a telescope with a diaphragm at the mutual foci of the objective and the eye-piece, the axis of the telescope being placed in a truly parallel direction with the crown of a sensitive level tube. The telescope with its level is mounted upon metal framework, carried up from a vertical axis upon which the telescope rotates. The vertical axis is adjustable in relation to the axis of the telescope, so that these axes may be brought perfectly perpendicular, the one to the other. The whole instrument is also adjustable to a position of verticality of its central axis, and horizontality of the telescope in relation to the surface of the earth, in what is termed the *setting-up* of the instrument; so that when it is set up in this position, levels may be taken from it in any horizontal direction from one point of observation, by rotation of the telescope about the vertical axis. Having these essential objects in view in the construction of the level, the form of the instrument may be varied as to details according to the mechanical skill and taste of the maker and the special demands of the civil engineer.

163.—In the design of a surveyor's level very important considerations are:—That the metal should be so distributed that every part is as light as possible, consistent with sufficient solidity to take a moderate amount of accidental rough usage and ensure freedom from vibration; that the whole structure should be in equilibrium about its vertical axis when the telescope is extended at mean range—that is, at about the focus of three chains—this is a quality often neglected; that there should be sufficient light in the telescope, and that it should possess a firm and durable stand. Every form of instrument should embrace these qualities.

164.—*The Oldest Form of Surveyor's Level* is that termed the Y-level, so named from the telescope being supported in Y-formed bearings. This instrument was originally invented by Jonathan Sisson, a leading instrument maker of the last century. It was much improved and brought nearly to its present state of perfection by Ramsden, to whom practical opticians owe so much for many advancements of their science and to his liberal publication thereof. This instrument is now very little used in Great Britain, but it still maintains its original position, to a certain extent, on the Continent and in America. In the eyes of the optician it is still the most perfect level, possessing all the instrumental refinements of adjustment he can desire. The reasons for its partial abandonment by the profession will be discussed further on.

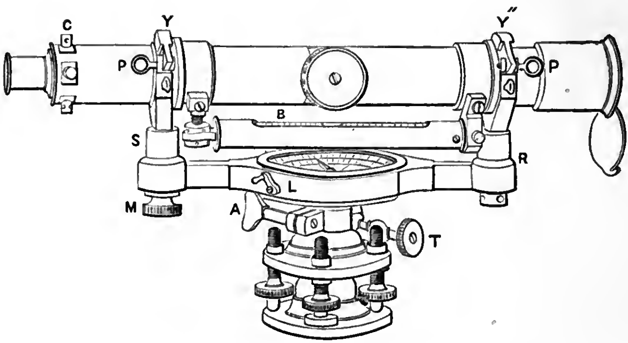


FIG. 53.—*Surveyor's Y-level.*

165.—**The Y-Level** in its modern form is represented in the engraving above Fig. 53. The Y's are shown at *Y Y″* edgewise. They are supported by standards upon the limb *L*. The telescope is surrounded by two collars which are soldered upon it at positions exactly corresponding with the Y's. The collars are turned perfectly cylindrical and parallel on the surface with the axis of the telescope, and ground in a gauge-plate to exact size, so that the telescope may be turned end for end in the Y's without altering the lineal direction of its axis in reversing it. The telescope is held from shifting longitudinally in its Y's by a pair of flanges placed on the inside of the collar pieces.

The Y's are erected upon the limb, to which they are each fixed firmly by a clamping nut at one end *R*, and a milled-head clamp at *M*. The telescope is held down by strap-pieces, each of which has a joint at one end and a loose pin at the other *PP*. The pin is secured from dropping when out of use by a piece of cord attached to a part of the instrument and to a loop through its head. At the top of the inner side of the strap-piece under *Y Y″*, a piece of cork is inserted in a cave. The cork by its elasticity keeps an equal but light pressure upon the collar of the telescope. It will be seen that by the above plan of holding the telescope, it is so far free that it may be revolved on its axis, by which perfect adjustment of the diaphragm may be made in any direction.

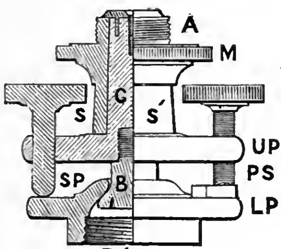


FIG. 54.—*Section of parallel plate and vertical axis—arrangement of Y and other levels.*

166.—*The Vertical Axis of the Y-Level* was formerly carried tapering downwards, and the upper parallel plate was placed at about the centre of the socket. Under this construction the socket was more liable to strain from the use of the parallel plate screws. It is more general now to construct the axis as represented in the illustration above Fig. 54, for Y and other levels. This construction also renders the instrument more portable, as the parallel plates and axis may be detached and lie closer in the case; the plan is nevertheless open to many risks, which will be referred to in discussing a three-screw arrangement. The general construction is shown in the figure, of which the left-hand side is a half-section. *A* is a screw by which the parallel plate foot is attached to the limb of the instrument; *M* a large *milled head*, by means of which the screw can be brought up firmly to its collar; *S S′* the *socket* which is ground to fit the cone *C*; *C* forms a part of the *upper parallel plate UP*; *B* a *ball pin* which screws firmly into *C*; *LP lower parallel plate*, part of which forms the ball socket, so that the whole instrument rocks about the ball *B* as a centre by the action of the parallel plate screws *PS*; *B′* female screw for fixing this part, which is called altogether the *parallel plates*, to the tripod head. In the old Y-level there was generally a clamping screw upon the axis for slow motion which generally caused a strain upon it. This has been abandoned in modern instruments. The parallel plate screws are *tapped*, that is, have female threads cut into the upper plate *UP*, and their points press the lower parallel plate *LP* at certain points, there being a *stop-piece* placed round the point of one screw to prevent rotation. The pressure upon the screws can be increased as desired by means of the milled heads and the instrument made rigid in proportion; but it is very undesirable that the pressure should be much greater than that necessary just to support the instrument firmly, as it is easy by the power of the screws to disturb the figure of the axis and thereby derange it.

The diaphragm of the telescope of the Y-level is generally webbed with plain cross webs. The diaphragm and webs were described arts. 85, 86.

167.—*The Setting-up of the Y-Level* is necessary to be understood before the instrument can be adjusted. The same description which answers for the setting-up for adjustment will also answer for the setting-up of the instrument in the field for actual work. In this description it will be convenient, therefore, to consider the instrument as being in this case *in adjustment* as it leaves the hands of the maker. The after adjustments will be presently taken as from the original state of the instrument, as the maker has to do them in the first instance. Practically, the civil engineer has only to make slight differential adjustments at any time, as an instrument will retain by the solidity of its construction its general adjustment nearly, upon which further adjustments take more the nature of corrections or final adjustments, which become necessary only from accidental causes.

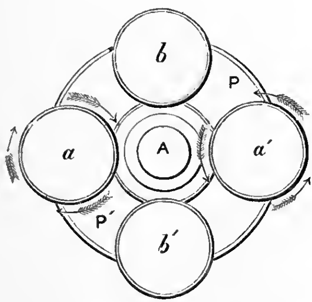


FIG. 55.—*Diagram plan of parallel plate screw milled heads.*

168.—*Setting-up of the Y or other Level with Parallel Plates.*—The tripod stand is opened out so that the legs stand, if on level ground, inclined towards the centre of the instrument at an angle of about 70° to the horizon. The toes of the legs are then each separately pressed into the ground sufficiently to make the instrument stand quite firmly. The instrument is then screwed down tightly upon the tripod head.

169.—*The Eye-piece is then Adjusted*, art. 70, by sliding it gently in and out until the webs can be seen most distinctly. On a bright day a white pocket-handkerchief may with advantage be thrown singly over the object-glass to prevent any confusion from objects in the field of view during the focussing of the eye-piece. For the setting-up adjustment of the telescope, it is brought to lie directly over one pair of parallel plate screws Fig. 54 *PS*.

170.—The milled heads only of these screws are represented in the plan in the diagram Fig. 55, *a a'* being the opposite pair over which the telescope will be assumed to be at first placed. The level tube is now brought to adjustment by bringing the bubble to the centre of its run by means of the parallel plate screws *a a'*, by taking the milled heads of these screws, one between the balls of the thumb and forefinger of each hand, and rolling them simultaneously the one in one direction and the other in the reverse. This action tips the axis of the telescope in one direction or the other. Thus by the screws being rolled inwards, as shown by the direction of the arrows in the diagram, the left-hand side of the instrument would be raised; if turned the reverse way, the right-hand end. The opposite end always requires to be raised from that to which the bubble runs. Where the ground is rather soft, adjustment when nearly correct may be made partially by pressing down one or other of the legs; in this case the telescope should be placed parallel with the toes of two legs, one of which is pressed.

When the level tube is adjusted over the screws *a a'* it is then placed over *b b'* and adjusted in a similar manner, returning again to the position *a a'* for final adjustment. When the level is in perfect adjustment the bubble should stand in the centre of its run in making a complete circuit of the horizon by revolution of the instrument upon its vertical axis.

171.—In and during the setting-up adjustment, it is most important that the screws should not be made tight enough to cause, by their pressure upon the parallel plates, distortion of the vertical axis. If this occurs the instrument will not level in all positions by the same setting. The screws also, from the great elasticity of the metal, whatever they press, the pressure should be about equal between the *opposite pairs a a'* and *b b'*. The difficulty of accomplishing this with certainty makes another form of adjustment for setting-up preferable with three screws only, which will be considered further on. Where the instrument is set up for use, if the adjustment of the bubble is fairly correct to the centre of its run, the reading of the staff may be sighted and the telescope brought to true focus upon it, by moving its milled head until the divisions of the staff are as sharp as possible, and then moving the eye upwards and downwards to be sure there is no error of parallax art. 91. After this the final adjusting of the bubble should be made, noting particularly that there are the same number of divisions in its run on each side from the centre.

172.—*Adjustment of the Axis of the Telescope* in true parallel direction with the periphery of its supporting collars in its Y's. This is performed entirely with the four capstan-headed screws which adjust the diaphragm, one of which is marked Fig. 53 *C*. Having the adjustment of the eye-piece in focus for the webs in the manner described art. 91, and the object-glass focussed upon a distant, distinct small object or mark, and without parallax, the instrument which carries the telescope is then exactly adjusted to make the intersection of the webs cut the mark. The telescope is now turned half round on its axis, so that the lower part becomes the upper, and observation is again made of the distant small object or mark. If the same intersection of the webs falls on the same point of the object, the collimation adjustment is perfect. If it does not do so, the upper capstan-headed screw at *C* or the under opposite one is loosened by means of the small pin provided with the instrument, and the opposite screw tightened until the webs are brought over a point situated half-way between the points cut by the first and second observation. The telescope is again directed on the point first observed and the adjustment checked to see if it has been done correctly, that is, if it reverses cutting the same point, or whether it requires further adjustment by the same process as before. The other web of the diaphragm, at right angles to the first, is adjusted in a similar manner as the first, but with the other pair of capstan-headed screws.

It is sometimes inconvenient to adjust out of doors: adjustment may be performed very well indoors. By daylight a small cross may be made with ink on a sheet of white writing-paper for the sighting object, which may be placed at as great a distance as convenient, say 20 or 30 feet. By night a pin hole may be made through a piece of paper and a candle or a lamp be placed behind it.

173.—*Adjustment of Vertical Axis.*—For this the eyepiece is first brought to focus on the webs. The telescope is then placed directly over one pair of parallel plate screws opposite each other, and the instrument is levelled. The Y's are then opened out and the telescope is directed so that the intersection of the webs cut or cover any distinct small mark upon a distant object, or preferably upon the centre reading of a foot line upon a levelling staff. There is no objection to adjust slightly to this by the parallel plate screws, as this adjustment is independent of the level of the instrument. The telescope is then taken out of its Y's and is turned end for end and replaced. The telescope is now turned half a revolution on its vertical axis, and the webs are again brought to read on the staff, if one is used. If they now fall upon the same spot or foot line the vertical axis is perfectly perpendicular to the axis of the telescope in this direction. If the webs do not fall upon the first reading or point, the amount of difference of reading is recorded and this space is bisected; so that now, if the telescope be adjusted at its bearings upon the limb upon which it is supported by the milled head *M*, for the webs to cut the bisection, the axis will be perfectly perpendicular in the direction of its bearing socket. The same process must now be repeated with the telescope placed at right angles to its first position, that is, by bringing it over the other pair of parallel plate screws which were not used at first. There is at all times a certain amount of disturbance of the instrument due to handling it; it is therefore necessary to repeat the whole of the above process until the instrument reverses in any direction, but this for final adjustment is better deferred until the adjustment of the level tube, to be next described, has been made.

174.—*Adjustment of the Level Tube.*—The telescope is placed as before over an opposite pair of parallel plate screws, and these are adjusted until the bubble is in the centre of its run. The telescope is then turned half a revolution, so that it is placed over the same pair of screws in the reverse direction, and the displacement of the bubble from the centre is now noted. The capstan-headed bubble screws at end of the level *B* are then adjusted to one-fourth of the difference observed, and the parallel plate screws are adjusted for the other fourth, so that by these two adjustments the difference of the run in two positions is bisected. The same process is repeated over the second opposite pair of parallel plate screws. If this be very carefully done with a correctly divided bubble, the Y's of the telescope may be opened out and the telescope be reversed end for end in its Y's, and the bubble will remain true. But it is quite as well to go over all the adjustments a second time as before stated.

175.—If the level is to be adjusted by night, this can be done very correctly by a fine cross drawn on paper placed on a wall, with a candle or gas burner shining brightly on it, at 20 feet or so distance from the instrument. For this adjustment by night, the instrument must be well constructed, as the tubes require drawing out to their full extent for focussing near objects. If the tubes are not quite straight, the object-glass suffers considerable displacement in the drawing out, or technically *droops*. This is a very common fault in badly made instruments.

Where webs are used for the reading, they are liable to become baggy or dirty and very frequently to break; nothing can therefore be more comfortable than to be able to reweb a stop in the evening, art. 87, with command of the easy and certain means of readjustment described, when far from the optician's aid.

176.—As the Y-level is so perfect in its arrangement for adjustments, and so nearly meets the optician's ideal, it will be well to enquire what are the objections made to its use by the majority of British surveyors. The first and most important is that it possesses so *many loose parts*, to which the practical man honestly objects. The author was, many years ago when Y-levels were more popular, trying to persuade a cautious, practical surveyor to take a Y-level at the time he was selecting a dumpy one, with extra level tube and stock of platinum wire, who appeared to be very anxious for the certainty of his work, when the author had his arguments stopped by the following question:—"Suppose you were surveying in a tropical country, thousands of miles and an ocean voyage from civilization, where your native porter objected to carry much weight and your instrument case had to be left at a back station—when your umbrella was all the burden you felt you could support. In this case, suppose your porter, whom you had lost sight of for a short time, arrived with your level, minus the telescope—lost by becoming loose, perhaps from having been played with while he was resting—how would you praise the Y-level?" This gentleman assured me that *he* did not, and that this was a true account of his experience with the last Y-level he possessed. Other objections besides loose parts are, that Y's and collars do not remain as perfect as when they leave the optician—that they are liable to wear by friction of constant movement in being carried about upon the points in contact between them, and thereby form facets; that the collars become corroded by exposure, and that as they have open spaces, collect sand from flying dust which fixes itself into the collars and Y's, so that this arrangement loses the perfection the optician claims for it. Further, that the cross bubble, which is uniformly placed on the dumpy level, effects a great saving of time over swinging the telescope backwards and forwards with every adjustment of the parallel plate screws. Another feature is that in the dumpy level, to be described, the vertical and horizontal webs of the diaphragm cannot be disturbed from their position by rotation of the telescope after the level is once set up; and this verticality indicates conveniently at once if the staff is held vertically, which is otherwise a great difficulty with the ordinary form of Y-level reading.

177.—**Improved Y-Level.**—The above-described defects the author has tried to remedy by a modification of the Y arrangement, in forming the Y's into circular collars, but retaining the effect of a Y bearing. This is done by cutting out a large portion of the outer collars, so that the telescope rests practically in Y's. This is shown in Fig. 57. The interspaces between the parts cut out, shown at $C\ C\ C\ C\ C'$, are filled in with soft cloth saturated with vaseline, so that no parts

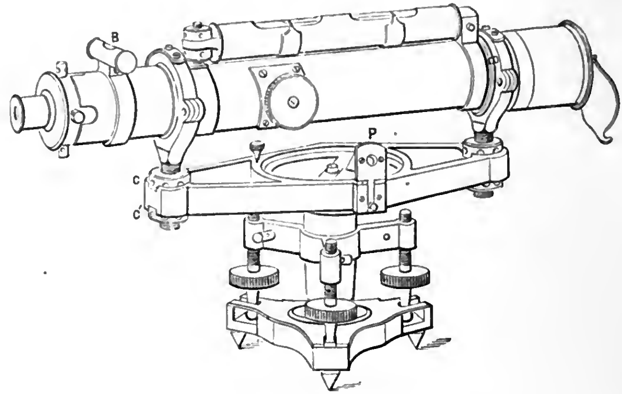


FIG. 56.—*Improved Y-level.*

of the collars are left open to exposure to dust or to become corroded. Instead of the old loose pin which

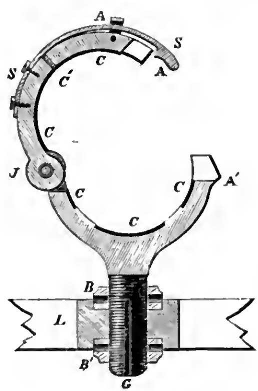


FIG. 57.—*Improved level Y's.*

is tied on, the author has made the collar to latch when it is down, so that it cannot be opened without releasing this latch. This, it is hoped, so far will obviate the danger of loose parts, as, by this arrangement, the telescope also becomes practically perfectly fixed. A cross bubble Fig. 56 *B* is also placed on the telescope for approximate adjustment, which saves the frequent disturbance of the telescope by making cross adjustments. The diaphragm of this Y-level is exactly the same as that of the dumpy, to be described art. 182. From the limb downwards the author uses the same construction he has employed many years on his improved dumpy level; this part will, therefore, be described with that instrument further on, art. 199, as also the setting-up adjustment with it, which is different from that already described where parallel plates are employed. This Y-level is intended by the author to contain all the refinements he can devise in this instrument.

178.—Perhaps upon the whole, the conditions which formerly rendered the Y-level undoubtedly the best practical level, have so much changed that the more solid construction of the dumpy may entirely supersede it, as it threatens to do in modern practice, and the optician will lose his ideal. Some reasons for this may be stated, but whether sufficient is a question. The manufacture of object-glasses of good figure and proper centring was formerly understood by few opticians, who were principally engaged upon astronomical telescopes, so that, with the exception of those of Troughton, no very good and accurately centred lenses were used in surveying instruments. With bad centring alone, in ordinary telescopes the webs in collimating were drifted quite aside, and needed the Y system of adjustment to make the telescope workable for levelling. In the modern good object-glass, of which there are several makers, the centring is so nearly perfect that the webs in adjustment fall in the centre of the diaphragm when it is placed true to the cylindrical axis of the telescope;

so that if the webs are so placed without further adjustment, no very serious interference is caused by want of collimation of the axis. With this fact in view, the instrument maker need leave little space for adjustment of the webs to become a source of error, even when the owner may not possess the necessary knowledge of the telescope to make it.

Further, with a well-centred object-glass as it leaves the hands of the scientific optician, and a solidly constructed adjustment to collimation being provided for in the making of a level, true working may be done even if there is a small error in the collimation. The late William Gravatt, C.E., was of opinion that firm construction, compact form, and plenty of light in the telescope were more important than easy facilities of adjustment. There is no doubt he found the less open adjustments the better in the hands of the imperfectly trained assistants who were pressed into service during the railway mania. At any rate, at this period we have his invention of the "Gravatt," or, as it was afterwards termed, the "Dumpy" level, which has remained with us with slight modifications in its mechanical parts and with increasing popularity until the present time. The late Mr. Troughton, recognizing the same facts, also made a level in which there was no adjustment to the supports of the telescope after it left the hands of the maker. In his level he also left no adjustment to the bubble tube, which no doubt would prevent tampering, but which could scarcely be called an improvement; as this tube is liable at all times to be broken, therefore to need replacing with another tube which cannot be made quite similar, and therefore needs easy means of adjustment for a surveyor to replace it when abroad. This level has gone out of use, but it is mentioned here as the old engraving of it remains in our *modern* text-books.

179.—**The Dumpy Level.**—One of the most important structural improvements made by the late William Gravatt in his dumpy level, was the addition of a cross bubble, which is shown end-view in Fig. 58 at *CB*.

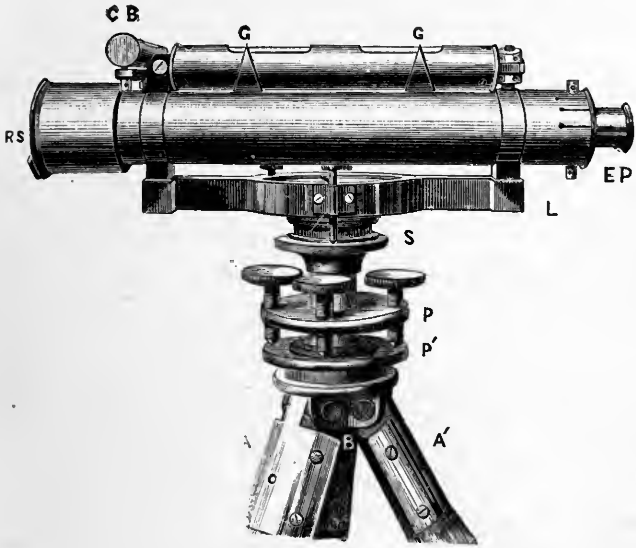


FIG. 58.—*Dumpy level.*

This improvement over the old form of Y-level permitted the setting-up of the instrument to be completed approximately, without turning the level a quarter revolution backwards and forwards several times during the operation, as was necessary in the setting-up of the Y-level. The compact form, lightness, and large field of view in the telescope otherwise commended it to civil engineers, when Gravatt had pointed out the possibility of sufficient practical adjustment without resorting to the cumbrous proportions of the Y-level as it was then made. Modern experience has shown that the dumpy form of telescope could very well be applied to the Y construction, and this has been done, as shown in the preceding pages; but at the time the dumpy was invented by Gravatt, the Y-levels were very commonly made 20 inches or more in length of telescope, and were altogether very flimsy affairs. Gravatt's 12-inch level was found to be quite equal in power and of less than half the bulk and weight. A 12-inch dumpy should read the ·01 foot on a Sopwith staff, which is described in the next chapter, at 5 chains with a webbed diaphragm Fig. 60; with a more open reading than Sopwith's a greater distance than this. A 14-inch dumpy should read the ·01 well at 10 chains.

180.—*The Dumpy Level* in its modern form is represented in the engraving Fig. 58. It consists of a telescope fully described art. 80, which carries a ray shade *RS* at the object-glass end, to work in the field to eastward or westward facing a low sun. The eye-piece *EP* is adjustable to the webs in the telescope by pressure in or out. Two straps or bands are accurately fitted and soldered round the tube of the telescope, one of which carries a hinge joint, and the other a pair of locking nuts to support the level tube *G G*, which at the same time permit its adjustment. The level casing tube has two three-quarter bands, which slide upon it, pointed at one end *GG:* these adjust to the length of the bubble for changes by temperature. The lower part of each strap-piece is left a solid block of metal, to give very firm support to the telescope as it rests upon the limb *L* beneath. The limb may be either a casting with a socket screw only in its centre, or a compass-box may be formed in the centre and the socket screw be placed under this, as it is shown in the figure. The attachment of the telescope support to the limb is made by three screws, two of which draw the limb down, and one in the centre presses it upwards, as shown in the section Fig. 59—*C C′* telescope, *T T′* drawing screws, *P* pressing screw.

It will be seen that by this means firm adjustment may be made either by raising or lowering one end of the telescope, as also by a lateral rocking motion should

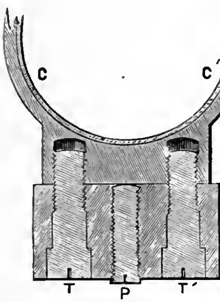


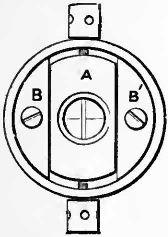
FIG. 59.—*Attachment of telescope block to limbs.*

the web or bubble not be quite to position. This plan is certainly moderately solid, and little fault can be found with it except that a little torsion may be put on the telescope by unequal screwing and that it appears slovenly in leaving an open gap between the limb and block; therefore the author prefers in his own form of level, which will be presently described, that the block be solidly fitted down upon the limb, as it is shown in the section Fig. 59, and the telescope be placed permanently exactly parallel with it. If the vertical axis is once fixed truly perpendicular to the axis of the telescope as solidly as possible, there is very little risk of a bell-metal journal of $\frac{3}{4}$ inch or so diameter being bent; therefore all parts may be closely fitted between the axis and the telescope. Some makers, instead of screwing down at both ends of the limb, make one end a rocking centre and adjust only by screw at the other end. This plan lacks a little of the stability looked for in the dumpy system. The general construction of the vertical axis is the same as that of the Y-level already described.

The parallel plates, tripod head, and tripod are also the same, art. 166, Fig. 54.

181.—As the telescope of the dumpy level does not possess any simple means of determining the accuracy of the fitting of its sliding tube, it is a very important point in these levels that this fitting should be good, so that the object-glass does not droop when extended. For this reason the inner sliding tube of the telescope should be as long as possible, and its adjustment by the rack sufficient to bring an object in focus at 15 to 20 feet distance. This point is sometimes neglected; and the author was once much amused by a young surveyor bringing him an invention, which was to fix two points by the side of the telescope *to enable him to read at short distances.* It was seen on examination that his telescope, a badly-fitted one, would not read at half a chain, hence the ingenuity of his invention. For cheaply-made levels, the solid ring fitting to the telescope, above described, which connects the limb firmly with the bubble tube, is replaced by blocks soldered on the telescope with soft solder: the method is very unsound from risk of imperfect soldering. The blocks are very liable to become loosened by a jar.

182.—The diaphragm of the dumpy level is generally webbed with two vertical webs and one horizontal. In use the image of the staff is brought between the vertical webs, and these indicate whether it is held upright. The upper margin of the portion of the horizontal web between the two vertical ones is the index of level to which all readings are made, either for adjustment or for reading the levelling staff in the field. The somewhat loose and slovenly four-screw adjustment for a level used in rough work with capstan-head screws, shown Fig. 22, which is necessary for the adjustment of the telescope in Y's, has been abandoned for many years in the better-constructed dumpy levels by all good makers, and the more solid construction, shown below Fig. 60, used in the place thereof. In this plan there



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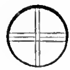

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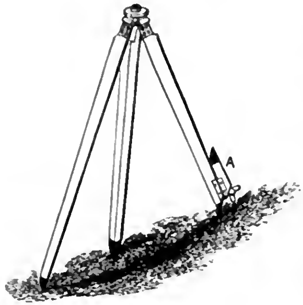
FIG. 60.—*Diaphragm of dumpy level with webbed stop.*
FIG. 61.—*Same, with stadia webs.*

is no lateral adjustment: the diaphragm is carried as a frame in a dovetail slide, and is adjustable by vertical screws only. The figure shows the face of diaphragm *BB'* slide pieces. *A* slide moved by capstan-head screws.

183.—*Subtense or Stadia Webs.*—It is very advisable in all levels to have two extra webs, placed one on each side of the central horizontal web, fixed at such a distance apart that the image of 10 feet of the staff when placed at 10 chains distance may exactly cut the inner space between the lines. These webs may be used as a means of measuring distances often more exactly than can be performed with the chain if the surface is irregular, or, in any case, they form a good check upon chain measurement. If the webs are separated to subtend an arc whose chord is 10 feet at 10 chains, it is easily seen that 1 foot of the staff will represent this chord at 1 chain, and that each ·01 of the foot on the staff will represent 1 link in distance. A diaphragm webbed in the manner described is shown in Fig. 61. There is some difficulty in placing webs in exact position, and allowance should be made for the optical conditions. This important subject will be fully discussed hereafter in chapter IX.

184.—**Tripods, or Stands.**—This matter was deferred in description of the Y-level. The same form of tripod is used both for Y-level and dumpy. In this country the tripod is generally made of straight-grained, well-



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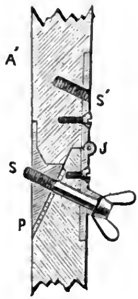
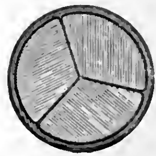


62 A



63

FIG. 62.—*Tripod.* FIG. 62 A.—*Section of one turn-up leg of the same.* FIG. 63.—*Section of tripod.*

seasoned Honduras mahogany, which stands better than any other wood. When the tripod is folded up for carrying or for putting by, it forms a cylindrical pole which is bellied out at about one-third its length from the top, and diminishes downwards and upwards from this point. For an 18-inch Y-level or a 14-inch dumpy the dimensions of the tripod are about $3\frac{1}{2}$ inches at its greatest diameter when closed, tapering off to $2\frac{1}{2}$ inches at both the top and the bottom ends. For a 14-inch Y-level or a 12-inch dumpy the section is somewhat less. Each leg of the tripod takes an equal section of the cylinder, the inner angle meeting in the axis at an angle of 120°, as shown in section Fig. 63. *Shovel-pieces* are shown in Fig. 58 *A A'*, attached to the top of each leg by four screws passing from the brass to the wood. There should be also two screws from a brass plate inside the leg to the shovel-piece, making connection brass to brass: this is important, as fixings from the brass to the wood only become loose and shaky. The shovel-piece is formed into a strong tenon at its upper end, through which a bolt passes connecting the *book-pieces B* together. The book-pieces are plates cut to an angle of 120°, so as to fall true on the tenons of the shovel-pieces. Where hand-work is used for making the tripod head, the book-pieces are attached by three screws to the tripod head; where machinery is used, the head is made in the shaping machine out of a solid casting, which is much better. The tripod head carries a screw about 1½ inches diameter, with coarse thread, which fits into a socket on the lower parallel plate of the level, whether Y or dumpy. There should always be a plain piece, technically a *lead*, above the screw. This holds the instrument steady before it is screwed down, and also leads the screw directly to its corresponding thread, and saves risk of crossing the thread.

185.—There is a little difference of opinion as to the form of the woodwork of the tripod for 14-inch levels, some few preferring an open framed stand in place of the solid form shown in section Fig. 63. These open framed stands are very heavy and clumsy to carry, and, as the author thinks, quite unnecessary for the level where the tripod head is solidly made. They are well adapted to heavy theodolites, 8-inch or so, therefore description of a framed tripod will be deferred to the discussion of these instruments further on.

A few engineers prefer yellow pine for the tripods instead of mahogany: this is much lighter for its relative stiffness, but it is rather soft for the fixing of the shovel-pieces and therefore scarcely so reliable as mahogany for durability.

186.—Immediately under the tripod head in its axis a long hook is placed which hangs down. This is only seen when the legs are opened out. The hook is used for suspending a plummet, which is supplied with the instrument, to ascertain that the axis of the level is placed exactly over a station. From this hook the height of the level is commonly taken, when this is required, by a tape measure, the ring of which is put in the hook, the measured height by the tape being supplemented by the known height of the axis of the telescope above the hook. The lower points of the legs, technically *toes*, are pointed to an angle of about 90° and are shod on the insides with steel plates, to bite the surface upon which the tripod stands when the legs are extended for use. Two brass rings slip over and bind the legs together when the tripod is out of use.

187.—Many years ago the author introduced the plan of having one of the legs to turn up at about 1 foot distance from the toe. This is shown Fig. 62 at *A*, and in detail section Fig. 62A. The joint is made perfectly firm by a winged screw at *S*, which screws from a boss cast on the hinge *J* to a solid metal shoe *P*. When the leg is turned up, the screw fixes it in the female screw *S*. This plan is very convenient for use in mountainous districts, as it enables the level to be set up fairly without an uncomfortable angle to any of the legs or risk of the instrument toppling over. This plan is more solid than a ball joint in the head to the tripod.

The tripod head shown to the level in Fig. 58 is by no means the best, but it is the easiest made, therefore the general form in use both for the level and theodolite. Some very superior forms will be discussed further on in description of the instruments to which they are attached.

188.—*The Adjustments of the Dumpy Level.*—As this instrument does not possess the means of revolving the telescope upon its axis as with the Y-level, the adjustments are more complicated, and are performed in a more difficult and entirely different manner when they are to be performed by the civil engineer. The differences are not so great in the hands of the optician, as he generally possesses a movable pair of Y's upon which he can adjust the telescope conveniently for collimation within his own works, by supporting the telescope tube in Y's at a position exterior to the bands which surround it. The tools for this adjustment the author has occasionally supplied upon demand with the dumpy level. But what is necessary here will be to give the mode of adjustment which the civil engineer can accomplish at any time without supplementary apparatus. In some cases it is most convenient to form a station for adjustment, which may be either near the engineer's home or near an important central railway station where there is plenty of open level ground; in this case all after adjustments may be much simplified. This case may therefore be briefly considered first, taking the conditions for any new position afterwards.

189. — *Permanent Station Adjustment for the Dumpy Level.*—In any level track upon a flat piece of ground take two oak stakes about 3 feet long, more or less according to the nature of the soil, and of about $3\frac{1}{2}$ inches by $3\frac{1}{2}$ inches section, pointed at one end, and drive these down into the earth to within about 6 inches of the surface, at 2 to 5 chains apart according to space at command. The level is then set up at the exact intermediate distance, and correctly adjusted to vertical axis by the equal run of the bubble when reversed, and the staff is read first upon one stake and then upon the other. The difference is recorded, and the one stake is sawn off or driven down the exact amount of the difference. The ends of the stakes are then smoothed off to exact level. With two stakes levelled in this manner, if the level is then set up at any distance, say a chain or two, from the nearest stake in direct line with them, and the staff reads the same when placed on either stake, the telescope is in adjustment. If it does not read exactly, the difference is adjusted by the screws

under the limb to bisect the difference. By another method the eye-piece of the level may be placed over one stake, the bubble adjusted to the centre of its run, and the height of the centre of the eye-glass be taken from this stake by means of a rule across the face of the staff reading. If the staff be now placed upon the second stake, and the telescope be adjusted to cut the height just taken and the bubble be kept in the centre of its run, the whole will be in adjustment. With such a permanent station, adjustment of the telescope takes very little time; and it is only necessary to examine the stakes occasionally to see that they are in perfect order.

190.—*Temporary Adjustment to Collimation.*—Upon a fairly level piece of ground the staff plate, fully described further on, is trodden well down on the ground, and the level is set up at say 3 chains from this, in which position the staff is read as a back sight. Now further on in the same line, at 3 chains distance from the level, a second staff plate, or in defect of this a stake or a boulder, is driven firmly down in the earth, and the staff is placed upon this erect and face to the instrument as a fore sight. The instrument is turned half round and the second station is read. These readings will be truly level with each other. If the axis of the instrument has been set up quite vertical, so that the bubble has kept its centre in all positions,

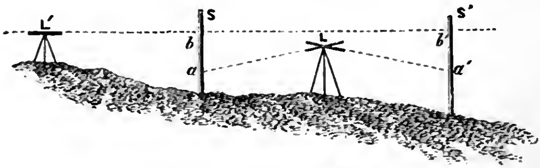


FIG. 64.—*Adjustment of dumpy level.*

this is true although the axis of the telescope may have been out of collimation. This arrangement is shown in Fig. 64, *L* the first position of the level taking sights at equal distance from S and S'. Let the level be now removed to L': if correct it should cut the staves $S S'$ at equal distances above or below the first readings at $a a'$, which are at equal distances from $b b'$ readings from L', therefore level and parallel with the first reading.

191.—In the dumpy level as it leaves the hands of any respectable maker, the adjustment required can never be great afterwards, unless the level has suffered a serious fall so as to bend the limb. The rewebbing the stop, if carefully done, would require only a slight readjustment; but it may be convenient to give an exact method for extreme cases, which may be given in detail for clearness, and at the same time we may consider the influence of the curvature of the earth.

192.—*Original Adjustment of the Dumpy Level to Collimation, with Consideration of the Curvature of the Earth.*—Suppose the readings of the two levelling staves at 10 chains apart, taken with the level placed at intermediate distance as before, read 7·50 and 4·50, and that we now place the level lineally at 1 chain outside the first reading and it reads the near staff 6·50 and the distant staff 5·50, by the inclination of the ground, this would be a + and a – reading; but we require both readings of one sign, and as the distant staff reading is much too high, it is clear we require – readings for correction. The correction will be of the difference of reading in proportion to the distances, calling the lower reading minus—

$$7·50 - 6·50 = -1, \; 4·50 + 5·50 = +1, \text{ difference} = 2.$$

That is – 2′, as our readings are – and as the – 2′ is in 10 chains, at 1 chain the distance of – the near staff = – ·2, and 11 chains the distant staff = – 2·2. The correction will therefore be for the near staff 1 chain distant 6·50 – ·2 = 6·30, and for the distant staff at 11 chains 5·50 – 2·2 = 3·30 = – 1·2 below each of the first readings. If the telescope be now collimated to the near staff reading 6·30, by adjusting the screws immediately under it for distance between the limb and the telescope, and the bubble be readjusted to the telescope without moving the instrument or touching the parallel plate screws, the adjustment will be perfect, less the small error due to the earth's curvature in 1 chain. If the telescope be adjusted to the distant staff 3·30, curvature of the earth will be corrected by the level for 11 chains, which is 0·0106 foot or ·01 nearly, the smallest reading we have on the staft.

193.—It was claimed by the late William Gravatt for his method of adjustment,* which was equivalent to that given above, but more complicated and with three staves, that the fixed correction for curvature at 10 chains would be uniform in the working of the level *pro ratâ* for all distances. There is some difference of opinion on this subject: at any rate, a 10-chain correction would only be applicable to very approximately level ground where average 10-chain stations could be taken.

Where space is not at command and curvature correction is not desired, adjustments of the level may be made with care at 1 chain distance on each side of the setting-up of the level with one staff only, which can be moved from one stake to the other, and with the final setting-up of the instrument at 1 chain distance from these stakes as before. For this the staff only requires moving twice, if the collimation adjustment is to the last reading only calculated out as above. This close system has a certain amount of merit, that by reading from one staff only for both stations it is more accurate, as any inequality between the divisions of two separate staves is avoided.

194.—**Collimator.**—Optical manufacturers in populous districts and some observatories, as that of the India

* See Simm's "Mathematical Instruments," page 3.

Store Department at Lambeth, adjust by means of the collimator by the exact method due to the late eminent German mathematician, Carl F. Gauss, which is hence termed the *method of Gauss.* The collimator consists of

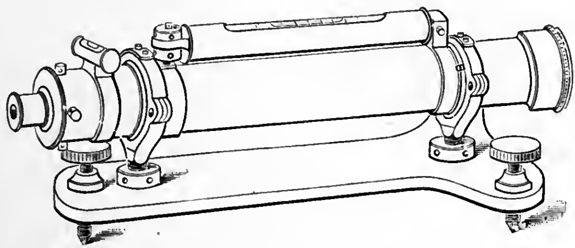


FIG. 65.—*Collimator for adjustments to horizontality of the telescope.*

any good telescope permanently adjusted to solar focus, with a webbed diaphragm placed in the focus, where it may be illuminated by a lamp or by the reflection of daylight, and provided with means of bringing the telescope to a level position. As the collimator is generally constructed, it consists of a 12 to 18 inch telescope Fig. 65, of the same description as that used for a Y-level, described art. 80, in which the telescope is surrounded by accurately turned collars formed to rest in Y's. The Y's are supported upon a heavy cast-iron stand, which is of somewhat triangular form, of nearly the length of the telescope, about 6 inches wide at one end and 2 at the other. The stand has two feet extended to the full width at the wider end, and one foot at the narrower end under the telescope. Each foot has an adjusting screw. The complete collimator is supported, at about the height of the telescope of the level on its stand, on a very solid pier of stone or brickwork in cement capped with a stout slate slab. The telescope is got to perfect collimation as with the Y-level, already described art. 172, and the level is fixed true with the axis of the telescope, when the collimation is perfect.

A lamp or gas flame is placed at a short distance from the eye-piece end of the telescope, so as to illuminate the webs that they may be distinctly seen when looking into the objective end of the telescope. In bright daylight, if there is a skylight over, a reflector will answer the same purpose. At the Lambeth Observatory a fine pin-hole is used instead of webs.

195.—The instrument to be adjusted may be placed at any convenient distance from the collimator. For adjustment of a level, where the collimator is already in adjustment, the level is raised upon its stand until the axis of the telescope sensibly coincides with the axis of the collimator; then if the telescope of the level to be adjusted be focussed into the objective end of the collimator, the illuminated webs will be clearly seen; and if these webs be brought by adjustment of the level exactly to coincide with its own webs, the two instruments are each exactly level. In this adjustment it is only necessary to be sure the vertical axis of the level is truly vertical, so that the bubble reverses without displacement and the whole instrument must then be in perfect adjustment.

196.—It would be very difficult to use this method of adjustment if it was necessary that the axes of the level and collimator should *exactly* coincide. It is only

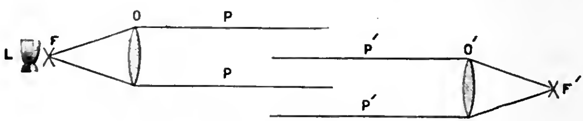


FIG. 66.—*Diagram of collimation by two telescopes.*

necessary that they should nearly coincide, on account of the imperfection of object-glasses, which rarely work so well near the edge as towards the centre; otherwise any directly parallel position in front of the object-glass would answer, as the above diagram will show. Let

O be the object-glass of the collimator, whose solar focus is at F. Then the rays PP, and all other parallel rays falling on the object-glass, will be brought to a focus at F; and reciprocally all rays departing from F in passing through this object-glass will leave in parallel lines PP. Let O' be the object-glass of a telescope to be collimated, F' its solar focus. Then all rays from P to P departing from F that fall within the parallel space $P'P'$ will be brought to focus at F'. When the image at F is illuminated by a lamp L, the webs or other index will be clearly seen by the eye-piece at F' when the two telescopes are exactly parallel with each other. In this position the webs of the level are adjusted to make this coincidence. It is easily seen that by this method we eliminate all errors of atmospheric refraction and are quite independent of the state of the atmosphere for obtaining distinct vision.

197.—When two levels are at command, one a Y-level, or even a dumpy in perfect adjustment, the one may be used as a collimator to the other by setting them up at a distance within their focal range on a firm basement floor. A candle or a lamp will give sufficient light to illuminate the webs of the instrument which is used as a collimator, being certain of course that this instrument is first placed in level adjustment and set at *solar focus*.

198.—**Improved Dumpy Level**.—The writer has attempted some improvements in the dumpy level which have so far met with very general approbation from the profession, Fig. 67. These improvements are directed to ensure much greater sensitiveness in the bubble, therefore greater accuracy in the work performed by it; more solidity of construction without increase of weight; and permanence of reading index, with some additional matters. In these improvements the mounting of the level tube, instead of being placed in a stiff joint at one end, or between rigid clamping nuts at both ends, has a barrel-fitting at one end which is ground into a parallel hole. This plan admits of circular self-adjustment to the bubble tube, which the clamping of the nuts

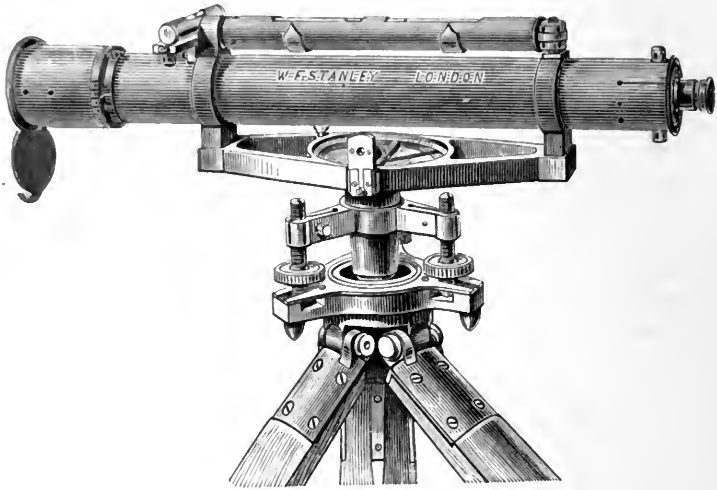


FIG. 67.—*Stanley's model 14-inch dumpy level.*

can never twist or strain during vertical displacement; and the joint can be made perfectly sound with certainty. This considerably saves the risk of accident to the bubble from expansion by heat and some other conditions. The telescope straps are fitted at their stumps solidly down upon the limb, as shown Fig. 59. Adjusting screws are placed under this as in the dumpy level described, but the pressure screw is not employed except in case of accident far away from an optician, when it is there simply ready for use. The limb is framed out into two edge bars: this gives greater vertical sectional strength and resistance to torsion without increase of weight in the instrument. Where a compass is used, this is included in the frame of the limb, as shown in the engraving. The compass is read with a prism, this being much more convenient and exact than looking down upon the divided circle, the instrument being necessarily placed at nearly the height of the eye. The compass ring is made of aluminium.

199.—The further improvement which the author considers of the greatest moment is, that the vertical axis is fixed directly and firmly upon the limb, and not through a loose screw fitting for separation at this point, as in the ordinary dumpy. This is shown to be important in that, with the dumpy, where a loose screw is employed, any little difference of screwing down upon the axis when the instrument is set up causes so much derangement of a sensitive bubble in relation to the vertical axis, that the optician is bound to use a rather dull level with the ordinary dumpy. Further, a particle of grit, or the slightest bruise on the collar in replacing the instrument in its case, throws it out of adjustment at this important point. The objection to the author's plan is that it makes the case for the instrument somewhat larger; but the advantage of certainty of permanent adjustment appears to him very far to counterbalance this objection where accuracy is aimed at.

The setting-up adjustment of the instrument is upon tribrach limbs with three screws only. These screws can never strain the vertical axis, which in this instrument is somewhat deeper and more firmly made than that of the dumpy. The author uses his own plan of mounting the *tribrach*, as it is termed. Instead of placing the points of the screws in grooves, as in Everest's plan, which will be described further on, for theodolites, which produces a certain amount of strain when the screws are unequally extended, the screws in this level are formed with ball ends, which rock upon displacement upon a flat supporting surface. The necks of the balls are held down by a stiff spring plate fitted over them. The general construction of the lower part of this level may be seen from inspection of Fig. 68: *L* limb, fitted with compass; *C* axis in one casting

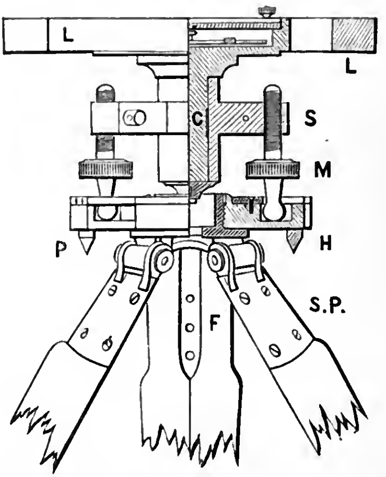


FIG. 68.—*Details of Stanley's dumpy level: half elevation to left, half section to right.*

with the limb; *S* sprang carrying the socket and supporting the instrument. *P H* shows the ball head arrangement to the screws. A central screw in this part detaches the tripod. One point is shown at *P*, of which there are three to support the level upon a wall or rock in cases where the tripod cannot be used. The tripod head is made more firmly than that of the ordinary construction, by extending two wing fittings, from the top of the shovel-plates *SP* as wide apart as possible, instead of the narrow tenon fitting before described. The shovel-plates are screwed to the staff by means of a stout nut-plate inside the tripod *F*. Those who have experienced how much defective levelling is due to a shaky tripod head will appreciate this precaution.

200.—**Ray Shade** to the telescope used in the above-described level, has two narrow slits opposite each other at 180°. A zero line is carried from one slit to a line on the ray shade fitting when the slits are quite horizontal. Sight through the slits at zero enables

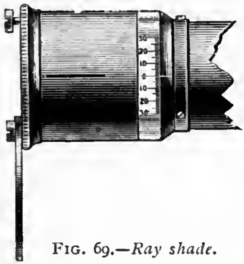


FIG. 69.—*Ray shade.*

an approximate cross-level to be taken. The edge of the tube of the ray shade is divided 20° on each side of the zero line to 2°, so as to take approximate lateral inclines of the surface of the land in levelling. This plan of cross-sighting was originally proposed by Gravatt.

201.—The most important variation from the telescope of the dumpy level described is in the diaphragm, where webs or wires of any kind are entirely done away with and are replaced by a special form of index. This is represented in Fig. 70. The movable part carrying the opening of the diaphragm is placed in a sliding fitting, as previously described art. 182 for the dumpy level. The index which replaces the web is a finely pointed needle formed of platino-iridium (platinum ·75, iridium ·25). This alloy has about the hardness of spring tempered steel, and is, as far as known, perfectly non-corrosive in air or moisture. A pair of vertical points indicate the position for holding the staff. It will be found by experiment that the point reading is much more exact than with the web, as iridation due to edge reading of the web is entirely avoided, as is also the covering of the object intersected by the web due to the angle its thickness subtends upon the staff, which is very palpable at 10 chains distance. The iridium point is sufficiently strong to be kept perfectly clean by

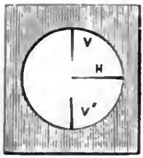


FIG. 70.—*Stanley's platino-iridium point level stop.*

touching it occasionally with the point of a camel-hair brush if it appears dusty. By care this point will last in adjustment for as long a period as the level itself remains in use. Upon first impression the point may not appear so fine as a web, but practically it is more exact, as the following exaggerated images will show—

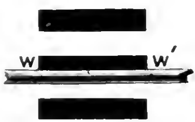


FIG. 71.

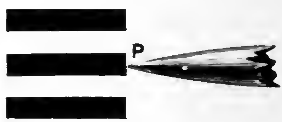


FIG. 72.

Difference of reading with a web and a point, shown much magnified.

Fig. 71 is the image of a division of the staff partially covered by a web *W W'*; Fig. 72 that of the magnified image of a point *P* brought towards a division for reading. It will be readily observed that the fractional part of the block which the point *P* cuts, is much more easily estimated than that in which the web cuts or covers of a similar block.

202.—*Stadia Points.*—The author commonly makes the points Fig. 70 *V V'* stadia points, by making the distance of the extreme ends of these subtend an angle equal to 10 feet of the levelling staff at 10 chains distance (+ a constant to be discussed chapter IX.), by which measurements of the distance of the staff can be taken or checked.

203.—*The Setting-up Adjustment of a Level supported on the Tribrach System* is different from that already described for the parallel plate system, particularly in that there are no opposite screws. For the setting-up adjustment the level is at first set lineally with any two of the screws, and the long bubble is adjusted by these screws to about the centre of its run. The cross bubble is then adjusted without moving the level, by the third screw only, which adjusts at right angles to the first adjustment. When the cross bubble is correct, the long bubble may have been slightly disturbed by the last process; therefore this may be returned to for final adjustment, and the instrument may be rotated to see if it is in good adjustment all round. If not, slight adjustment may be made alternately with the telescope lineal with any two screws, and then with the telescope turned over the remaining screw, so that all adjustments are in this manner finally made by the long level tube. With this tribrach system the level tube may be much more sensitive than with the parallel plate system, therefore the adjustment, although not taking longer time, is much more exact. In a large level the divisions of the tube may represent a displacement of five seconds of arc only, representing less than $1\frac{1}{2}$ inches in the mile displacement of the direction of the telescope.

It may be observed that the foot screws of the tribrach are adjustable for tightness if they become worn by the cross screws at any time. The tightness should be just sufficient that there should be no sensible shake on the screw, and yet it should be sufficiently easy that it may be turned with a force less than that which would disturb the instrument in the slightest degree.

204.—The further discussion of the subject of high-class levels becomes somewhat difficult. Leaving out of consideration the levels sold by the trading optician, who deals in the commercial article but sometimes superadds a little fad, every genuine manufacturer has his pet plans of carrying out details, some of which may be very meritorious, but which could scarcely be described without full discussion. There are also, no doubt, a great number of mistakes that have been made in the construction of the surveyor's level. The direction in which the scientific optician generally fixes his attention is to give the advantages of the Y-level in the dumpy form, assuming the civil engineer holds a certain amount of prejudice against the use of the Y, for which in its old form at least, the writer must admit he was fully justified.

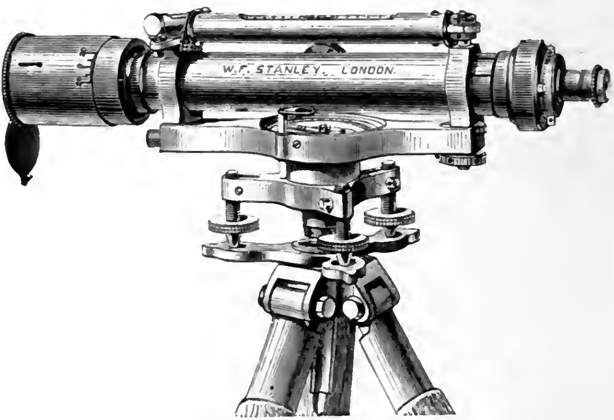


FIG. 73.—*Cushing's 12-inch improved level.*

205.—**Cushing's Level.**—The level illustrated above Fig. 73, by Mr. Thos. Cushing, F.R.A.S., Inspector of Scientific Instruments for India, would under any circumstances claim attention from this gentleman's well-known high technical scientific attainments. It has also the merit of being in extensive practical use in India at the present time.* The principal improvement in this instrument over a scientific dumpy form, which it otherwise represents, is in the construction of the telescope, which possesses all the necessary adjustment of the Y-level. The telescope is firmly fixed in collars soldered to the tube, as in the dumpy. The tube at each end is formed into a stout socket collar. These socket collars are exactly alike, and are ground to fit either the objective or the eye-piece end of the telescope, so that these parts may be reversed, the one for the other. This reversing is exactly equivalent to turning the telescope end for end in the Y-level. The end also rotates in its fitting, which is equivalent to rotating the telescope half a revolution in the Y-level. The reversible ends of the telescope are held in their ground fittings by studs and slides (*bayonet notches*). It is easily seen that by this plan adjustments may be made of collimation and of fixing the line of collimation perpendicular to the vertical axis as with the Y-level. In the diaphragm there is also an improvement over the employment of webs. The stop is of the slide form described for the dumpy Fig. 60, but in place of webs the opening is glazed with a piece of parallel glass upon which very fine lines are engraved, which have the appearance of webs in the eye-piece. One important arrangement is also made in this part—which is necessary, as glasses become frequently bedewed in the telescope—which is, that the eye-piece end may be removed from its ground fitting and the glass cleaned and replaced without disturbing the adjustment in any injurious degree. The general construction of the instrument can be seen from the illustration. The supports of the telescope have a rocking axis at one end and are adjusted by capstan-

* See pamphlet on "A New Form of Levelling Instrument," by Thos. Cushing, F.R.A.S., 1879.

headed nuts at the other. The adjustable support for setting up the instrument is upon Everest's tribrach system for theodolites, which nearly resembles the author's plan previously described, except that the instrument may be detached at this point by means of a sliding fitting formed in the covering plate. The tripod head has also wider bearing than is general, which is produced by extending the book-plates into the form of a socket fitting. The illustration given is of a 12-inch level; in the 14-inch an open framed stand is used in place of the solid tripod, which will be described further on, for theodolites. The level is a decidedly good one; but the author has experienced with it some slight defects when compared with his own Y form. The ground collars are a little inclined to bite, particularly if the instrument has been set by some time, so that in reversing for adjustment there is great risk of disturbing the instrument. The glass index, although permanent, has the same defect as the web—of covering the image of the staff reading. It also obstructs a little light, and is subject to dew, which the point system avoids. The weight of the instrument is increased by the collar fittings.

206.—*Cooke's Level.*—A somewhat equivalent instrument to the above has been patented by Messrs. T. Cooke & Sons. In this, instead of the objective and eye-piece ends of the telescope only being reversible in the collar fittings, as in Mr. Cushing's level, the entire end portions of the telescope, from the supporting collars, reverse end for end, by means of prolongations of extra inner tubes which fit and slide into the outer body tube. These tubes also permit the rotation of the whole optical parts about the axis of the telescope for adjustment for collimation, although in a manner more frictional, and therefore more likely to disturb the instrument than in the simple Y adjustment. In this instrument, again, it is easily seen that it is the perfection of the Y-level that is aimed at, without its outward appearance, and to gain this the weight is increased by extra fittings and double tubing; so that altogether it is not quite so convenient and simple as the best constructed Y-level; but if it gives the adjustments the optician holds to be most important, in a form that may be acceptable to the civil engineer, we may in this manner perhaps, from the optician's point of view, count it a certain gain in the same direction as Mr. Cushing's level just described.

207.—**Supplementary Parts to Levels.**—As a rule, supplementary parts fixed to the instrument, beyond the magnetic compass, are very objectionable, if the object of the level is to be levelling, as these additional parts inevitably increase the weight which has constantly to be borne in carrying the instrument. Supplementary parts have been carried, in various schemes, to the extent of combining the entire level with the theodolite, at the same time nearly combining the united weight of the two instruments. As a rule, professional men rarely care for complex combinations; and even after a limited popularity is granted to extra parts not absolutely required, these are generally finally abandoned. Mention of two such parts, therefore, only will be made, as these owe their respectable introduction to the late William Gravatt, and are found as a part of many levels in use, or at least contained in the case with the instrument.

208.—*Bubble Reflector.*—This was generally placed upon all dumpy levels. It consists of a small mirror about 2 inches by $\frac{5}{8}$ inch fixed in a frame that is jointed at its lower end to a short piece of tube which is partly cut away so as to form only a little over a semi-cylinder. This tubular part just clips firmly upon the brass casing tube of the spirit level. The reflector, when placed vertically on the level tube, can be adjusted by its joint, so that the run of the bubble can be observed by reflection in looking above the eye-piece to see that it is in adjustment at the time of taking an observation. Its use was thought to be a precaution in levelling, particularly on marshy ground.

209.—*Sight Vanes.*—Two sight vanes placed above the telescope, either as loose fittings or to hinge down upon the level tube. One vane has a vertical narrow slit and cross hair; the other has a window with a vertical horse-hair placed in its centre. This arrangement gives sight of distant landmarks lineal with the direction of the telescope, upwards or downwards, beyond its field of view. A slider, fixed upon the window sight, reads at its upper edge into divisions cut on the vane, by means of which an approximate rate of inclination

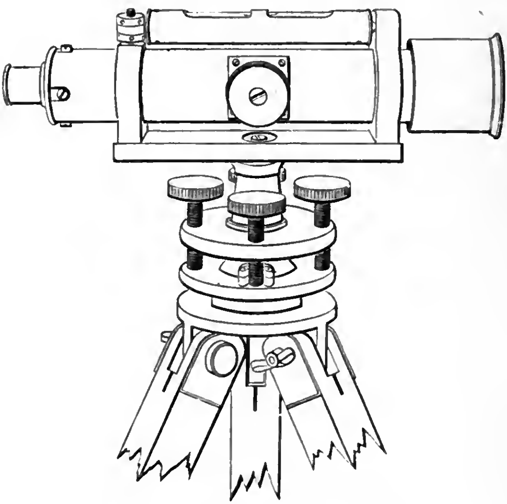


FIG. 74.—*Compact cheap form of dumpy level.*

of forward land may be taken. This sighting arrangement adds about half-a-pound weight to the instrument.

210.—**Lower-class Levels.**—A level is often required by an architect or a contractor for works of limited area, where it is quite unnecessary to go to the expense of a civil engineer's level of refined manufacture. In such cases the level may only be used occasionally and under favourable circumstances, so that extreme solidity is not demanded, neither is distant view in the telescope required. The level generally made for such work is a simple dumpy, without cross bubble, compass, or any extra fittings, and with one eye-piece only.

211.—The instrument Fig. 74 illustrates the author's newest design for a simple level. It has an American form of tripod without brass fitting. The split-up legs clamp directly on angle plates with wing nuts—these are not quite so portable or so neat as cylindrical legs, but they are easily made, very firm, and will bear considerable wear and keep in order.

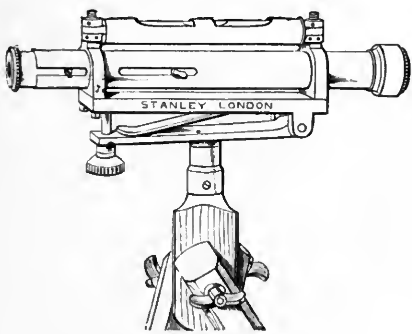


FIG. 75.—*Contractor's or builder's level.*

212.—The illustration Fig. 75 represents the cheapest form of level with a tripod stand that has been constructed, which contains the important factor of a telescope. The telescope has a sliding fitting which is moved by a knob outside, this being cheaper than a rack and pinion fitting. The level tube is solidly supported in collars.

The adjustment is in one direction only, so that the bubble must be set and examined at the time of reading the staff. The instrument is supported on a *sprang*, jointed at one end and held by a milled-headed screw at the other. Any shakiness of the thread of screw there may be is taken up by a stiff German silver spring between the sprang and the limb. The tripod head is of simple construction, of a well-known French form, made of pearwood. The legs are oak and are clamped on the head by wing nuts. This simple tripod is fairly firm in use. The level is good enough for ordinary building works, laying drains, etc., within limited areas. It is much more accurate than any form of open sighted level without telescope.

The consideration of various kinds of hand levels will be deferred to a future chapter on clinometers, with which they may be conveniently grouped.

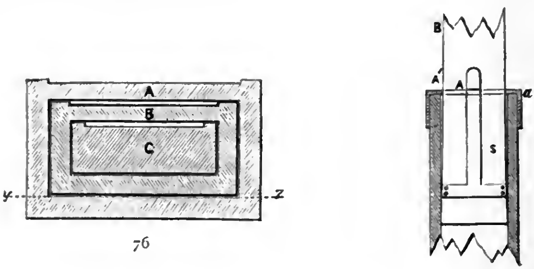
CHAPTER V.

LEVELLING STAVES — CONSTRUCTION — VARIOUS READINGS DISCUSSED—SOPWITH'S—FIELD'S—STRANGE'S—STANLEY'S NEW—METRICAL—SIMPLE CONSTRUCTION MINING STAFF —PAPERING LEVELLING STAFF—PRESERVATION—PACKING PADS—STAFF PLATE—STAFF LEVEL—PRACTICE OF LEVELLING—INDEX OF BUBBLE—LAMP—CURVATURE CORRECTIONS —STATION PEGS—REFINEMENT OF LEVELLING—LEVELLING BOOKS—INK BOTTLE, ETC.

213.—**Levelling Staves.**—Since great improvements have been made in the telescopes used as part of all modern surveyors' levels, particularly by increasing their light receiving capacity, all systems of vanes which were formerly made to be seen distinctly at a distance have disappeared from use with British surveyors; and it is now found that the plain reading of a divided staff can be taken by means of the telescope at a sufficient distance from the observer for all practical purposes. In this country one uniform construction of staff is now generally adopted; and the only variations that are made in this are found occasionally in the readings. The construction of the level staff in common use is that due to the late Thomas Sopwith,* sometimes called the *telescopic staff*, the face view of which is shown Fig. 79. For ordinary open field work this is made 14, 16, or 18 feet in its extended length; but generally, except for levelling on mountainous land, the 14 feet is used. This staff when closed is about of the same length as the tripod, 5 *feet* 4 *inches*, which is a length convenient to stow away under the seat of a railway carriage. Sopwith's staff, as it was formerly made, consisted of two square parallel

* Brit. Assoc. Report, 1838, page 154.

tubes and one inner solid parallel slide. Made in this manner it was liable to be rather shaky when extended, besides which it frequently got jammed in the telescopic boxes if put away damp from rain: this tended at first to limit its use. It is now general to make the boxes slightly conical, that is, diminished towards the upper part, so that they form a fair fit when opened out but are very free when closed, which quite remedies the defects first mentioned.



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Figs. 76, 77.—*Section of Sopwith's staff.*

214.—The ordinary construction of Sopwith's staff and the best mode of manufacture is shown, with the joints grooved together, in section Fig. 76. The outer tube or case *A*, which in the 14-feet staff is 5 feet in length, is made of mahogany $\frac{5}{16}$ inch thick, the front being $\frac{1}{4}$ inch. The outer dimensions of the section are $3\frac{1}{8}$ inches by 2 inches. The second tube *B* is 5 feet 1 inch long, of outer dimensions $2\frac{3}{8}$ inches by $1\frac{1}{4}$ inches. The inner slide *C* is solid, 5 feet 2 inches long, $1\frac{3}{4}$ inches by $\frac{3}{4}$ inch. All the slides are sunk on the face about $\frac{1}{16}$ inch to prevent the divisions being rubbed by exposure in sliding together. The slides have each brass shoes and cap. They are held when extended by a spring catch, the detail of which is shown in Fig. 77, section *y* to *z* of Fig. 76—*S* spring of T form screwed firmly to the edges of the box. The catch is made at *A* over the edge of the brass cap *a*. The spring should be of very hard rolled brass. It is well to have one or two brass bands round the body of the outer casing to secure this as far as possible from being split by accident.

The most important consideration in the manufacture is that the telescopic work should fit well, and that the boxes should be glued up quite square and out of winding. The boxes should, after the glue is quite set, be screwed with brass screws at distances of about 6 inches apart, to secure the joints if they are afterwards at any time exposed to long continued rain. The fittings should be carefully made, so that when the staff is extended there should be no shakiness sufficient to cause serious vibration when it is used in windy weather. The interior of the slides when finished should be thoroughly oiled with raw linseed oil, and the outer surfaces be well soaked in shellac dissolved in spirit, and be French polished over this. The brass-work should be well lacquered.

215.—**Semi-circular Staff.**—This is another kind of telescopic staff, with Sopwith sliding arrangement, which possesses considerable merit, but which is more expensive to make. It is semi-cylindrical, the cylindrical part being made without any joint. This is shown in the section Fig. 78. The general dimensions are the same

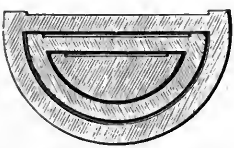

FIG. 78.—*Section of semi-cylindrical staff.*

as in the Sopwith staff. This staff is a little stiffer, but there is more risk of its not standing true. As in the union of four pieces of wood in the square form, the tendency of one to warp in a certain direction is resisted by the other pieces; but in this cylindrical form there is no such resistance, so that it is found that staves when exposed to wet are much more liable to get fixed in the slides. There is also more difficulty in getting the conical form fairly accurate in the working. One particular merit, when a pair of staves of this kind are used, is that the two go together and form a cylinder, which is a very compact form, but perhaps a little more difficult to carry, from the tendency to roll off the shoulder.

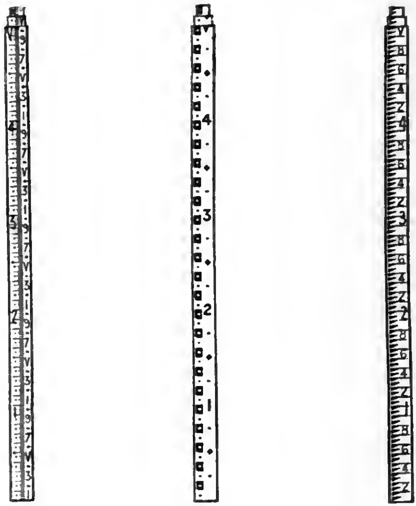

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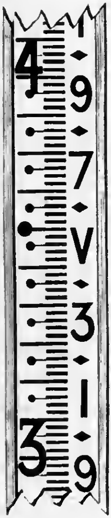
FIG. 79.—*Sopwith pattern staff.* FIG. 80.—*Field's pattern.* FIG. 81.—*Stanley's old pattern.*

216.—What was originally considered as the defect of the Sopwith staff, besides its shakiness as it was first made, was the diminished width of reading of the upper length, this being only $1\frac{1}{4}$ inches wide. This caused for a long period other forms of staves, which maintained the same width of reading surface right to the top, to be preferred by many. This fault has been partly remedied by the author making the feet readings of the upper staff by dots, instead of the narrow figures which were very difficult to read. Otherwise the light and portable form of the Sopwith staff has ensured its general use.

The original form of reading designed by Sopwith is still much more in use than any other. It is similar in pattern to Fig. 79, shown in detail for 1 foot Fig. 82.



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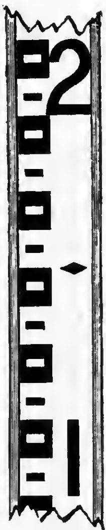

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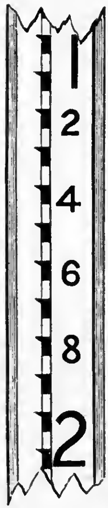

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Fig. 82.—*Sopwith's staff.* Fig. 83.—*Rogers Field's staff.*
Fig. 84.—*Col. Strange's staff.*

The dots at the ends of the lines shown in the figure were introduced by the author to render this staff more distinct than when lines only are used, as in the ordinary pattern.

217.—Sopwith's pattern is sometimes printed on paper for pasting on the staff, and in this manner the staff comes out much cheaper than by drawing the readings in solid paint. Paint, however, is strongly recommended, not only that it wears much better and keeps cleaner, but that the painting and after varnishing add very much to the durability of the staff, exposed as it must necessarily be to rainy weather. Further, the paper however well it is fixed at first, is liable to creep away from the edges of the staff, and leave a space into which rain enters very freely by capillary attraction and does not again freely evaporate, so that it rots the staff and makes the paper reading after a time mouldy. It is nevertheless convenient to take a set of first length papers if a surveyor is going abroad, as from accidents, or grazing by carrying the staff with the tripod of the level, etc., the first length surface is very liable to become too much injured and effaced for fair reading. A description of fixing the papers will be given further on.

218.—*For Reading the Sopwith Staff*, the foot readings are taken from the tops of the red figures. The ·1 foot figures are in black and are all odd numbers, 1, 3, v, 7, 9. These read also from the top. The height of the figure is exactly ·1 foot, so that the bottom of each figure reads the lower even number—thus the bottom of 3 reads 2, of 5 reads 4, of 7 reads 6, and of 9 reads 8. The 6 and 9 foot figures if made alike, from effect of telescopic inversion, may cause error. The author has for many years made the head of the 9 a solid black block to avoid this.

A very large number of surveyors design their own staff readings. This was formerly very much the fashion, consequently a great number of patterns come before the manufacturer.

The author for about twelve years kept a copy of what he considered the most meritorious of these patterns, both for future reference and to judge of their comparative merits. This was discontinued, in that it was found that the number of designs became a little perplexing, and they were rather dangerous to show to a customer, who often selected a pattern by appearance which proved afterwards unsatisfactory in use.

219.—**Rogers Field's and the Author's Staff Reading.**—The author made some experiments to obtain a clear staff, readable beyond the ordinary range of staves with a 14-inch level; but much more complete experiments were made with the author's patterns by Mr. Rogers Field, C. E., whose ingenuity is well known. This gentleman finally designed a staff which in the author's opinion is still the best, but it has not generally pleased the profession: this is illustrated Figs. 80, 83. The author has tried it at all distances: at 20 chains he has found a reading of ·01 foot could be taken with a good 14-inch level very approximately with his point index-stop level Fig. 70.

220.—**Colonel Strange's Staff Reading.**—The late Colonel Strange made a series of experiments with the author's patterns placed at 10 and 20 chains distance. He also had for these experiments one of Mr. Rogers Field's staves. He arrived at the conclusion, for distant reading particularly, that the black markings on all the twenty staff patterns he had were excessively heavy—that the lightest and most open readings were the clearest. This led him to design a staff, a part of which is shown in Fig. 84, which has been since generally used on the great India survey. This staff somewhat resembles the English ordnance pattern. The fault found with these patterns is that they do not read the ·01 foot, which is necessary for close reading in hilly districts, otherwise they are read very clearly at a distance of 20 chains where the Sopwith becomes a blur. But we may take it that the surveyor, if he is a fairly good draughtsman, would subdivide the ·05 block to the ·01 foot; but it is argued that his assistant, who might be a fair leveller, might not. Another objection is that the reading is on one side and is not cut through by the horizontal web, so that a white margin can be seen in the telescope on both sides of the vertical webs, between which it is most pleasant and exact the reading should be taken. This objection does not however hold for the point reading Fig. 70. Colonel Strange's pattern has not been very generally accepted by civil engineers. The author tried to meet the matter by making the block ·05 foot, but so subdivided as to indicate ·01 foot. This has frequently been preferred to his dotted Sopwith.

221.—The author has lately designed another staff especially for his point index. This is shown below.

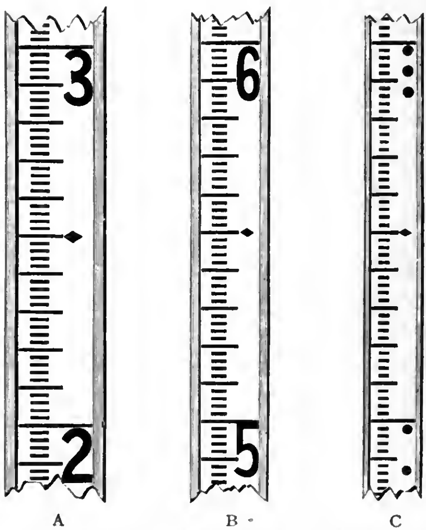


FIG. 85.—*Details of Stanley's new staff; A bottom length, B middle, C top with dot figures.*

It appears all right on experiment, both for distance and near sight; but its value has not yet been fairly tested. In this staff for the close figures 11, 12, 13 on a 14-feet staff, which are with great difficulty distinguishable at a distance, the author employs dots only—one dot for the 11, two for the 12, and three for the 13, as shown *C* for the 12 and 13 in the right-hand figure. It must be remembered that a good clear staff is a great desideratum, as it means less size, weight, and cost in the level necessary to be used with it for equal exactness. A clear staff with a 12-inch level is quite equal to a complex misty one with a 14-inch level, with the advantage of saving about 2 lbs. in the weight in the level to be carried.

Our space will not permit the discussion of the various staff readings that have been designed, many of which are, in the author's opinion, superior to the Sopwith; but some variations are necessary occasionally for personal reasons. Some surveyors, from imperfect colour vision perhaps, strongly object to the red foot figure as being indistinct at a distance, hence in many patterns a clearer black figure is employed. Some get confused with the number of equal lines of ·01 in the Sopwith, in what is sometimes termed *Sopwith's ladder*. In this case these lines may be made unequal in different ways: several patterns have this peculiarity. Some cannot get over the inverted figure as seen in the telescope. In this case it would be much better perhaps to read with an erecting eye-piece to the level; but practically the manufacturer has to invert the figures. Other less important variations are common.

222.—**Metrical Staves.**—These are in this country generally made 14 feet, to keep the length the same as the tripod. The most approved pattern is shown Fig. 86. In using the metre at short distances often a complete metre cannot be taken in the field of view, so that there is a little difficulty in being certain to what metre interspace the subdivisions belong. To avoid this the author places a dot or dots after the decimetre figures that follow the metre—one dot for 1 metre, two dots for 2 metres, three dots for 3 metres. Thus 1·4 metre reads ·4; 2·4 metre reads :4. The dots need only be very small, as they are not required except for very close readings, that is, within about 30 metres: at 40 metres distance one complete metre comes into the ordinary telescopic field.

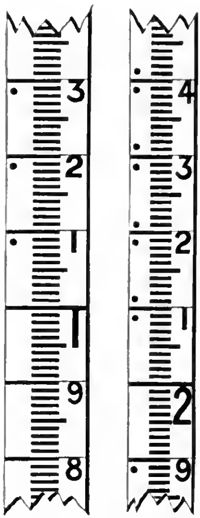


FIG. 86.—*Metre levelling staff.*

223.—**Feet and Inches Staff.**—For building works, drainage, and some other cases, the staff is divided into feet and inches and subdivided again into quarter-inches. This is most convenient when the work has to be carried out with 5 or 10 feet rods and the 2-feet rule. The intermediate inches between the feet are better marked 3, 6, 9 only than fully figured. For rough usage the author has made a solid 10-feet pine staff, well painted. This has a strong hinge in the centre, and is kept stiff when open by a strong open hook. It closes face to face in two parts, which keeps the face clean.

This is important for dock and drainage works, where the staff holder's hands in many cases necessarily get

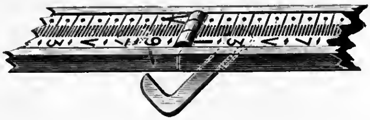


FIG. 87.—*Stanley's rough levelling staff.*

dirty by climbing; otherwise it bears much more rough usage than the telescopic staff and is much cheaper to make.

224.—**Mining Staves.**—For levelling in mines, large sewers, and other cases where there is no height for the ordinary staff, the Sopwith staff is made in its closed form, commonly 2 feet 3 inches and 3 feet 3 inches only in length, to open out respectively 5 feet and 8 feet, or in some few instances even shorter than these dimensions. The mine staff is in every way, except its length, similar to the ordinary Sopwith, art. 214.

225.—**Stanley's Portable Staff.**—The writer has recently designed a portable staff which is made in reading lengths of 18 inches, somewhat like a French folding rule. The staff may be formed of three, four, five, or six lengths, opening out respectively 4 feet 6 inches,

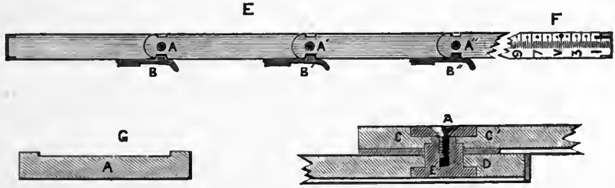


FIG. 88.—*Stanley's patent mine staff.*

6 feet, 7 feet 6 inches, and 9 feet. The separate pieces are flat boards, slightly sunk on the face to prevent the divisions being scratched in opening and closing, but left solid at the joint ends. The boards are attached

together with a kind of rivet at each joint. A strong spring at the end of each piece with a catch and notch keeps the length opened or closed with sufficient rigidity.* The entire length of the staff when closed is 20½ inches. The same kind of staff forms a very useful builder's or drainage staff, divided in this case in feet and inches; and it is conveniently portable for carrying abroad.

226.—A portable mine staff designed by Mr. G. J. Jee,† of which the author has had no personal experience, is said to be a useful staff for colliery work. It is constructed in three lengths, sliding one into the other. The bottom length of 3 feet is graduated in the ordinary way. The top of this length has a band attached to it, painted to continue the lower division of the staff upwards. The other end of the band passes over a roller attached to the top division of the staff. The roller contains a spring which keeps a constant tension on the band. By extending the lengths of the staff and clamping them, the staff may be lengthened out any distance to 9 feet. The weight of the staff is 5 lbs.

227.—*Papering or Repapering a Sopwith Staff.*—The staff, if new, is painted with three coats of rather flat, thin white-lead paint on the face, and left to season till the paint is quite hard. It is then washed thoroughly with a sponge dipped in Guinness' or other stout, until this adheres without beading, and is again left to dry. For repapering an old staff, this is soaked with hot water in which there is some washing soda, and rubbed until the old paper is brought off. After the staff is in either of the states described above, it has to be made warm and coated with one or two coats of size. The size may be made of a piece of glue left in water for a night, and then melted in a jam pot placed in a saucepan of water over a slow fire. When the staff is sized and dry it

* Patent No. 12590, 1889.
† "Colliery Guardian," vol. XXXVIII., page 576, 1879.

has to be divided carefully into foot lengths, which are marked with a set square in pencil across the face of the staff. The foot lengths may be set off accurately from an engine-divided chain scale, or by beam compasses. The papers, which are printed short, are then pasted over, preferably with paste made of starch with boiling water, but not afterwards boiled. As the lengths of paper are pasted they are laid aside, pasted side upon pasted side, to thoroughly absorb the paste for a few minutes, the time varying according to the increased length required above that of the original printed paper. While still wet, the upper paper of the two is lifted up and cut with scissors at the same time as the lifting to the boundary lines. This wet cutting ensures the paste being equally distributed quite up to the edges. The foot length of pasted paper is then laid by setting the upper edge exact to the upper foot line, and gradually bringing the paper down from this by dabbing with a clean cloth or by a straight hat-brush. If the paper does not reach the foot mark when laid, it is again lifted, and a little more pressure used in laying it the second time, which will lengthen it out as required. Other lengths are laid in the same manner. The skilled workman requires no lap to the joins of the papers, but brings them up edge to edge; with the amateur a lap of $\frac{1}{8}$ inch is advisable.

After the papers are thoroughly dry they require two coats of thin isinglass size, and then a coat or two of varnish. Paper varnish can be bought; but in defect a varnish may be made of Canada balsam dissolved in oil of turpentine. This should be laid on with a flat bristle brush (varnish brush), and set in a warm room to dry for a day or two.

228.—*Preservation of the Levelling Staff in Use.*—Where two staves are used they may be placed face to face for carrying and be strapped together, and will take little harm with moderate care. Where one only is used it is generally strapped to the tripod. A strip of wood is sometimes used to protect the face of the staff: this is very troublesome to take charge of. The author has recently made an arrangement for the protection of the front of the staff when it is carried or handled, or when it is strapped with the tripod. This is by making light shutters to fold over the face, and unfold right back to the sides of the staff when it is in use. This arrangement is shown in section in the engraving Fig. 89: *A* block

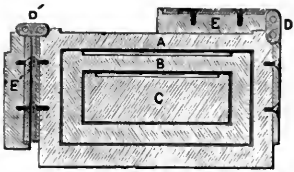


FIG. 89.—*Protecting shutters for a staff.*

section of the lower length of the staff; *E* one shutter closed; *E'* one shutter opened back, leaving the face of the staff open. At the inner edges pieces of leather are attached to the shutter, so that when the tripod is strapped upon it the shutter does not bruise the face or tend to crack it, but the pressure comes upon the sides of the face, where it is strong to resist it. This arrangement makes the staff heavier.

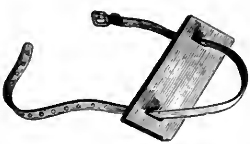


FIG. 90.—*Pad for holding a staff and tripod.*

229.—*For the Preservation of the Ordinary Staff* during the carrying with the tripod only, a convenient plan is to have two pads formed of stout ox-hide butt, each pierced with two slots near their ends at the exact distance apart of the width of the staff Fig. 90. The strap of calf leather is passed from one slot round the staff into the other slot, and then passed round the tripod and pulled up tightly and buckled. The pad of course protects the front of the staff from grazing by the friction of the tripod against it.

There is a certain amount of risk, under any circumstances, of the cylindrical tripod pressing against the front of the staff and splitting it. To avoid this the author has lately made the pads with an included hard-rolled German silver spring covered with leather, so that the pressure is distributed, the greatest pressure coming near the edges of the front where the staff is strongest to resist it. The section of this spring is shown Fig. 91 at *E* with the general arrangement of the staff *S*, and the tripod *D* fixed upon it by the strap *F*.

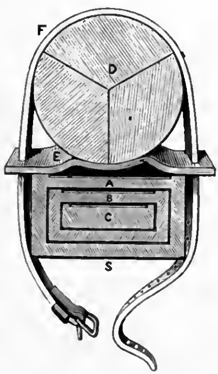


FIG. 91.—*Spring pad for staff and tripod.*

For the entire protection of the staff a leather-bound sailcloth case is very generally used. This may be divided in two compartments for the staff and the tripod, with pads between. The whole case has a neat appearance, and forms a protection from slight bruises and dirt, either in travelling or when set up in an office corner for future use.

230.—*Repairing Figures and Divisions.*—Surveyors going abroad will find it very convenient to have a few tubes of artists' oil colours—white, black, and vermillion, with one or two sable brushes to touch up any divisions or figures upon the staves that have become accidentally injured or worn off by friction. A tube of medium is also useful, which will cause the colour to dry quickly and leave it bright. The tubes of colour will keep any number of years if the caps are carefully replaced. The brushes after use should be well washed with soap and hot water, rubbing the soap in quite thickly till they are quite clean, and then be well rinsed before putting them by.

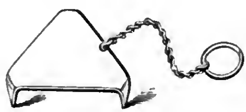


FIG. 92.—*Iron triangle to support a staff.*

231.—**Iron Triangle.**—For use of the staff in the field, particularly in open grass lands, a triangular plate of iron, as represented Fig. 92, is very useful. This is trodden down firmly by the staff holder before he places the staff upon it. In use it gives a certain base to turn the staff upon from fore to back sight.

232.—**Staff Level.**—This is a small circular level, shown in section Fig. 93, the upper surface of which is formed of a glass worked slightly concave and fixed over a short cylindrical box. The glass is generally burnished into the box and cemented round with elastic cement. The box is nearly filled with spirit from a hole covered by a screw with a large head and an India-rubber washer under it, in the centre of its bottom. The circular level is mounted on a plate with studs. The studs fit in two holes with bayonet slots in the holding plate which is attached to the back of the staff. In use the staff holder has to observe when the bubble under the concave glass is in its centre. A very little practice is required to hold the staff vertically by means of this little contrivance, which only weighs with its pocket case about 2 ozs. From the unequal expansion of the brass and glass by heat the spirit will slowly evaporate and the bubble will enlarge (say after a few months' use), but it is easily refilled by removing the screw and adding a little whisky or other spirit.

FIG. 93.—*Section staff level, ½ scale.*

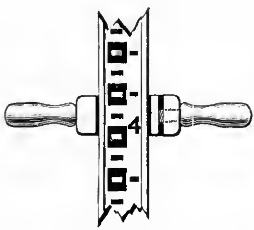


FIG. 94.—*Staff-holder, $\frac{1}{10}$ scale.*

233.—**Staff-holder.**—This implement, shown Fig. 94 striding a staff, is very generally used in Germany and other parts of the Continent. The staff is sunk into one side of a hardwood block. The block is turned at one end to form a handle. A second similar handle is cut with a strong screw and screwed into the end of the block. This screw handle by turning brings up a following piece, shown inside next the staff, which is covered with leather. When it is screwed up, the staff may be held firmly by the handles only, without risk of the fingers coming in front. With this piece of apparatus it is also held more easily and truly vertical.

234.—*Practice of Levelling with the Staff.*—This subject can be followed here only so far as to exemplify the uses of the instruments and of accessories connected with such instruments. For practical levelling we have the standard original works of Simms, Ainsley, and others, with many modern works.*

For Holding the Staff, Mr. Holloway, in the work referred to in the last note, gives instructions in such concise form that they may be quoted with advantage. He says:—"I generally enter into confidential chat with my staff holder, in which I explain to him the vast importance of his duties, *i.e.*, I endeavour to make him a man of importance in his way, and I never fail to get those duties properly performed. My instructions to him are seven in number:—

"1. Draw out the slides of the staff, and be sure the joints are properly locked. Draw out one length only unless signalled to do otherwise.

"2. When the staff is once on a point never move it unless signalled to do so.

"3. Examine the staff regularly before setting it down to see that no dirt is sticking to the bottom of it.

"4. Always stand erect behind the staff, so that the figures face the level.

"5. Do not let any part of the hand come before the face of the staff.

"6. In no case put a downward pressure on the staff.

"7. If the grass be long, mossy, or spongy, tread it down, so that the staff shall have a firm footing—select a firm spot if the selection is left to yourself." †

* "A Treatise of the Principles and Practice of Levelling," by F. W. Simms, 1842; "A Treatise on Land Surveying," by John Ainsley, revised by William Galbraith, 1849. Quite modern works—"Aid to Survey Practice," L. Du Jackson, Crosby, 1886; "On Levelling and its General Application," by Thomas Holloway, Spon, 1887; "Practical Surveying," G. W. Usill, Crosby, 1889.

† "Levelling," page 49.

235.—The manner of setting up a level has been already described in the previous chapter. The leveller generally follows a definite tract which he has previously arranged and marked out on a map. The distances apart for placing the staves or staff are measured by the chain or by the subtense system, to be fully described hereafter. Where the levelling is very important, as for canal work, topographical survey, etc., wooden pegs are driven down at the measured stations over which the levels are to be taken. A general rule followed, as far as practicable, for starting is to select an easily recognised, permanent, solid station for first placing of the staff—a mile-stone, large boulder, or other solid object answers: a datum line is generally assumed to be at a certain depth below this, to which all levels are referred. From this station, if the ground is fairly level, 5 chains is the ordinary advanced position where the level is set up and the first staff reading taken. The tripod is adjusted to the measured distance, which is indicated by a peg or other marked point left by the chainman, over which the level is set.

236.—Occasionally in town surveys the height of the level has to be taken. For this a small, steel spring, pocket tape is used to take the height of the axis of

FIG. 95.

the telescope. The tape may be adjusted by taking a piece off the first end, and allowing for the width of the tape case, so that by placing the ring of the tape upon the hook under the instrument and bringing the case just to the ground, the height of the axis of the telescope above the ground may be read off at the point where the tape leaves its case.

The reading of the first staff, the position of which is afterwards termed the *back reading*, is taken and recorded exactly as it appears in the telescope, the height of the telescope being also noted in the levelling book, to be described, if required. Thus in Fig. 96, S the first staff; L the first station for taking levels. The fore reading L to S' reads to a lower part of the staff S'; L' next level station back sight. $L' S'$ reads high on the staff S'; fore sight $L' S''$ reads low; back sight $L'' S''$ again low, following the contour; fore sight $L'' S'''$ low: thus giving data in the levelling book from which the contour can be plotted from the datum line, which is taken low to make all readings plus.

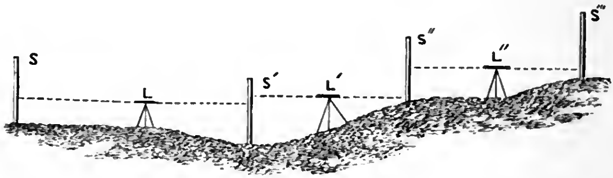


FIG. 96.—*Practice of levelling.*

The staff reading, as already described, is divided in feet, with two places of decimals. The safest method of taking this reading is to take the second decimal place first and then record it, then the first decimal, and finally the foot. In this manner no effort of memory is required, and the staff being sighted three times assures the certainty of the reading. The telescope should not be touched during the operation, so that the reading in this manner is only a cautious transfer.

237.—If two staves are used on fairly level ground, the second staff is now advanced 5 chains from the level to a measured station, the staff holder here sighting the line through the level to the back staff, and firmly treading down the staff plate if the land is soft or grass, or otherwise requires it. When time is given to hold the staff vertically by means of the staff level, the reading is taken in this position by the leveller as before, and this is recorded in the levelling book. The level is now moved forward 10 chains, that is, 5 chains ahead of the forward staff. The staff is carefully turned half round, without pressure upon its standing place, to face the level as now placed, in which position it is then read off by the level as the back sight, the back staff now being moved 5 chains forward of the level, and so on alternately staff and level until the distance required to be levelled is completed, if there is no obstruction which causes another method of procedure to be adopted. A similar plan is pursued with a single staff; but care has to be taken in securing the right line of march, which will be by placing the staff in a sight line through the level with a fixed landmark instead of the back staff mentioned.

238.—The equal back and fore sights as far as practicable are insisted upon by all levellers, as by this means any inaccuracy in the level, if the run of the bubble is kept constantly true, is thereby compensated; but it is not always convenient, and when it is not, the accuracy of the work must depend largely upon the qualities of the level. It is not necessary or convenient at all times to take the back and fore sight in a line—obstructions may occur of woods, rivers, etc. In these cases very often what is quite equivalent may be done by taking equal angular back and fore sights from the apex of an equilateral triangle, thus:—Say an obstruction occurs for the chain by a pond or wood, but that both points of which the levels are to be taken are visible at some lateral distance, these may be taken from this point, and if of equal angles to the intermediate point of distance, they are subject to no instrumental error. Thus, suppose the direct level line east (90°), and that the two stations can be seen and the staves read at

$150°$ and $210°$; here, evidently, this is equivalent to a direct back and fore sight, the right angle to the level course being $180°$—the one station is $150° = 180° - 30°$, and the other $210° = 180° + 30°$. If these equal angles can be even approximated with a fairly good level, the error will be small. In this manner intermediate and extended points may often be conveniently taken by previous arrangement with a good staff holder. It is in this angular levelling that the greatest use of the compass is found to give the angles, where this forms a part of the level.

239.—In levelling hilly ground great loss of time would sometimes be incurred from taking equal back and fore sights: the best plan in this case is to make as much use as possible of the length of staff in use. It is in hilly districts only that a staff longer than 14 feet is advantageous. With any staff in descending a hill only 5 feet of the staff can be used for the back sight, that is, a part of it equal to the height of the level, and sometimes 4 or less if there is grass, brambles, or other obstruction. Whereas for the fore sight all the staff upwards of the height of the level, that is, about 9 feet in a 14-feet staff, can be certainly used. The distance of setting up of the level and staves must in this case entirely depend upon the length of the staff.

240.—For near reading of the staff on sharp inclines, reading to two places of decimals is not near enough, as errors may accumulate rapidly. It is in such cases that a fully divided staff is best. The divisions upon a near staff appear in the telescope much magnified; and three places of decimals may easily be taken by anyone used to reading a chain scale, particularly if a point index be used.

241.—Through valleys the level may be often checked at some point from hill to hill by a back sight: the contour must nevertheless be followed for a section. It is in these shorter unequal ranges and in distant sights that accuracy in the level is demanded; and it becomes interesting to know how nearly this may be depended upon for such readings.

242.—As already mentioned, a sensitive 14-inch level of Y construction, or a dumpy in perfect adjustment, supported on the tribrach system, will work with a level tube divided to read 5 seconds in divisions $\frac{1}{20}$ inch apart. There will be a little personal error in reading the bubble from difference of reflection, according to the direction of the light from the two ends of the bubble, as before discussed; but the bubble may be assumed to be read within less than half a division, that is, within $2\frac{1}{2}$ seconds—say 2 seconds. A distinct staff may be read with a good glass within ·1 foot at one mile. A second of arc subtends ·025598 of a foot = approximately ·3 inch at a mile distance. Therefore a back reading at this distance could be taken within an inch or so allowance for instrumental errors. A reading taken in this way at a mile distance would require a plus allowance for curvature of the earth of 8 inches, minus say 1 inch for refraction = 7 inches. From this data we can get a fair check level for hilly ground, possibly more accurate than by contour levelling for a distant station, even if we allow double the probable error, say ·1 foot for error of reading the staff at a mile distance.

243.—The value of the divisions upon the bubble, when a certain number of these are equal to about 1′, may be ascertained in the open field very fairly by the use of the divisions of the staff, placed at such a distance as the minute reads ·1 foot, a minute of arc = 3437·7 radius. We may consider this small arc as equal to its sine; therefore, at 343·77 feet, or 520·8 links distance, 1′ = ·1 foot. If we now divide the number of divisions we find on the tube equal to one minute by 60, we get the value of each division in seconds of arc.

244.—**Lamp.**—At heights between hills in wide valleys, check levels may be taken from five to ten miles very well with a good 14-inch level, in still, clear weather in dark nights, by the use of an oil lamp. Coincident points above datum being selected, the lamp is set upon

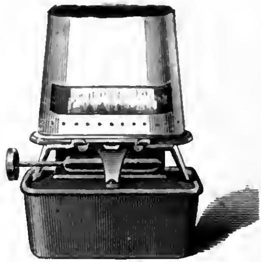


FIG. 97.—*Calder stove used as a lamp.*

the ground, or at a measured height at a calculated point, or raised or lowered to lantern signals, allowance being made for curvature and refraction. The wide band of light is read very easily by shifting the observer's position and raising or lowering his tripod. The "Calder" lamp stove answers very well as a lamp. It has a wick about $3\frac{1}{2}$ inches wide, and by means of a masked chimney may be made to present a clear white line of light of 1 inch in depth.

The heliostat is used sometimes for check levelling in sunlight. This will be hereafter described for use with the theodolite.

245.—*Curvature Corrections of the Earth and of Refraction* to be made use of occasionally for check levelling. The rule for finding curvature is "*That the difference between true and apparent level is equal to the square of the distance between two places or stations divided by the earth's diameter;*" consequently, by this rule the correction is always proportional to the squares of the distance. By proportioning the excesses of height as the squares of the distances, we may obtain a curvature table for corrections. This is, however, always in excess of the true curvature by the refraction caused by the increase of density of the air towards the earth's surface, which bends the visual ray. The curvature of the earth may be corrected for refraction one-fifth to one-sixth,* which varies according to the atmospheric pressure.

The following table, which takes curvature minus refraction, will be found useful to be at hand: it may be written out and pasted inside the lid of the level case.

Table of Differences of Apparent and True Level for Distances in Chains.

Distances in Chains.	Curvature minus Refraction in Dec. Ft.	Distances in Chains.	Curvature minus Refraction in Dec. Ft.
1	·000089	14	·02
2	·000417	17	·03
3	·0009	20	·04
4	·0016	22	·05
5	·0026	24	·06
6	·0038	26	·07
7	·0051	28	·08
8	·0067	30	·09
9	·0084	40	·14
10	·010	60	·31
11	·013	80	·56

Where great precision in levelling is required, as for important trigonometrical surveys, many precautions are required to be taken which would be quite superfluous in railway work, for instance. Thus much greater exactness and freedom from personal error is secured by two levellers going over the same ground simultaneously. Errors by two persons in any single part of the track

* "Deschanel's Natural Philosophy," by Prof. Everett, page 1018, 1876.

are very unlikely to occur, and by comparing books every part may be checked.

246.—**Pegs.**—Where the work is to be entirely pegged for chain measurements, the pegs may be made of natural sticks sawn off and pointed up with a bill-hook. If

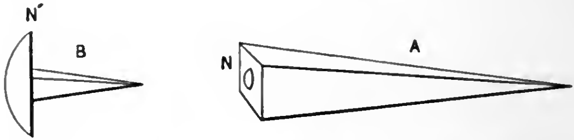


FIG. 98.—*A, staff pegs of sawn timber, $\frac{1}{8}$ scale; B, nail, full size.*

they are sawn from timber they are generally made about 9 inches long and sawn to a point, the head being full 2 inches by 2 inches. Where great precision is required a cast-brass or iron nail is driven into the head after the peg itself is driven down. This is used to turn the staff upon, Fig. 98. *A* the peg shown with a nail in its head, $\frac{1}{8}$ size; *B* nail, about full size.

247.—It is considered a precaution with an ordinary level to mark one leg of the tripod and always place this in the same position to the staff. Thus, if the marked leg is placed to the forward staff at first, it is put at the next station backward to the back staff. This corrects any general error from defective work in the instrument and want of adjustment; and if the staves are placed at equal stations any instrumental defect whatever, to act cumulatively upon a distant station is then prevented, as this principle produces an alternate plus and minus error.

248. — Differences of true level have been found between working southward towards the sun from working northward from it, which are caused by the expansion of the instrument and bubble tube upon the side heated by his rays. These matters of higher refinement may be followed in some of our best works on levelling.

Most excellent instructions in this matter will be found in the appendix of "A Manual of Surveying for India,"*

LEVELLING BOOKS.

Back Sight	Intermediate	Fore Sight	Rise.	Fall.	Height above base.	Distance	Total Distance.	REMARKS.

No. 1.—ORDINARY FIELD LEVEL BOOK.—

Levels taken for ________ *going from* ________ *to* ________

Datum Line ________ *Day of* ________ 187 __

No. of Stake.	Back Sight.	Fore Sight.	Rise. +	Fall. —	Reduced Levels.	Formation Level above Datum.	Difference between Reduced and Formation Levels.	Distance.	Remarks.

No. 2.—RAILWAY ENGINEERS' LEVEL BOOK.—

Levels taken from ________ *going from* ________ *to* ________

Datum Line ________ *Day of* ________ 187 __

Distance.	Back Sight.	Fore Sight.	Rise. +	Fall. —	Reduced Levels.	No. of Stake.	Bench Mark.	Remarks.

No. 3.—RAILWAY AND HYDRAULIC ENGINEERS' LEVEL BOOK.—

Levels taken from ________ *going from* ________ *to* ________

Datum Line ________ *Day of* ________ 187 __

No. of Stake.	Bench Mark.	Reduced Levels.	Formation Level above Datum.	Depth of Cutting.	Horizontal half width of Surface Cutting.			Depth of Embankment	Horizontal half width of surface of ground below Embankment.			Horizontal half width for Boundary Fence.		
					Calculated half width.	Corrected half width.			Calculated half width.	Corrected half width.		Calculd half width	Corrected half width.	
						Right side.	Left side.			Right side.	Left side.		Right side.	Left side.

No. 4.—COUNTY AND PARISH ROAD SURVEYORS' LEVEL BOOK.—

Levels taken for ________ *going from* ________ *to* ________

Datum Line ________ *Day of* ________ 187 __

Distance.	Back Sight.	Fore Sight.	Rise. +	Fall. —	Reduced Levels.	Formation Level above Datum.	Difference between Reduced and Formation Levels.	Finished Road Level above Datum.	Remarks.

No. 5.—CITY AND TOWN SURVEYORS' LEVEL BOOK.—

Levels taken for ________ *going from* ________ *to* ________

Datum Line ________ *Day of* ________ 187 __

Distance.	Back Sight.	Fore Sight.	Rise. +	Fall. —	Reduced Levels.	Formation Level above Datum.	Difference between Reduced and Formation Levels.	[illegible] Level above Datum.	Difference between Reduced Level and [illegible] Level.	Remarks.

FIG. 99.—*Specimens of levelling books, ¼ scale.*

* "A Manual of Surveying for India," by Colonel H. L. Thuillier, C.S.I., F.R.S., etc., and Lieutenant-Colonel R. Smith. Thacker, Calcutta, 1875.

in a paper by Colonel J. T. Walker, R.E., F.R.S., etc., of the Great Trigonometrical Survey of India, wherein levels have been carried across from ocean to ocean for over 1,500 miles of land surface.

249.—**Levelling Books** which record the levels as they are taken are considerably varied in form, much influenced no doubt by the method pursued by the civil engineer for the execution of his work. These books have printed headings and are ruled in blue and red. The top illustration Fig. 99 shows a very general form. Some very excellent books by Andrew Scott, C.E., are adapted to special purposes; these are shown in the engraving of specimens Nos. 1 to 5. In these books the lines are printed, therefore show up distinctly in a dim light, and are perfectly permanent against effects of wet or moisture.

250.—Entries are very generally made in levelling books in black lead. Faber's artists' pencils, which require no cutting, are very generally used, No. 2 being black and moderately hard. It is very convenient to carry a small file for sharpening the lead frequently. In the author's surveyor's knife a file forms one of the blades.

FIG. 100.—*Excise ink bottle.*

251.—Where it is desirable to make the original levelling book readings permanent for reference or otherwise, they are very commonly written in ink, Morrell's registration ink being very generally used; or the author's drawing ink answers, this being permanent and not corroding the pen or being effaced in any degree by wet.

252.—*The Ink Bottle* generally used is that known as the excise bottle. This is of a smooth, oval form, covered with black leather, with a tab and button hole to hang the bottle upon a button of the coat Fig. 100. A No. 2 Perryan pen, with fine point, is a good pen for use with the levelling book in ink.

CHAPTER VI.

DIVISION OF THE CIRCLE AND METHODS EMPLOYED IN TAKING ANGLES—DIVIDING ENGINE—SURFACES FOR GRADUATION—VERNIER—VARIOUS SECTIONS—READING MICROSCOPES—SHADES—MICROMETERS—CLAMP AND TANGENT MOTIONS—OF LIMBS—OF AXES—USE AND WEAR—DIFFERENCE OF HYPOTENUSE AND BASE.

253.—**Division of the Circle**—*Sexagesimal Division.*—All true surveying instruments depend, as their special function, upon taking the direction of, or angular position of, surrounding objects or definite parts of the surface of the earth from positions which are at first accurately measured or ascertained. The instruments required for such work must possess an accurately divided circle or arc, with means of subdividing the visible divisions of this to greater closeness than any possible method of drawing lines simply would permit. The lines upon the circle in practice are divided to degrees, which are subdivided to 30, 20, or 10 minutes, according to the size of the instrument, and arranged for further subdivisions into minutes or sometimes to seconds of arc. Upon large circles, say of 12 inches diameter, angular displacements in the direction of the telescope are ultimately read off with a microscope by means of a screw with divided head, termed a *micrometer*, placed tangentially to the divided circle; or by a series of lines placed at equal distances apart in front of an eye-piece or within a microscope; but in the ordinary portable instruments, or those that a surveyor can personally carry about the country, the ultimate subdivisions of the circle are made by a *vernier scale* which will be presently described.

254.—*Centesimal Division.*—On the Continent generally and in America the division of the circle into 400-grades and $\frac{1}{2}$-grades, and the subdivision of these decimally to centigrades, appears to be coming more and more into use, particularly with the more extended use of the tacheometer. Upon this system it will be seen that the right angle subtends 100 grades. This division with its centesimal parts is found to blend conveniently with logarithmetical calculation and to permit the free use of the slide rule with great saving of time. It is no doubt the division of the future.

255.—**Dividing Engine.**—This important tool is used for cutting the graduations on all surveying instruments. If possible a position should be secured for it on the ground floor at a mile or more distance from any railway, and at a good distance from roads upon which there is heavy traffic, as small vibrations are sufficient to cause unpleasant working and some error in the division of large instruments. For very accurate work some makers divide at night for the sake of stillness. The principles of construction of this machine, as at present in general use, were invented by Jesse Ramsden, of which an account was printed by the Board of Longitude in 1777. Refinements of detail have been added to the invention, and the steady action of steam power has been applied in place of the foot, but otherwise the machine remains practically the same. Therefore a brief description of this machine as originally invented will be sufficient for the purposes of this work, which is not intended to describe the tools used in the manufacture of instruments fully.

Ramsden's Engine consists of a circular brass surface plate, made generally of 36 inches diameter. This plate is supported from below upon a hollow vertical axis, which moves in an adjustable collar placed at its upper end and in a conical point or pivot at its base. The pivot rests in a cup of oil and supports the weight of plate and axis, so that this part rotates with little friction. The outer edge of the surface plate is cut with 2,160 teeth or threads, into which an endless or *tangent* screw works, so that the plate can be revolved any desired quantity by means of the screw. Six turns of the tangent screw moves the plate 1°. The head of the tangent screw is divided as a micrometer into 60 parts; therefore the movement of one of the divisions of this head revolves the plate 10″ of arc. A ratchet wheel of 60 teeth is attached to the tangent screw, which is so arranged that by reciprocating motion applied to a rack which works into it, the circle can be advanced any multiple of 10″. Motion is given to the tangent screw by a catgut over a pulley worked by the foot. The work is centred and clamped down upon the surface plate. While the divisions are being cut this surface plate remains for the time quite stationary.

The dividing knife is attached to a swinging frame which has a reciprocating motion. The forward extent of its swing is regulated by a detent wheel with teeth of varied heights, which, as they are brought by the mechanism consecutively forward, stop the knife at a definite position; so that the cuts upon the circle—technically the *limb*—are regulated for length to represent 10 degrees, 5 degrees, degrees and parts.

In the use of the machine, the divider who worked it had alternately to press his foot upon a treadle and then pull a cord attached to the dividing knife frame. These motions are now performed by self-acting mechanism. For full particulars and details of the dividing engine see Troughton's Memoir, "Phil. Trans.," 1809: "Memoirs of the Royal Astronomical Soc.," vol. V., page 325; vol. VIII., page 141; vol. IX., pages 17 and 35. For various plans that have been tried see "Holtzapffel Turning," pages 651-955.

256.—*The Material* upon which the *limb* or circle is divided is almost uniformly of silver, except for mining survey instruments which need a very strong cut. Silver being dense and of extremely fine crystallization, or *grain* as it is technically termed, bears a uniform smooth cut with sharp outline. Occasionally circles or arcs are divided on platinum, certainly the best metal as it keeps constantly clean, but it is expensive. The verniers are then made either of this metal or of gold. The silver of the circle, when this metal is employed, is rolled down from a surfaced cast plate of about ·25 inch in thickness to about ·045 inch, by means of which it becomes uniformly dense and fine grained. In all cases possible, that is, upon all flat internal surfaces, the silver is placed in an undercut groove and planished down to fill the groove, without any other fixing being necessary. This plan of insertion is employed for all vertical circles—the horizontal circle of Everest's theodolite, limbs of sextants, box sextants, etc. In Fig. 101 the silver is shown at *A*, in the section to which it is drawn by a plate after it is cut in slips. It is shown placed in its groove *B* ready for planishing down. By this method certainty of dense surface is obtained for the future division.

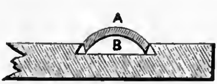


FIG. 101.—*Insertion of silver in circle.*

257.—Upon bevelled edges and outer surfaces the rolled silver is planished to form, and then soldered to the metal of the part of the instrument to be divided. The surface, after being made as dense as possible by planishing or otherwise, is turned to form and stoned to surface ready for the dividing knife.

258.—**Graduating.**—The object aimed at by the skilful divider is to obtain as deep a sharp-edged cut as possible, which shall be at the same time as fine as it can be read clearly by the microscope with which it is to be used. This matter is most important to the possessor of the instrument afterwards for use, as the silver in the atmosphere soon forms an oxide and a sulphuret upon its surface which has to be cleaned off; and at every cleaning a portion of the silver is necessarily removed, so that in old or badly divided instruments the divisions become dull or lost from this reason.

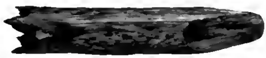


FIG. 102.—*Piece of charcoal.*

After the instrument is divided it is engraved with figures and stoned off with fine blue stone, and finally finished with willow or pearwood charcoal, which has just sufficient cut to leave a hard edge to the division lines.

259.—It may be useful to the surveyor, far from aid of the optician, to know that divisions on silver that are much oxidized may be brought up to sharp lines by the use of a piece of fine-grained charcoal, sharpened by a clean file to a chisel point. This should be frequently dipped in water, and rubbed lightly with the flat of its end surface Fig. 102, keeping the motion of the hand in the direction of the circumference of the circle. The piece of charcoal before being used should be first tried upon a piece of plain, smooth metal—an old coin which is worn smooth will do—to see that it is not *scratchy*. No kind of polishing powder should in any case be used for cleaning limbs or verniers, as *this* is sure to rub down the edges of the cuts and thereby ruin the divisions of the instrument.

It must be quite understood that the above directions are not intended for the ordinary cleaning of the circle for an instrument in general use, as such would be injurious to it. In the ordinary daily use of the circle, if it is not in any case touched by the hand, and is kept carefully brushed with a large, soft camel-hair brush when taken from the case and the same when returned to it, it will keep a long time in an excellent state. If the circle is slightly tarnished, this tarnish may be removed by a piece of quite clean wash leather; but the brush is always the safest if sufficient. If the vernier gets *grubby* against the circle, a piece of clean, thin, writing paper may be passed between these parts, and this will clear out any dirt or grit there may be therein sufficiently.

260.—**The Vernier Reading Index.**—This is one of the most important inventions ever applied to instruments of precision for measuring upon the circumference of the circle. It was invented or brought into practical use by Pierre Vernier, a native of Ornans, near Besançon, in Burgundy. The first publication of the invention appears in a pamphlet published at Brussels in 1631, "*Construction, Usage, et Propriétés du Quadrant Nouveau de Mathématique.*" This invention was possibly foreshadowed, as it is mentioned by Christopher Clavius in his "*Opera Mathematica,*" 1612, vol. II., page 5, and vol. III., page 10; but he did not propose to attach it permanently to read into an arc, that is, to place it in its practical form.

261.—The value of the vernier as a means of reading small quantities depends upon the fact that the eye cannot separate lines, drawn at equal distance apart, of above a certain degree of closeness, there being a point for all vision where such lines appear to mix with the ground upon which they are drawn and form a tint; therefore, an index reading into such close lines would be, unless under extreme magnification, most indefinite; whereas the eye can see a single line clearly and detect any break in it. The vernier for reading subdivisions depends upon the functions of the eye having power to detect any break in an otherwise straight line, so that a line that appears without a break may be taken as the index of reading from among others that appear broken or separated. It is found in practice that a line as fine as it can be clearly seen will appear broken in its continuity with another equally fine line, if at the meeting the rectilinear displacement is as much as ·25 to ·2 part of the diameter of the line. It therefore follows that we may read closer by displacement of parts of a single line than by any possible series of lines that can be drawn in spaces apart upon a surface; so that if we can arrange lines in such a manner that they open out or separate into distinct lines to admit of this principle, we obtain the full value of the unbroken single line reading, and this is the principal aim of the vernier.

On the same principle that we can find the straight or most direct line of a series of lines to take as our index, we can also estimate the amount of the displacement of our selected line, if this does not read perfectly straight from the vernier division to the circle division. This small difference is deducted in practice by many experienced surveyors, so that a vernier reading nominally to minutes only is recorded $n' + 15''$, $30''$ or $45''$, that is, to $15''$. There is no doubt that this will be approximate, but it may be much nearer than the even minutes, say to the $30''$ on a 5-inch, or the $15''$ on a 6-inch sharply divided circle.

262.—*The Vernier Scale*, as employed by Vernier, was divided to read minutes upon a circle or limb divided to half degrees, by taking thirty-one divisions of the scale and dividing these in thirty equal parts for a separate scale to read against it. This plan is now termed an *inverse reading*, the reading being the reverse to the direction of that of the arc. In modern practice the vernier to read minutes is divided to the length of 29 half degrees, and this length is subdivided into thirty equal parts; consequently, where the vernier and scale are placed edge to edge or reading to reading, every division of the vernier *advances* consecutively on the scale one-thirtieth of the half degree, that is = 1′ of arc on the scale divided to half degrees. The following diagram represents the scale and vernier at the position

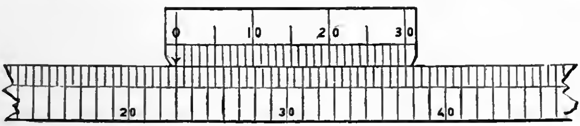


FIG. 103.—*Origin of vernier scale.*

from which the construction is taken, wherein the vernier is shown to cover 29 half degrees or 14° 30′, and this length is divided into thirty parts. The consecutive advance of the vernier on the scale is shown + 1′ for each half degree. In this position of the vernier, or at a similar position in relation to any other half degree of the circle, the arrow placed at the zero of the vernier reads direct into the half degree, so that this reading must be *n*° or *n*° 30′ at any equivalent position in relation to any line on the limb.

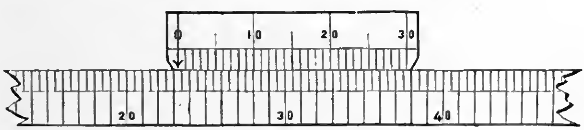


FIG. 104.—*Vernier scale, reading 23° 12′.*

In Fig. 104 the arrow upon the vernier scale is shown reading at a position beyond 23°, which we then know must be 23° *n*′. Now, if we look along the vernier, the lines of this and the scale appear coincident at the twelfth division of the vernier; consequently, the n' is 12′, and the reading is altogether 23° 12′.

Learning the reading of the vernier is very similar to that of the clock, wherein a child at first gets confused by the difference of value of the minute hand and the hour hand. In the case of the vernier we have only to get clearly in our minds that the degree reading and the vernier reading are quite distinct processes, in which the vernier reads *minutes* only, and this *by coincidence of lines only*, and that it has nothing to do with degrees, which are indicated by the arrow *only*. The arrow may be assumed to be placed on the vernier scale to save an unnecessary line of division; but this, practically, might just as well be placed quite outside of it, as it has nothing to do with the vernier reading whatever.

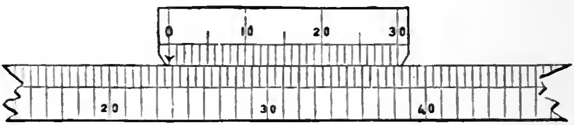


FIG. 105.—*Vernier scale, reading* 23° 47′.

It is important to make this matter of reading the vernier clear; therefore in Fig. 105 the index arrow and vernier are shown reading past a half degree. At this position the arrow reads 23·30 on the limb + the vernier, or 23° 30′ + n' of the vernier reading. We find the coincident line of the vernier with the limb is at 17, therefore the reading is 23° 30′ + 17′ or 23° 47′.

263.—The principle of the vernier, upon which it takes its reading from the coincidence of lines, as just stated, points out that the figuring of values of points of coincidence may be varied at discretion, and the zero index may be in any convenient position. The above described is the common reading to the theodolite and many other instruments. In mining-dials and some other instruments the zero is placed in the centre. We may, for example, take a central reading with a vernier reading to 3′, wherein the circle being divided into degrees, the vernier is then, necessarily in the direct method, divided into twenty divisions ($20 \times 3 = 60$) which correspond with nineteen degree marks of the circle. With a central reading the vernier in this case is figured 30, 45, 0, 15, 30. This is rather a simple reading, as the zero to which an arrow is attached gives the true bearing, and it is readily seen to which degree it refers. In Fig. 106 the 45 of the vernier is coincident with a line of the limb, this must therefore be 45′; and as the index arrow is past 44°, it is 44° 45′. If the vernier had read the division next past the 45, the division being to 3′, this reading would have been $44° + 45' + 3' = 44° 48'$. The same principles may be applied to any subdivision. Circles are commonly divided by the vernier in various ways to give readings from 5′ to 5″.

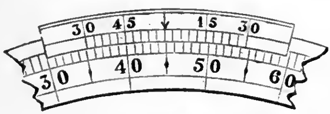
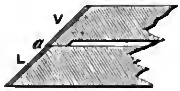


FIG. 106.—*Vernier reading centrally to 3′.*

264.—*For Centesimal Division* the vernier to read minutes is generally divided 50 into 49 for the half grades, for small circles 4 inches to 5 inches, 6 inches to 8 inches. For larger circles verniers are cut 25 to 24. The circle is then divided to ·25. Where there is space for five divisions to the grade, ·20 the third decimal place, may be estimated or read exactly to ·005 by a vernier 40 to 39, or more closely if desired by a micrometer to be described presently.

265.—**Surfaces of Limb and Vernier.**—To get a perfect reading of a vernier the scale and vernier should be brought in contact upon a plane. This for many reasons is impossible in a great number of cases upon an instrument, from the conditions of its construction, convenience of vision, and in some cases for want of means of ensuring durability of the edges which work together. Therefore verniers and scales are more commonly constructed upon the methods shown in



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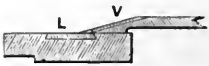

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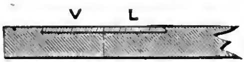
FIGS. 107, 108.—*Sections of scales and vernier for circular readings.*



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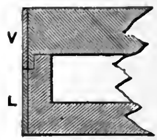


110

FIGS. 109, 110.—*Sections of scales and vernier for circular readings.*

section Figs. 107, 108, where *V V* are verniers, *L L* limbs. The plan shown in section Fig. 109 gives a nice reading on a new instrument; but the part of the edge not covered by the vernier is open to accident, or if nearly covered by a part of the instrument, open to the introduction of gritty dust which wears the meeting line open and thereby causes loss of edge to edge reading. Fig. 110 shows a section we find on some French instruments. This plan was introduced by the late Colonel A. Strange for the section of the limb reading of theodolites for India, but it was found in practice awkward to use upon this instrument, as it required unpleasant stooping to read it. It is nevertheless one of the best permanent vernier readings, as the division remains constant under the amount of wear occasioned by the sliding of the vernier upon its circle.

266. — With the reading planes shown in section Fig. 107 we require great care to bring the eye, whether open or through the microscope, directly radial with the centre of the circle at the line into which the vernier cuts. If we read the line in the slightest degree one-sided it is quite possible to make a difference of a minute or more on a 5-inch or 6-inch circle. This is the section of the general reading plane of theodolites, where, from the necessary height of the telescope, the limb has to be placed much lower than the eye. With this section the circle comes fairly square to a comfortable position for reading. It will be noticed that there is in this case a lap shown to the vernier over the limb at *a*. This is always found in new instruments of this section. It gives an allowance for slight wear between the vernier and the limb caused by the fretting of the metals together, but much more by the intrusion of grit, always present in instruments used in the open air. This lap should not be great and it should be nearly equal along the edge of the vernier, although it is a difficult matter for the maker to get it perfectly so.

267.—Fig. 108 is a section of the reading planes common to sextants and parts of many instruments. This plan requires the same care to obtain a truly perpendicular reading to the division as that described above for Fig. 107.

268.—In the very best of work there is at all times a certain amount of error, both between the divisions themselves, and in the place of the axis in relation to the centre of the divided circle, and of the position of the vernier in relation to both these. It therefore becomes necessary, where exactness is required, to place at least two verniers to read opposite sides of the circle. These bisect every reading through the axis of the instrument and detect very small errors in the work, as well as personal errors of the observer, of which the mean reading of the minutes or seconds only may be taken and used for correction to mean position. Where very great precision is aimed at, three or even five verniers are sometimes placed round the circle, and the mean reading is taken of the small difference in minutes or seconds, after calculation for correction, to find the direct position of the axis of the telescope required for the record of the observation.

269.—**Reading Microscope**.—The microscope usual for reading the vernier is either a simple plano-convex lens of short focus or a Ramsden eye-piece of the kind described for observing lines on the diaphragm of a telescope, art. 70. Frequently the microscope, technically called the *reader*, is made of a compound form, or with a diagonal prism or mirror. It is uniformly mounted in such a manner as it may move concentrically to the divided circle into which it reads. In English instruments it is placed normal to the surface of the vernier, so that following its curvature it may read opposite any line upon it. In French instruments the reader is frequently placed obliquely, so as to look along the line of the limb into that of the vernier, which is said to be advantageous in certain lights.

270.—In theodolites for reading the horizontal circle, the reader is sometimes mounted to slide in an undercut groove near the circumference of the limb to follow its curvature. This motion is not pleasant: it is better in this and all cases of vernier reading, if possible, to mount the reader on framework proceeding directly from and moving upon the axis. Where it is practicable it is much better to have two readers where there are two verniers, and in all cases to have one to each vernier, than to shift one reader about after the instrument is placed in position, which is liable to disturb it. With opposite readers mounted on a pair of arms formed of one piece of metal, where these bisect the circle working through its axis, by the setting of one reader truly normal to the coincident division of the vernier the opposite reader will be set also; so that this does not only save time, but the instrument need not be touched for reading the second vernier. The same principle should be applied to any greater number than two verniers.

271.—Instruments that have to be packed in cases for conveyance should always have readers removable from the instrument, with proper fittings in the case provided for them, or they should be hinged to turn up to a secure position. They are always mounted on light, fragile arms which easily catch any object, and thereby are liable to get injured. It is better also, if possible, to remove the light frame with the reader if this does not turn up, so that it cannot be injured in replacing the instrument in its case.

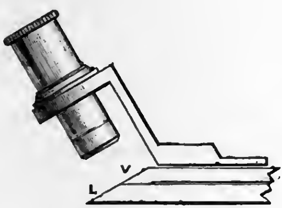


FIG. 111.
Reader fixed normal to surface.

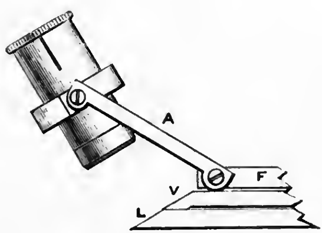


FIG. 112.
Jointed reader to set at any angle.

Fig. 111 shows a good rigid form of reader for an oblique plane of division; *V* vernier, *L* limb. This reader is placed on arm radial from the centre of the instrument, more generally in pair with an opposite reader. The connection with the arm is commonly made for portability with a dovetail slide fitting to the reader, sprung by a saw-cut down it to ensure constant contact after wear, as shown in section Fig. 113; *N* arm of reader, *O* fitting to arm. Another form more used on the Continent is shown Fig. 112. In this the arm is jointed, so that the reader out of use is turned up into the central part of the instrument. This plan admits of adjustment of the reader for reflection of light from the division, or for reading *down the lines* if preferred. The magnifying power of either of these microscopes is

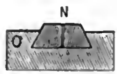


FIG. 113.—*Section of movable arm fitting to reader.*

generally about two diameters. The adjustment of the glasses should be such as will produce a flat field (Ramsden principle), so that several divisions of the vernier and limb may be read sharply when it is in focus, although the central division only is taken for the reading.

272.—*Surface Reflection to Reader.*—In reading with the microscope the silver surface, from its brightness in certain lights, gives unpleasant reflections which render the reading difficult. In practice the hand or a piece of white paper is used to shade the open vernier in such cases. In large instruments a piece of ground glass is fixed in a frame over the vernier, which throws a soft light producing the effect of a dead surface upon the silver, or the light is reflected from a cardboard or

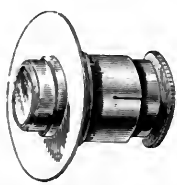


FIG. 114.—*Reflecting surface reader.*

ivory surface. Fig. 114 shows a common form of microscope for reading a vertical circle, by which the light is reflected from a card surface surrounding the field glass end of the reader.

273.—*Shades for Vernier.*—It is very general on the Continent to place the divided reading of the circle and its vernier on a plane perpendicular to the axis Fig. 109, and to place the reader at a fixed angle for down-the-line reading, the object-glass of the reader being constructed to focus parallel rays. In this way the division of the circle is followed into its vernier or *vice versâ.* In this case the silver may be shaded by ground glass and give a soft, pleasant reading in most

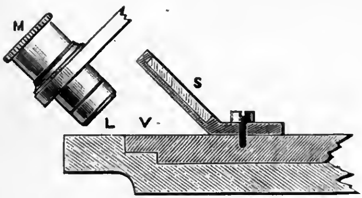


FIG. 115.—*Oblique reading microscope with shade, French plan.*

lights. The general arrangement is shown Fig. 115; *L* limb, *V* vernier, *S* shade of ground glass, *M* reader. Objection is made to glass shades by civil engineers as being too delicate and liable to fracture, with risk of the particles of glass getting into the working parts of the instrument. To obviate this the author has made the shade of a piece of thin horn or transparent ivory, which appears to answer very well and to save this risk.

For ordinary instruments with no provision for shading, a piece of transparent horn about 2¼ inches by 1¼ inches may be carried in the waistcoat pocket, and will be found a great comfort if held over the vernier when the lines appear glairy, or the horn may be placed in a pocket frame with the case containing reflector for bubble reading Fig. 52. In large theodolites used for geodetic surveys, the object-glass of the micrometer microscope is sometimes surrounded by a thin belt of turned ivory. This gives a very soft light upon the divisions.

274.—**Micrometer Microscopes** *for Reading Subdivisions.*—Where more exact reading is required than is possible with the vernier, as in the case of the reading of circles 12 inches or over to seconds, a micrometrical microscope is employed, which gives means of measuring the distance from line to line of the division upon the limb by the displacement of a web or line moved by a fine screw with a divided head.

275.—The construction of the reading micrometer as originally designed by Troughton has not been materially modified in those in general use. Certain refinements have been introduced for astronomical work: these are sometimes expensive and often cumbersome, so that they need not be considered in relation to surveying instruments.

In all cases where micrometers are used, the structure of the framework of the instrument which carries them should be made extremely rigid, as very minute deflections or vibrations render the reading to seconds of arc impossible. The number of micrometers applied to a circle is generally 2, 3, or 5.

276.—If a circle is to be read with micrometers, the vernier is generally dispensed with. The circle is usually divided to read in 5′. The first approximate reading is taken by a single index line with the aid of the ordinary reader Fig. 111. From the index line the degrees or minutes are taken to the last 5′ line indicated. When a microscope is adjusted to one line, it should be observed that all the other microscopes upon the same circle should read also exactly to a line that should be true from microscope to microscope to the arc they subtend between each other.

277.—**The Micrometer**, as it is now technically termed to include the whole piece of apparatus, is a compound microscope consisting of three lenses, with measuring apparatus at the neutral focus of the field glass and of the pair of lenses which form the eye-piece. The field glass, which is placed nearest the divided arc, is generally an achromatic microscopic lens of an inch or more in focus. The eye-piece is of the Ramsden form Fig. 16. By the construction of the compound microscopic arrangement the eye of the observer may be placed at any convenient distance from the limb, and

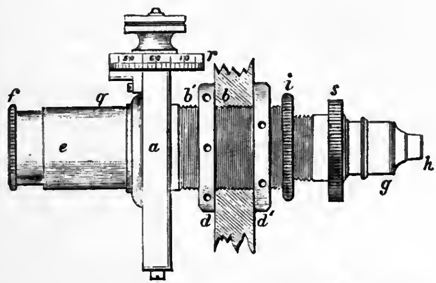


FIG. 116.—*Side elevation of Troughton's micrometer.*

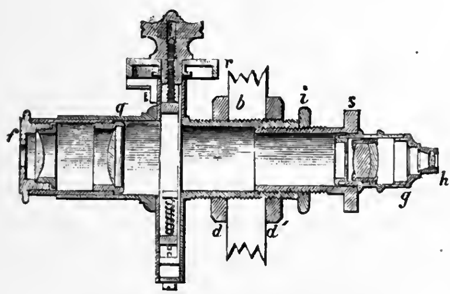


FIG. 117.—*Section of micrometer.*

any desired magnification may be obtained to assure micrometric nicety of measurement. The engravings represent the micrometer Fig. 116 in side elevation, Fig. 117 longitudinal section, and Fig. 118 the micrometrical slide, which is shown partly in section for demonstration in all the figures; *a* the micrometer, *q* microscope body tube. This has a male screw outside at *b' b* upon which there are two collars *d d'* with capstan heads. These collars hold the microscope upon the reading frame *b* at any required distance from the limb to secure proper focal adjustment. *g* objective tube. This screws into the body tube and permits adjustment of the objective to the divisions of the limb and the micrometer index web by the milled head *s*. This tube has a jamming nut at *i* to secure it from after movement when it is once properly adjusted. *h* an achromatic object-glass of an inch or over in focus. *e* the casing that receives the eye-piece which screws into the outer plate of the micrometer. *f* the eye-piece, generally made about $1\frac{1}{2}$ inches long. This slides by friction in its cell to produce distinct vision of the spider lines in the micrometer.

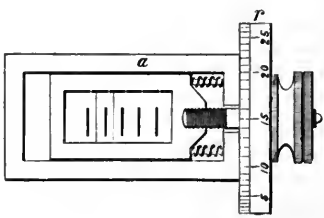


FIG. 118.—*Micrometer slide.*

278.—The micrometer frame Fig. 118 *a* has a fixed scale or *comb*, with ten or more points or teeth formed upon it, and a movable sliding frame, upon which a spider web or webs are inserted and cemented in finely engraved lines to form an index, brought as nearly as possible to the mutual focal plane of the object-glass and the eye-piece. The index web frame has a fine screw of about a hundred threads to the inch tapped into it. The micrometer screw, divided drum, and milled head are now generally constructed as shown in Fig. 119. Two springs press upon the index frame and the outer frame, and thus keep the drum up to its collar. The drum *r* is divided upon its edge into sixty equal parts, to read seconds of arc generally to a single line index. The screw is moved by the milled head above the drum, so that the divided surface of the drum need not be touched.

279.—The portion of the arc measured being generally 5′, the distance of it, as it appears at the magnified image of the arc at the position of the index of the micrometer, is made to correspond with five turns of the micrometer screw divided into 60. By this means the 5′ is divided into 300, that is, to single seconds, and by approximation of the interspaces on the micrometer head, as far as the reading is concerned, by fractions of a second. The fixed scale, or *comb* as it is termed, is commonly placed in the focus of the eye-piece with five webs upon it, fixed to agree with five turns of the screw on a rack with points at the side. These webs or racks divide the 5′ of arc in minutes, and indicate the number of revolutions of the screw, as shown by the displacement of its index line. A pair of lines or webs are commonly placed in modern instruments at 1′ apart, to assure certainty of reading by the means of two observations.

280.—The magnitude of 5′ of arc depends necessarily upon the radius of the divided circle; therefore the microscope of the micrometer has to be made to suit the division it is required to subdivide—that is, using the same micrometer, the smaller the circle the higher the magnifying power is required to be to take register by the same screw. Within a wide range the micrometer is perfectly adjustable, to ensure exactness upon this point, by varying the distance of the object-glass from the limb, for which purpose the microscope is made adjustable by the pair of screws *d d′* which clamp it to its standard as already mentioned. The principle of this adjustment is easily seen, in that if we place the object lens at a distance equal to its solar focus from the limb, the image will emerge in parallel lines; but as we cause it to recede from the limb, the image may be brought to any position within the tube greater than the solar focus of the objective of the microscope. The image is therefore brought to a position where it may be picked up conveniently by the eye-piece. In this manner we have only to make the adjustment of the object-glass from the limb such as the space of any pair of divisions of the limb may be magnified up equal to the displacement of five turns of the screw for seconds measurement.

The two points where the divisions and their images are situated are termed the *conjugate foci* of the lens, and the magnifying power is proportional to these distances; thus, if we call the distance of the object, that is the limb, from the object lens f, and the distance of the focal plane of its image within the tube F, the image will exceed that of the object in the ratio of $F\,f$, or $\frac{F}{f}$ will represent the magnified image. By this method it will be seen that the expression $\frac{F}{f}$ will have an increased value, if we either increase F or diminish f, which we have to consider in the construction of the microscope to bring it to the conditions under which it will adjust to bring the micrometer screw exactly to its required reading.

281.—It is very general in instruments at the present time to tap the micrometer screw directly into the micrometer frame, and to make the drum and milled head a part of the screw. In this case a very soft motion may be given to the screw by dividing its nut longitudinally and bringing the parts together with a certain amount of spring. Sir Howard Grubb, of Dublin, has placed a spring ball fitting, as shown Fig. 119 at $E\,E'$, over the screw upon his astronomical instruments, which gives a very soft motion to the screw. These refinements are very important, as it is not desirable that any undue pressure should be put upon a delicate instrument which under all conditions must be made rigid enough to resist it, and the greater the pressure required to bring the instrument to bearing, the stronger it must be made.

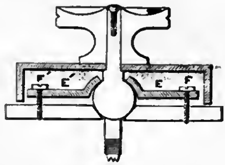


FIG. 119.—*Grubb's plan of securing micrometer screw.*

282.—**Stanley's Micrometer.**—The author has made an arrangement in which the screw has a long, double, tubular sliding stem Fig. 120. The inner stem which carries the milled head has a groove cut down it, into which a stud from the inside of its covering tube slides. This arrangement permits the milled head to be pressed inwards or outwards in turning it without any pressure coming upon the micrometer greater than the friction upon the sliding tube, and that of a weak spring which keeps the stem nearly extended in its tube. A simple Hook's joint *H* is formed at the head of the screw, so that no part of the weight of the hand comes upon the screw. A tubular guard-piece *T* prevents the milled head hanging down too far when out of use. When the screw is used it is lifted to about the centre of the guard tube. With this arrangement, as no practical weight or pressure comes upon the micrometer from handling the micrometer frame, the work may be made much lighter than is necessary with any other form of micrometer.

The author prefers to form the micrometer scale and the index of fine lines engraved upon parallel worked glass for surveying instruments. This avoids the risk of breaking webs, and what is much more important, he finds that with engraved lines on glass he is able to bring the scale and index exactly and permanently into the plane of mutual focus of the object-glass and eye-piece by placing the lines upon the same faces of glass, thus avoiding a great difficulty of focussing to guess-work of an intermediate position between two sets of webs at different distances.

The strip of glass *A* is fixed by a clamp and two screws to the side of micrometer box. The slip *B* is ground and polished to fit *A*. *B* is carried by the micrometer frame *F*, which holds it in a clamp by two screws. A spring not shown presses *B* against *A*, so that any displacement of the micrometer lines may be made by the milled head. The lines upon *A* are adjusted to the position of the circle they are intended to read at exactly 5′ or other quantity.

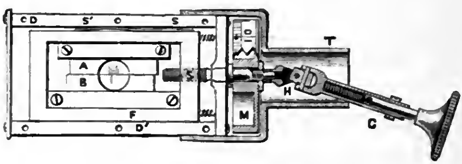
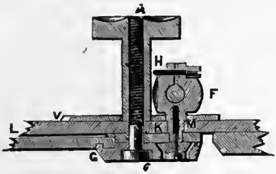


FIG. 120.—*Stanley's micrometer slide.*

283.—**Clamp and Tangent Adjustment.**—The vernier reading to the circle, when this was adjusted by the hand, was scarcely practicable at nearly its full value until the discovery of the *clamp and tangent screw motion* was made. This useful invention is due to Helvetius, the celebrated astronomer of Dantzic (about 1650). By this mechanical arrangement the circle or arc is left quite free to move about its axis until the clamp is screwed down, which then fixes it firmly. The fixing arrangement of the clamp is attached to a solid part of the instrument, but is so constructed that when it is clamped it may yet be moved without unclamping, in relation to the fixed part of the instrument, by the tangent screw which, as its name indicates, is placed in a direction tangentially to the circle or arc. This arrangement may take many forms in detail, two of which, the most general and especially adapted to surveying instruments, will be described.



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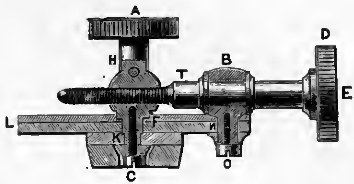


122

FIGS. 121, 122.—*Sections of clamp and tangent in two directions.*

284.—The above illustrations Figs. 121, 122 represent a clamp and tangent motion in two sections at right angles to each other. This form is common to vertical circles and arcs generally, of a theodolite, arc of sextant, circles upon some mining-dials, protractors, and many other instruments. Fig. 123 is partly a front elevation

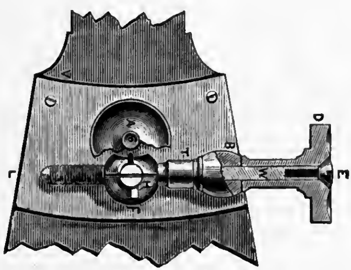


FIG. 123.—*Elevation and part section of clamp and tangent.*

of the same, but with part of the clamp screw *A* cut off. The stem of the tangent screw is shown in section at *E*. The lettering of this figure was accidentally placed sideways. In all the figures *L* is the limb of the circle or arc. This has a groove at its under side at *G*, which has been omitted from the cut, into which a fillet of the clamping piece *C* is inserted to make the clamp slide freely about the periphery of the circle when the clamping screw *A* is loose. A spring is sometimes inserted to open the clamp between the sliding piece *K* and the clamp *C*. *F F* Figs. 121, 122 is the tangent nut to *E*. This nut is sawn down and has a cross screw to keep sufficient tightness to prevent loss of time, and yet to allow the tangent screw to work pleasantly at the same time that it holds the circle and vernier quite dead to the position to which it is adjusted by the screw. The tangent nut *F* has to move to the direction horizontal to the plane of the tangent screw; therefore it has an axis vertical to the plane of the clamp. This is shown at *K*. The axis is held down firmly by a nut and a washer fitted with a square hole to prevent the nut unscrewing. The tangent screw has a collar fitting or *shank* at the tangent boss *B*, which is turned down from the full-sized metal of the screw. The fellow collar on the outer side of the boss is formed by the shank of the milled head of the tangent screw *D*. The hole through the milled head is made square, so that it can be adjusted up to the boss without risk of after unscrewing by the friction of the nut *E*. This is generally tightened up by means of a forked screw-driver applied at *E*. The boss *B* has a vertical axis *N*, similar to the tangent nut, which is attached to a solid part of the instrument by the washer and nut shown at *O*.

285.—The above construction is solid and good, and will bear considerable wear; but there is a little delicacy of touch required to adjust the collars to the boss and to give pleasant tightness to the screw; therefore some makers dispense with the split in the tangent nut and the inner collar turned on the tangent screw, and place a spiral spring over the tangent screw which follows the adjustment, or in some cases a long, bow spring is used in place of the spiral. These plans appear to answer very well: one of them will be presently described for axis clamping. In place of the groove at *G* the clamp is sometimes constructed to move on an arm direct from the axis of the circle. This is on the average a pleasanter motion, but in complex instruments it would often interfere with the motion of other necessary parts.

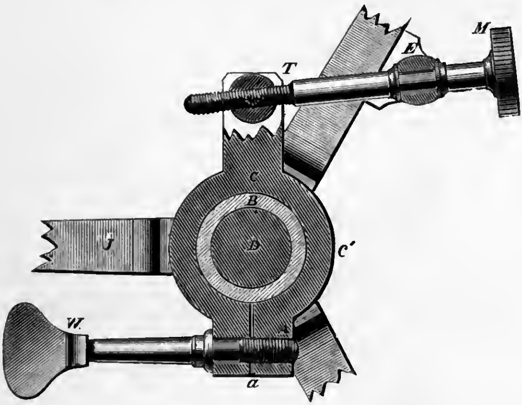


FIG. 124.—*Clamp and tangent to a vertical axis.*

286.—**Axis Clamp and Tangent.**—This is generally used to bring the horizontal area of an instrument to bearing, and is made independent of the circle and vernier. The ordinary form, which is very effective when properly constructed, is shown Fig. 124. This form is used for clamping the vertical axis of a theodolite, mining-dial, Y-level, and some other instruments. The clamp *C* surrounds the axis as a collar, from which two *lugs* in the same casting are projected at *a*. These are brought tight upon the outer axis socket *B* by means of the screw *W*, which has a *wing-nut* head to give good purchase. In the construction of this form of clamp the collar should be fitted and ground to its bearing with the lug in the solid, and the cut at *a* be sawn through afterwards.

The tangent screw adjustment is shown at T moved by the milled head M, the boss E being fixed to the instrument. This part of the arrangement is just the same as that described above for a vernier tangent. Objection has sometimes been made to this form of clamp, that it tends to become weak after a time from the constant clamping and releasing, which causes loss of elasticity in the metal. If this occurs it is no doubt due to the metal of the clamp not being good gun-metal; or if brass, not thoroughly pressed or hammered before the piece is made up. A plan, in not uncommon use in Germany, of avoiding this supposed source of

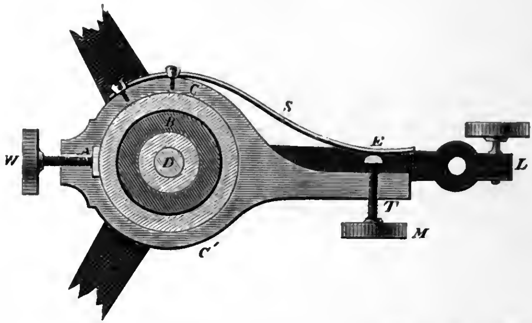


FIG. 125.—*Clamp and tangent to vertical axis, German plan—Hunäus.*

weakness is to bring up a *tumbling piece* direct on the axis by a screw. This is shown in Fig. 125, screw W; tumbling piece A. This produces a direct clamp upon the axis socket B'. The clamp ring $C\ C'$ is made loose on its socket.

287.—In practice it is found impossible to clamp the axis of a theodolite without disturbing the centre more or less. In some experiments the author made he found the direct or tumbling piece clamp Fig. 125, although this holds firmly, disturbs the centre much more than the clasping clamp Fig. 124. Therefore when the former is used the clamp should be upon a strong flange. This increases weight and it can scarcely be so well for a portable instrument. In all cases in the construction of the instrument, clamps should be fitted and screwed down before the centre is ground and finished. This ensures the centre being made correct in its clamped position, in which it will afterwards be used.

The arrangement Fig. 125 shows also a spring *S* falling upon a stud at *E*, fixed upon a part of the instrument upon which it acts as a fulcrum. The spring should be of hard rolled German silver. In this case the tangent screw needs no split or other adjustment to make it tight, as all loss of time is taken up by the spring.* The plan is found practically to answer fairly; but unless this is very carefully made there is a want of solidity in the movement which a well-fitted, direct-acting tangent screw possesses.

288.—The French generally in all their superior instruments clamp upon a flange carried out from the lower rim of the socket, with the screw placed longitudinally to the axis. When this plan is very carefully

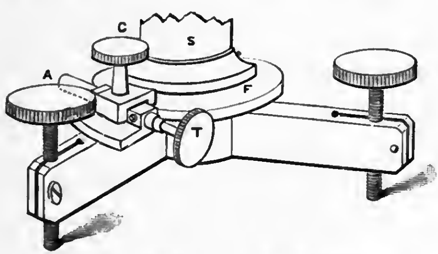


FIG. 126.—*French axis clamp and tangent.*

carried out, so that the clamping has neither tendency to raise or lower the socket-piece, it is no doubt very good. In large instruments, where weight is no object and the flange may be made large, it is certainly the

* The illustration is taken from "*Die geometrischen Instrumente*," Dr. G. Chr. K. Hunäus. Hanover, 1864.

best plan. In such cases the clamp may be released as a free fitting to prevent the possibility of strain. Fig. 126 shows the French plan attached to a tribrach; *S* socket, *F* flange, *C* clamping screw, *T* tangent screw. The tangent in this arrangement acts against a spiral spring contained in a tube *A*, which gives a very steady motion to the instrument.

289.—Some particulars of the care required in the manufacture of the tangent screw were given art. 17. The test for the equality of this screw, which is important where it moves a vernier, is to loosen its clamp and to see if it works equally, firmly, and smoothly at all parts when it is turned down from end to end. The test for its straightness is to screw down the clamp, then to notice any little mark on the milled head of the tangent screw, or make a slight mark with a pocket-knife upon it, and to place this mark uppermost, and then to take a reading with the vernier, then to turn the milled head a quarter turn and take another reading, and then another quarter, and so on consecutively. By comparing the rates of reading of the vernier at the quarter turns, if we find these equal the screw is straight or *vice versâ*. A little allowance is necessary for imperfect work. If the work is very bad at some quarter turns there will be little advance at the opposite quarter, nearly double the proper mean quantity.

290.—*For Testing the Fitting of the Tangent Screw and Adjusting It.*—The clamp should be tightened down, and the ball *B*, Fig. 122, held tightly between the thumb and forefinger; then, by using a gentle reciprocating motion in the direction of the tangent just sufficient to move the circle, if there is any looseness in the screw or the ball fitting *B* it will be felt as a jar, or technically, a slight *loss of time*. If this is in the ball *B* it can be taken up by the screw *E* at its end. If it is in the screw, it can be taken up by the cross clamp screw.

If it is in neither of these, it may be in one or both of the axes *N* and *K*. In this last case it will need refitting. It appears a somewhat simpler test with a theodolite to lightly press the telescope on one side of the eye-piece and take a reading of the vernier, and then to press the other side and again take a reading. This, no doubt, indicates loss of time in the clamp and tangent if there is found any difference in these readings; but this would not be with any certainty, as the fault might be in some other part of the instrument. It, nevertheless, is a simple plan to test the whole instrument, including the clamp and tangent, although it does not localize any defect there may be in any special part.

291.—*Use and Wear of the Clamp.*—The common fault of a novice when he commences to use an instrument is that he employs too much violence to all clamping parts. Thus we find the lower parallel plate of an instrument soon becomes deeply indented and the clamp of the tangent screw often strained, or its screw worn loose by extreme clamping. The best rule to avoid this with a clamp is to make a personal test of how little force is required to produce sufficient hold for the action of the tangent screw, and when this is found out to try to clamp *only slightly in excess of this.* A novice scarcely recognises the power of a screw. It is, perhaps, a fault of some makers of giving much too large heads to clamps, which to a certain extent permits this overstraining from clamping. In discussing this matter with a scientific civil engineer upon an instrument which had been very much strained, to which small clamping screw heads were suggested, this gentleman replied that he looked to the optician to "supply instruments, not *brains*," and made the user responsible; but, really, a young surveyor is generally so intent on the object of his work, that he cannot consider the mechanical details of his instrument, to which his attention possibly has never been properly directed; so that there is a policy in cutting off possibility of injury to the instrument where it can be conveniently done.

292.—*Use and Wear of the Tangent Screw.*—Seeing that the axis of an instrument is quite free to the extent of the loss of time on the tangent screw which holds it, and that this freedom, by any slight touch of the telescope, may cause a difference of reading—in some cases of several minutes of arc—it becomes important to observe that the tangent screw is in good order. This matter considered at its full value, we may wonder, perhaps, what kind of work may have been done with the tangent screw loose and worn down in its central part, as we find it in many old instruments sent for repair. A great amount of the common defects we find in worn tangent screws might have been prevented by using certain precautions; and even the much-worn tangent screws would sometimes go on fairly by a different method of using to that which it has evidently been submitted. The wear of a tangent screw is due principally to the fact that this screw is necessarily oiled to make it work freely, and that the oiled part being exposed to dust, that this dust attaches itself and works into the thread with the oil so as to cut both the screw and the nut. Precautions are necessary to be observed that this should be obviated as far as possible. One precaution may be taken, that when the screw is oiled, say once in three months, the parts outside the nut should be cleaned off quite dry with a few strands of thread. The oil left in the nut, if the screw has been turned through it, will be quite sufficient to lubricate the screw. Another better precaution is to use only one part of the screw for a period, say one month. The screw may be divided mentally into three parts—a *near part*, *middle part*, and *end part*. If one part only be used for a period, and the vernier be set in using the instrument so that not more than about 1° of motion is required of the screw, no grit can be carried far into the centre of the nut; and if the precaution of cleaning the screw with thread is taken every time the instrument is returned to its case after a day's work, the screw being left at about the same place on the screw and nut, it will keep true with little wear. When another part of the screw is taken into use, this part should be first cleaned with thread and then oiled with watch oil, after which the former position of the nut should be cleaned quite dry with thread. In this manner a tangent screw will last for ten years or so in constant wear in fairly good order. Where a spring is used to take up loss of time there is less risk, and the only precaution necessary is to be sure the spring continues to act properly. There is generally, however, a little more wear with a spring than with a free thread.

293.—If the instrument is not touched after the tangent is set, and there is no wind to cause vibration, the instrument will read correctly although the tangent may be out of order. But it is always necessary to set the microscope to the vernier after the adjustment by the tangent screw which may cause a disturbance. This is one important reason why the microscope should move as softly as possible, and that it is advisable to centre it upon the axis. Where any doubt of the quality of the tangent exists, the telescope should be reobserved for verification of its position after reading, which is also undoubtedly the safest in all cases.

294.—Some contrivances have been applied to tangent screws to prevent wear from dust and also to take up the nut after wear. A very good plan common on American instruments is to insert the end part of the screw beyond the nut in a closed tube. This entirely prevents dust resting on this part; and if the precaution is taken to clean the exposed part of the screw after use this is very effective for preservation. This plan the author has combined with a spring arrangement, which appears to render it thereby very safe from loss of time and much wear. This arrangement is however a little expensive to make, therefore can only be applied

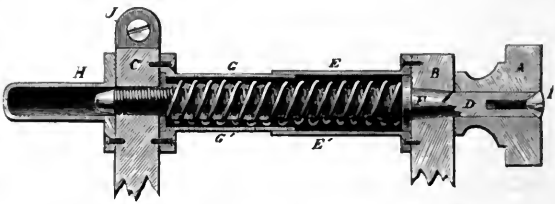


FIG. 127.—*Protected tangent screw with helical spring.*

to high-class instruments. Fig. 127 *C* nut, through which tangent screw passes, *B* tangent boss, *A* milled head, *H* covering tube to the point of the screw, *G G'* *E E'* pair of telescopic tubes which cover the screw during adjustment. A German silver or platinum spring works inside these tubes, keeping a constant separating pressure between *C* and *B* to take up any loss of time in the screw.

FIG. 128.—*Tumbling piece adjustment for wear of tangent screw.*

295.—*Loss of Time by Wear* of the nut is variously taken up when no spring is used. One plan was shown of splitting it up. A plan common in Germany is to make the nut in two pieces which are brought up by two screws. This is a very effective plan. The author has found a tumbling piece arrangement also effective.

Fig. 128, *S* section of tangent screw, *T* tumbling piece moved by the adjusting screw, shown above, for wear of the tangent screw. This adjusting screw *A* should be tapped tight without oil, and be put together dry to prevent its receding by pressure.

296. — *Hypotenuse and Base.* — Other trigonometrical values besides the division of the circle into equal parts are occasionally placed on instruments for special purposes. The most common of these is the scale of difference of hypotenuse and base, which is generally placed upon the back of the vertical arc of a theodolite and upon some dials and clinometers. The division for this purpose is generally done by hand. The scale gives a percentage difference for certain angles. Thus when used with chain measurement, it gives the number of links of the chain to be deducted per chain of 100 links for the inclination of land that the theodolite or other instrument indicates in following the surface contour.

297.—*A Horizontal Scale of Tangents* was placed upon the surveying theodolites by Ramsden. This was divided upon a scale carried by the vernier plate, which read to the zero line (0°) of the limb. It is found in practice more accurate to take the tangent to any curve from a scale of tangents, as for instance that in Molesworth's pocket-book, and set this off upon the limb by means of the vernier.

CHAPTER VII.

THEODOLITES—5-INCH AND 6-INCH TRANSITS—CONSTRUCTION—ADDITIONAL PARTS—PLUMMET—STRIDING LEVEL—LAMP—ADJUSTMENT OF AXIS OVER A POINT—BURT'S SOLAR ATTACHMENT—8-INCH AND LARGER INSTRUMENTS—EVEREST'S TRIBRACH—PLAIN THEODOLITES—FRENCH INSTRUMENTS—EVEREST'S THEODOLITE—STANLEY'S NEW MODEL—MECHANICAL TRIBRACH STAGE—ALTAZIMUTH THEODOLITE—GREAT INDIAN THEODOLITE—SIMPLE THEODOLITE—MOUNTAIN THEODOLITE—EXAMINATION AND ADJUSTMENTS.

298.—**The Theodolite** is the most perfect instrument for measuring both horizontal and vertical angles by the aid of a telescope and graduated circles. For the purpose of surveying, the theodolite is mostly employed to take a system of triangles upon the horizontal plane of objects of any altitude in which they may be placed naturally upon the surface of the land. When altitude angles are taken separately these are generally applied to give corrections to chain or other actual measurements upon the surface, by calculation of the difference of hypotenuse and base.

The theodolite in all its essential features, as differenciated from sighted compasses for taking angles, was the invention of Jonathan Sisson, a celebrated mathematical instrument maker of the beginning of the last century.* Great improvements were afterwards made in this instrument by Ramsden, who brought it up nearly to its modern efficiency.† Later improvements in portable instruments consist in the application of the *transit*

* Gardiner's "Practical Surveying," page 59, 1737.
† Adam's "Geometrical Essays," pages 217-229, 1803.

principle to the telescope, which was formerly applied to astronomical and the larger geodetic instruments only. Other improvements have been made in constructive details.

FIG. 129.—5-*inch transit theodolite.*

299.—**Transit Theodolites.**—5-inch and 6-inch are those most generally in the hands of the surveyor, of which Fig. 129 represents a perspective view of a 5-inch. The dimensions by which a particular *transit*, as it is termed, is indicated is the diameter of the horizontal circle of division, or technically of the limb. The 5-inch or

6-inch instrument is the largest size that may be carried comfortably in a single case; and no great advantage is gained by having an instrument beyond this size if the work is that of the ordinary surveyor on town and county surveys. The verniers of these instruments read sharply to single minutes of arc, which is as near as can be plotted with any degree of certainty with an ordinary protractor, which reads by vernier also to minutes. Occasionally 4-inch transits are selected for lightness at a sacrifice of capability of distinct and exact reading. These small instruments can scarcely be recommended for good service or hard wear. The following table gives the average weight of the transits in general use:—

	Instrument.	Case.	Overcase.	Tripod.
4-inch Transit,	11 lbs.	8 lbs.	4 lbs.	8 lbs.
5-inch ,,	13½ ,,	9 ,,	5 ,,	9 ,,
6-inch ,,	19 ,,	10 ,,	6 ,,	11 ,,
8-inch ,,	36 ,,	20 ,,	10 ,,	18 ,,

If with lamp extra about ¾ lb. If with striding level extra about ¾ lb.

It will be seen that the 5-inch instrument with cases and tripod, say altogether 36 lbs., is really of quite sufficient weight for a fairly strong man to carry through a hard day's work. This instrument is therefore becoming more and more popular with practical civil engineers, and its performance, if of good modern work, is quite equal to the 6-inch of less than half a century ago.

By giving description in detail of the transit theodolite, the general principles of a great number of other instruments, particularly those of larger dimensions, will be included, except for certain details that the specialities of the particular instruments demand. The most convenient plan to follow in this description will be to take the structure of a 6-inch transit theodolite of ordinary construction, as it is built up from its base piece by piece according to the rule of ordinary building.

300.—**The Tripod Stand** of a theodolite of 6 inches and under is generally made identical with that of a level, a general form being that described for a dumpy art. 184. The arrangement of one turn-up leg, as shown Fig. 62, is very advantageous for the theodolite if it is to be used on mountainous or even very hilly ground. For instruments exceeding 6 inches a framed stand is better, which will be described further on in this chapter. Some makers use a framed stand for a 6-inch instrument. This is perhaps better than the ordinary tenoned stand shown on the instrument Fig. 129, but it is very clumsy to handle and heavy to carry, and is quite unnecessary when any tripod head of the forms shown on a level Fig. 67, or as that of Mr. Cushing's level Fig. 73, are employed. The rigidity of the stand ought to be quite equal to the rigidity of the work in the theodolite, or even a little in excess, and when this is attained it is sufficient. Where the stands of theodolites so often fail is from the defective construction of the tripod head, not at all from deficiency of timber in the tripod itself; and overloading this with weight without attention to scientific construction is worse than useless.

301.—In the following description of the transit theodolite it will be convenient to take the parallel plate setting-up arrangement, as this is at the present time by far the most general in use in this country and in America. There is nevertheless great probability that it will not long continue to be so, as year by year the tribrach system, described art. 199 Fig. 68, for level tripods is coming more into use, both for this instrument and for theodolites. This tribrach system the author holds to be much more scientific, and when thoroughly understood quite as, if not more, simple and

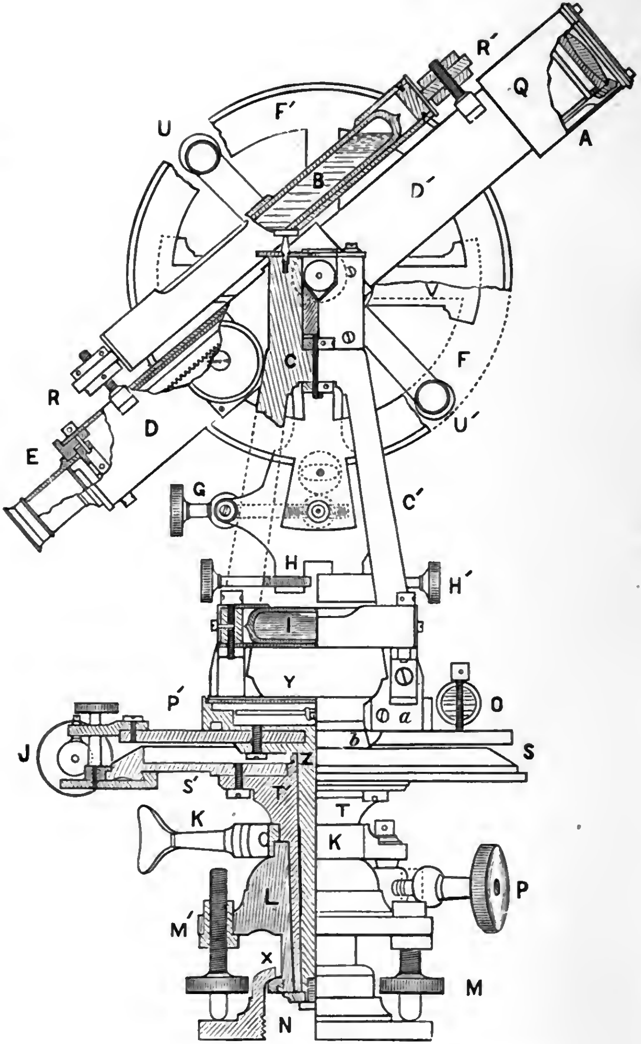


FIG. 130.—*6-inch transit theodolite—back view with sections.*

expeditious to work; it is also important, in that there is no possible risk of strain upon the general work of the instrument, or risk of error from distortion of the vertical axis.

A constructive drawing of the transit theodolite with parallel plates is shown Fig. 130, with a section of the more important details.

302.—*The Lower Parallel Plate N.*—This has a large boss-piece taken up from its central part, which forms a dome of hollow globular section, technically termed the *socket*, shown at *X*. In the interior of the lower part *N* a coarse female screw of about fourteen threads to the inch is cut, which is used to attach the instrument to its tripod.

303.—*The Upper Parallel Plate* is constructed as a flange from a solid *boss L*. This piece is generally made in gun-metal of a form as solid as possible, to resist the straining action of the parallel plate screws. The boss is prolonged downwards by a *stem-piece*, upon the lowest part of which a *ball collar* of globular section is firmly screwed. The screw is turned by means of two opposite holes, into which a powerful, forked screw-driver is inserted until it is jammed up too tightly against its shoulder to ever become loose by the ordinary use of the instrument. The ball collar fits into the socket carried up from the lower parallel plate. The whole of this globular arrangement is termed the *ball and socket*. The boss *L* of the upper parallel plate, with its stem, has a hollow conical hole through its axis, into which the *body-piece*, to be described, fits accurately. Upon its outer upper part an inset collar is formed which acts as a guide to the clamp *K*. At the outer edge of the parallel plate *M'* four vertical, conical holes are made which take *socket-pieces*, which are tapped as *nuts* to the parallel plate screws *M*. These socket-pieces are jammed into their holes tight home to their shoulders.

The socket-pieces are made separate, both to give a greater length of female screws than the thickness of the plates, and that they may be easily restored at any time if worn loose in the threads by the work of the plate screws.

304.—*The Parallel Plate Screws.*—One in elevation is shown at M, with its point dotted, and one in section at M'. The four parallel plate screws are in opposite pairs, placed exactly at right angles to each other in a line passing through the vertical axis of the instrument. These are made of gun-metal about $\frac{3}{8}$ inch in diameter, with a deep thread of about thirty-two to the inch. They require cutting on a nice, steady screw-cutting lathe. The lower points of the screws are slightly domed, sufficiently only for the amount of rocking they have to take, so as to impress the lower parallel plate as little as possible. The milled heads M are placed between the parallel plates, not above, as previously described for levels. There being a constant strain upon these screws in use and from intrusion of grit from flying dust, they soon become worn. After wear the threads may be recut deeper, and new socket-pieces fitted to the upper parallel plates. To prevent wear the upper parts of these screws are sometimes encased in tubes—a plan very generally adopted in America. At the foot of one of the parallel plate screws a *stay-piece* is fixed to the lower parallel plate, which forms a kind of ring round the screw. This prevents the parallel plates shifting upon the axis at the ball and socket. The parallel plate screws should be without any shake, or what is termed technically *loss of time.* They should move firmly but softly. They should *support* the instrument against the ball and socket upon which the whole rocks to position by their aid, but not be screwed down too tightly, as this has a tendency to disturb the axis of the instrument however solidly it may be made.

Makers often have instruments in their hands for repairs in which the parallel plate screws have been deeply indented into the lower parallel plate, with the centre of the instrument permanently strained more or less.

305.—*The Body-piece.*—The only outward part seen in elevation of this is shown at *T*: it is shown in section *T'*. This piece carries the *limb* of the instrument *S S'* by a centred collar to which it is attached by screws. About the centre of the body-piece an inset collar is formed to take the clamp *K K* which bites upon it. The lower outer part of the body-piece forms a conical fitting in the boss of the upper parallel plate *L*. The interior is a hollow conical axis. The body-piece is generally made of hard gun-metal. The greatest possible care is required in its manufacture art. 16. The interior and exterior should be perfectly concentric at every part. Much of the value of the instrument depends upon the perfection of the work in this piece.

306.—*Axis Collar Clamp K* has been already described art. 286, and is illustrated in Fig. 124 which is taken from a theodolite, so that only specialities in relation to the instrument Fig. 130 need be noted. This clamp surrounds the body-piece and clamps it by means of the screw *K K* shown on the left hand. The clamp is connected with the upper parallel plate through the *tangent screw*, the head of which is shown at *P*, so that when the screw *K* is tightened the conical fitting between the parts *L* and *T* are fixed together, except that a slow motion can be given to these parts by the tangent screw *P*. By this clamp and tangent arrangement the whole of the upper part of the instrument is rendered free to revolve when the clamp is loosened to bring the instrument to bearing, the final adjustment being secured after clamping by the tangent screw. It is this part of the instrument which is used after setting it up to bring the magnetic needle to true magnetic north, or otherwise to direct the telescope to any established distant mark, object, or star that may be fixed for the zero or other index point of the horizontal circle, to which all readings are referred.

307.—*The Central Vertical Axis* is shown only in half section at L. This is made uniformly of bell-metal. It is a conical journal, extending from horizontal circle plate S to the interior of the socket N. Its fitting surfaces are at the two ends of the cone, extending about half of an inch, the central part being chambered back. At the upper part a *pin-piece* centres the *vernier plate*, to which it is attached by a wide collar with three or four screws. A square shoulder rests with weight only just sufficient to support the instrument upon the body-piece. This part has to be so adjusted that the axis perfectly fits and yet moves freely. A square-hole collar and screw is fixed on the lower end of the axis, just to touch the socket of the body-piece, so as to secure the axis in its position when the instrument is lifted. An eye or a hook is fixed into the screw at the lower end, to take the cord of the plummet used for fixing the instrument over a definite point on the ground. This is not shown in the engraving.

308.—The axis of an ordinary theodolite is made the weakest part: it is generally considered in the trade right to be so, as in case of accident no other part of the vertical axis system is likely to be deranged; and this is the easiest part to replace, being, as it were, independent of other fittings. Whether this may be taken *cum grano salis* is a question; at any rate with the axis weak it is not policy to load the upper part of the instrument with metal, which in places at least is generally made ten times as strong as the axis, when the instrument has to be carried about by a person. Some suggestions will be made on this point hereafter.

309.—*The Horizontal or Lower Plate or Limb.*—Sometimes the whole of the piece $S\ S'$ is termed the *limb*, but more generally this word is applied to the divided part only. This plate is of brass: it is attached to the body-piece by screws. The outer rim, which is of somewhat triangular section, is undercut upon the inner side of its lower surface to support the *clamp-piece*, the outer edge being turned to a fillet to take the clamp which is rabbeted to fit it. The upper surface of the rim, or limb proper, is turned to the frustum of a cone of about 45°. This part is covered with silver, which is beaten out to the conical form and soldered down upon it, and afterwards turned to true form. The division has been discussed in the last chapter.

The 6-inch instrument is divided generally to 30′, but sometimes to 20′, and the vernier reads upon it generally to minutes, more rarely to 30″ or 20″. The figuring is from 0 to 360, left to right, as taken from the centre of the instrument.

310.—*The Vernier Plate*, shown in section under P'. The vernier from which it is named is shown at $V\ V'$ Fig. 132. The vernier plate is carried from the central axis and forms the foundation for all the superstructure. The upper and lower plates are left very free where they are brought together, the verniers being generally sprung down just to gentle touch with the limb. The vernier surface is let down some distance into its plate for protection. The reading of the vernier has been discussed in the last chapter.

311.—It may be particularly noted, as already stated, that the central axis and the body-piece are attached to the vernier and horizontal plates by *screws*. This plan might strike one as being unsound: it is not really so, the reason for this construction being that these axes are, or should be, of bell-metal, and that this metal being very hard and brittle, it would not be so easily worked, or so serviceable as brass for the limb and vernier plate, neither would there be means of correcting errors which generally occur both in the workmanship and in the dividing of this delicate part. The adjustment for fixing the limb and vernier plate, technically called *centring*, in particular requires considerable technical skill. It is generally performed by the divider, who is a specially intelligent artizan.

The vernier plate carries the ball nut of the tangent screw, shown at Fig. 130 *J*. The general arrangement may be seen by the section, but is more fully described art. 284. One thing is important in this screw, which is that it should range without strain quite parallel with the plates, so as not to give the slightest tendency to elevate or depress the edge upon which it is placed during motion in any part of its thread. The clamp is sometimes placed between the plates.

312.—*The Compass-box.*—The general construction of this is shown Fig. 132 *W*. In the transit theodolite it is fixed firmly by screws to the vernier plate and is made to form a steadying piece to the A-frames $C' C''$ which support the upper part of the instrument. For this purpose the compass-box is made as a solid casting in brass, which is much stiffened by the raised step which forms the divided circle. Four solid lugs in the same casting project from the rim of the compass, and form stiffening pieces between the lower parts of the A-frames; these are secured to the lugs by four screws, one of which is shown Fig. 130 at *a*. The lug screws hold the whole superstructure together quite independently of the vernier plate, to which it is afterwards firmly fixed. The compass needle is lifted by means of a milled head, just inside one of the standards not shown. For general description of the compass-box see art. 116. The vernier plate carries two or more verniers. The verniers are read by a pair of microscopes Fig. 132

M M' placed one on each end of a radial arm *N* which has its axis of motion upon a large collar of the vertical axis. By this plan when one microscope is set to read by the coincidence of lines upon one of the verniers, the other microscope on the other arm or arms will be set also in like position over the other vernier or verniers.

The verniers are adjusted ready for reading when the telescope is accurately directed upon any object of which it is desired to ascertain the angular position in relation to magnetic north, or another object. The vernier plate also carries a spirit level at *O* Fig. 130, which is adjustable by a pair of capstan-headed screws.

313.—*The Standards or A-Frames*, shown *C' C''* Fig. 132, are solid castings in brass of about 7 inches in height. They are set up upon the vernier plate, to which they are attached by four stout screws, as also by cross screws to the compass as stated. This renders the superstructure of the transit almost as firm as though it were a solid casting. Upon the front of one of the standards a spirit level Figs. 130, 132 *I* is placed, adjustable by two capstan screws. This level and one shown Fig. 130 at *O* on the vernier plate are used entirely in setting up the instrument; and being placed at right angles to each other, are a means of making the vernier plate quite level. Upon the inside of each of the standards, at about 2 inches from the vernier plate, a *clip-piece* Figs. 131, 132 *P* is secured by two screws. This takes the clipping screws Fig. 131 *H H'* to be described. At the top of the standards two V's are formed, which the transit axis rests upon. One of these is cut in the solid casting, the other as shown Fig. 132 *c* in half section. It is formed as a parallel sliding piece with the V at the top, placed in a vertical slot formed in the standard. This sliding piece has a screwed stem continued from its lower surface, that passes through a vertical hole at the top of the A-frame, which is formed here as a cross-piece. Upon the screw two capstan nuts are placed, one on each side of the cross-piece Fig. 132 *x x'*; these permit the adjustment of this in height so as to get the transit axis *perfectly horizontal* when the vertical axis is perfectly perpendicular to the horizon. The sliding piece is covered by plates back and front to render it firm in its position. The transit axis in practice is adjusted with a striding level which will be described presently. An axis *cover cap b b'*

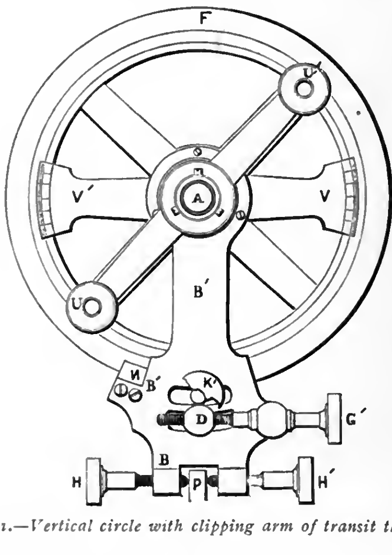


Fig. 131.—*Vertical circle with clipping arm of transit theodolite.*

is placed on the top of each standard. The cap is screwed down at one end with a cut screw and collar. The screw is used for adjustment to gentle pressure on the axis. The second screw is a milled head *E E'*. Under this screw the cap is slotted out to one side, so that the cap turns on the cut screw as an axis to open the cap without removing its milled-head screw, so that the telescope can be lifted out to turn its face to the opposite side of the instrument. In the under side of the centre of the cap a cell is bored out, into which a small cork is fitted, which produces, when the cap is clamped down, a soft, elastic pressure on the axis.

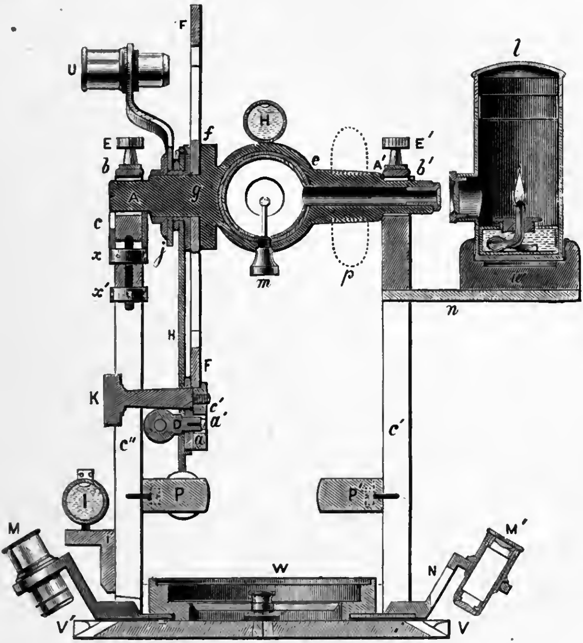


FIG. 132.—*Cross section of upper part of a transit theodolite.*

314.—*The Transit Axis* which supports the telescope rests at its ends upon two trunnions Figs. 131, 132 *A A'*, technically called *pivots*, in the Y's of the standards already described. The pivots are turned as true as possible, and afterwards ground to exactly equal size in a collar, so that they may be reversed end for end in their bearings without changing the lineal direction of the transit axis, except by the little difference of pressure that one end of the axis imposes by the weight of the vertical circle and its attachments being eccentric. In larger instruments this difference of weight is counter-balanced, as shown in dotted lines at *p* Fig. 132. The centre of the transit axis is formed into a *collar* *e* of about $1\frac{1}{4}$ inches in width, which exactly fits the outer tube of the telescope, and to which it is fixed with soft solder. The collar is directly connected with and supports a *flange f*. Upon this flange the *vertical* circle $F F'$ is fixed by three or four screws.

In front of the vertical circle a flanged collar-piece carries the *vertical vernier frame* $V V'$ Fig. 131 centred upon it. The vernier frame is attached by three screws to the *clips* to be described. In front of the axis of the clips the vertical microscope arms are centred. These carry two *readers* U Fig. 132 exactly similar to those which read upon the horizontal circle, and they are similarly centred, so that by setting one, the other is set at exactly 180° from it. In front of the centre of the microscope arms on the transit axis, an *axis collar-piece j* is attached by three screws cut directly into the axis. This collar and one at the other end of the axis A', turned out of the solid, are nicely fitted to the opening between the standards to prevent lateral displacement of the axis.

315.—*The Clips.*—The clipping arm, which is centred on the transit axis and attached to the verniers, is shown Fig. 131 $B B' B'$. It is fitted to move freely on its axis at A, so as to permit unrestrained motion of the telescope. A milled-head clamping screw with clamp Fig. 132 K, and the same partly cut away to show the slot in which it works, is shown at K' Fig. 131. This is used to fix the verniers stationary on the circle, except for the adjustment by the tangent screw G' which has its collar attached to the clipping arm at K' and its ball nut attached to the clamp at d' in using the telescope for levelling.

This clamp and tangent sets the vernier to zero on the circle. It is also used in setting the telescope before angles of altitude or depression can be measured. The clipping screws *H H'* are used to bring the principal bubble *B* on the top of the telescope to the centre of its run after the verniers have been brought to zero by means of the clamp and tangent screws. The clipping screws hold either of the clips Fig. 132 *P* or *P'* to the one standard or the other. The whole of the vertical adjustment is exactly equivalent to that already described for the horizontal motion, but placed in the vertical plane.

316.—*Vertical Circle*, Figs. 131, 132 *F*, is carried by four arms from a central boss attached firmly by screws to the transit axis. It is grooved at the edge to take the *clamp-piece*. The silver is inlaid in this circle in the manner shown Fig. 101. The vernier is read upon the circle on the plan shown Fig. 108. The circle is divided generally to half degrees, and is figured to right and left from zero on both sides. The zero lines are made directly coincident with the optical axis of the telescope. The vernier reads to minutes in either direction, the rising arc above the level datum being considered as plus, the falling arc as minus.

On the outer edge of the circle or at the back a scale of difference of hypotenuse and base reads to a line on a fiducial edge upon a part of the clip *B B'* Fig. 131 at *N*. This scale is calculated for decimal quantities, and gives the percentage number of links, feet, or metres to be deducted from the chain measurements upon the ground line to give the corresponding horizontal distances to the angle of inclination at which the telescope is set for observation.

317.—*Telescope* Fig. 130 *D D'* has been described art. 80. Its general construction is also shown in partial sections in the figure. Its body tube passes through the transit axis to which it is soldered.

318.—*The Principal Level Tube* is mounted upon the telescope upon two stiff screws which rise from plates attached to the telescope body by pairs of screws. Each level screw has a pair of capstan nuts. The level is mounted in a brass tube with stop-pieces at the ends, each of which carries a *tenon* with a hole in its centre through which the level screw passes to be clamped top and bottom by the capstan nuts. These nuts give adjustment to the level, so that the centre of its inner upper surface may be placed parallel with the optical axis of the telescope.

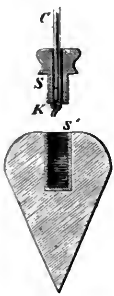


FIG. 133.—*Plummet.*


FIG. 133 A.—*Loop.*

319.—*The Plummet* supplied with the theodolite is made to hang from a hook under the centre of the axis of the instrument, the cord, which is of soft silk, being looped or knotted to hold in the hook. The lower end of the plummet is brought to a point which, when in use, falls directly under the vertical centre of the instrument upon the surface of the ground. In Fig. 133 the screw and plummet are shown detached. The cord *C* is attached to the plummet by passing it through a hole in a milled-head screw *S* at the top of the plummet and by making a knot *K* in the cord.

The Loop.—It is somewhat difficult in the ordinary way to adjust the plummet to the station mark on the ground or on a peg. The cord is sometimes placed in an ivory runner fixed to the top of the cord Fig. 133A. This gives friction on the cord and permits extension and contraction of the loop for adjustment. Where the plummet has to be suspended from the instrument as well as from a hook inside the stand, which is sometimes convenient, it is better to have the runner cut out on one side. This permits easy change and it is just as firm.

Messrs. Gurley Bros. of Troy, N.Y., have a good plan of shortening the plummet line. This is effected by making a reel in the plummet, which is wound by a milled head at the top of it. The author's observation of this method was not made till this work was ready for press or an engraving would have been cut of it.

320.—*Screw-drivers and Tommy Pins, etc.*—A screw-driver and a tommy pin, the last to turn the capstan heads, are placed in the case with the theodolite. Two screw-drivers with proper handles are better, as there are small and large screws. A camel-hair brush is also very useful to dust the instrument, and a piece of clean wash-leather in a pull-off case, also a small bottle of good watch oil. These little refinements are generally kept out to keep down the price of the instrument.

321.—**Additional Parts, and Variations in the Transit Theodolite**—*Illuminated Axis.*—6-inch transits sometimes, and larger instruments always, have the transit axis bored on one side through to the interior of the telescope, as shown in Fig. 132. Through the hole a small pencil of light is sent by a lamp *l* with a plano-convex lens front, to a lens placed in the end of the axis. This, by a slight adjustment of the lamp on its stand, focusses the light upon a small mirror placed within the telescope, which reflects the rays to the diaphragm. The lamp gives a faint light only sufficient to distinguish the webs for night and underground observations. The mirror is about $\frac{1}{10}$ inch in diameter, and is generally mounted upon a milled-head screw placed upon the telescope *m*. The point of the screw is extended as a thin stem into the axis of the telescope, where the mirror is held by it. This arrangement permits the mirror, which is generally made of silver, but is much better of platino-iridium, to be removed to be cleaned. The lamp is mounted on a wooden stand *w* carried upon a slide *n* or upon two brass pins direct to the A-frame. The wood is employed in this case to cut off conduction of heat to the near standard from the lamp as much as possible to prevent disturbance of the axis from expansion by heating. The stand may be removed when the lamp is not required and placed in the case. In large theodolites a pair of lamps are used, that the transverse axis may not be heated more on one side than on the other.

322.—*The Lamp*, which is found so convenient for bringing a star or distant light to read with the webs, becomes difficult to use when the object is very faint, as the light thrown into the telescope by the lamp takes off the effect of blackness of the night sky or that of total darkness. This becomes important in taking observations of small stars, as, for instance, the circum-polar stars of the southern hemisphere. In some theodolites, made first for the Sydney Government, the author placed a very small lamp to throw light upon the face of the webs only, making these appear as light lines on a black ground. The reflecting eye-piece Fig. 20 will be found to answer very well, and this is a simple, inexpensive contrivance. Any amount of illumination desired may be thrown on the front of the diaphragm, according to the distance at which the light is held from the eye-piece: generally a very faint light only is required.

323.—The author has illuminated the webs front and back by means of a very small (one-tenth candle power) incandescent Swan lamp which is charged by a portable hermetically sealed Leclanché battery. The plan answers very well experimentally: the objection is the weight of the battery, which weighs 3 to 4 lbs., and the difficulty of its renewal. A small magneto-electrical machine would possibly answer the same purpose.

324.—*A Trough or Long Compass, in Place of Circular Compass.*—A long compass Fig. 33 is often applied to a theodolite, either upon the top of the telescope, or more generally and conveniently for reading, under the limb. In this last case the trough needle is a separate piece, which is only attached to the limb of the theodolite, when required to take a bearing, by means of *loop slides* or *bayonet fittings* under the limb. The engraving Fig. 134 shows the long compass with bayonet fittings. There are four slots, two of which are shown $S S'$, which fit in under the heads of round-headed, shouldered screws.

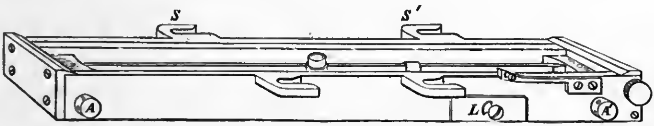
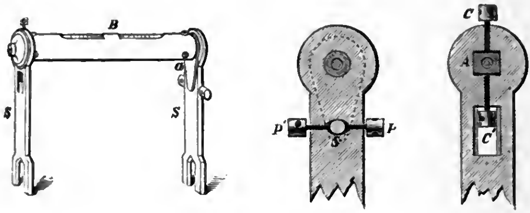


FIG. 134.—*Trough needle for 5-inch transit.*

The trough needle is generally made 5 or 6 inches long, and reads into a short scale of about 20° at each end. The division is best placed upon a sliding fitting, so that it may be adjusted by four screws from the outside of the box—screws shown $A A'$. This enables the needle to be adjusted to its own axis, and also to the 0° reading of the horizontal limb of the theodolite. A slide lift to the needle is shown at L. When the same form of compass is used upon large instruments a reader is placed at each end of the needle.

325.—*Striding Level.*—For the adjustment of the transverse axis of a theodolite a very sensitive spirit level is used. This is mounted upon a bed, which may be formed of brass tubing, from the two ends of which adjustable legs descend, the ends of which are *forked*, the hollows of the forks forming V bearing surfaces. The V's rest upon the pivots of the axis. By reversing the *striding level* on the pivots the transverse axis of the telescope, or transit axis, can be readily adjusted truly perpendicular to the vertical axis. In the construction of the striding level, shown in detail in Fig. 135,



135 135A 135B

FIGS. 135, 135A, 135B.—*Striding level.*

the two striding standards *S S* are carried down from the ends of the casing tube *B* of the spirit level. These are adjustable, one Fig. 135 B by raising or lowering the end of the level tube by the capstan screws *C C'*, and the other Fig. 135 A by a lateral adjustment of the capstan screws *P P'* that act upon the stud *S*, which is fixed upon an arm centred upon the axis of the tube. This connection is shown by dotted lines. By these two motions the standards are brought to perfect parallelism with each other for their bearing surfaces and adjustment of the crown of the bubble tube.

326.—*Covering the Divisions of Instruments.*—Some years ago there was a general impression that it would be better to cover the divisions of instruments with some form of capping, to prevent rain reaching the interior parts, particularly between the horizontal plates. No very successful plan has been found of doing this and at the same time preventing the intrusion of dust—a much greater enemy than rain to the durability of the instrument. The plan has been generally abandoned, surveyors preferring to have this part of the instrument as come-at-able as possible, and to depend upon themselves for keeping it clean and in order. As regards dust, its effects are well known and justly feared; but with regard to water it is very doubtful whether it does much harm, except to the needle, when all fitting parts are kept properly lubricated.

327.—*Adjustment of the Axis for Setting it Up over a Point.*—Every surveyor experiences an amount of difficulty in getting the plummet to fall from the axis of the instrument exactly over a point upon the ground, or a mark upon a rock, which is necessary for exact work. It is easily got near the point, that is, within half-an-inch or so, by pressing and shifting the legs; but the difficulty increases as the exact point is approached, so that the setting has generally to be left at a certain state of approximation. There are a great number of schemes in use to bring the axis by adjustment of the instrument the small quantity required, without disturbing the legs of the tripod when they are firmly set down nearly correct to position. One of these schemes would no doubt be generally applied to the theodolite, except for the reason that every means yet devised adds greatly to its weight, and also to the expense of the instrument. The most general moderately simple plan, which is especially adapted to the parallel plate adjustment, is to make the lower flange of the theodolite, upon which it stands when set down off its tripod, somewhat larger and thinner. This flange, instead of being screwed directly down upon the tripod head, is placed between two ring plates, which are clamped together when the theodolite is set in position. The large hole in the centre of the ring permits movement of the lower plate of about 1 inch. In Fig. 136 an arrangement by Mr. J. Wallis is very simple and effective for a parallel plate theodolite. This is made entirely independent of the theodolite, and may be used or not as required. *I* is a screw that corresponds with the head of tripod which takes the theodolite; *T* similar female screw to take the tripod head when the shifting centre is used; *C C′* a box formed by screwing two tray-pieces firmly together; *S* clamping flange; *H H′* clamp screwed into the top of box *C*. This has four handles by which the screw is moved to clamp when the instrument is in position. The weight of this additional part is about 3 lbs.

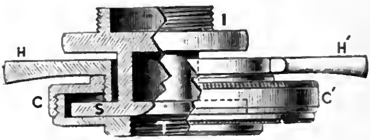


FIG. 136.—*Wallis's shifting centre for theodolites.*

Instead of a flange to the lower part of the theodolite, this may be made with three arms to clamp between two rings, which is a somewhat lighter than the above arrangement, but it has not the convenience of entire detachment. In an American plan of a transit by Messrs. Heller & Brightly, the flange is lifted by the parallel plate screws, which tighten it at the same time.* Messrs. Troughton & Simms have a plan of shifting the axis by means of a pair of eccentric plates, which carry the instrument in two directions nearly at right angles to each other. By this arrangement an amount of leverage is secured which produces an easier motion than that of shifting the weight of the instrument on the plans mentioned above. The method is fully described by Mr. Usill in his "Practical Surveying." †

* "Civil Engineers' Pocket-book," by J. C. Trautwine, C.E., page 188.
† "Text-book of Practical Surveying," by Geo. W. Usill, A.M.I.C.E., page 42. Crosby: Lockwood, 1889.

The author's plan will be described as a part of his new theodolite a few pages on.

328.—*Stadia Webs* used for taking subtense angles by the telescope for measuring distances, which are frequently applied to theodolites, will be fully described chapter IX. in treating of subtense instruments generally.

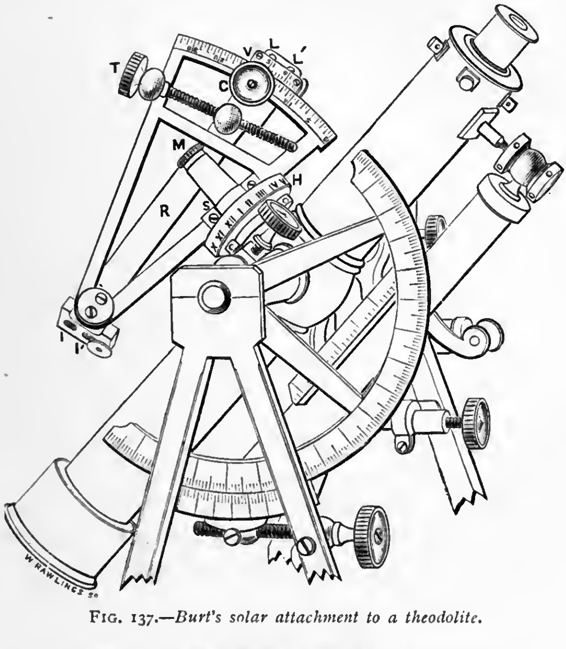


FIG. 137.—*Burt's solar attachment to a theodolite.*

329.—**Solar Attachment to a Theodolite.**—This appliance, designed by Messrs. W. & L. E. Gurley, of Troy, N.Y., is an adaptation to the theodolite of the *solar compass* of W. A. Burt, of Michigan, which was made to replace the magnetic compass in determining a true meridian, or north and south line, by observation of the sun only. It was brought into general use in the surveys of the United States public lands. The solar compass consists mainly of three arcs of circles by which the latitude of a place, the declination of the sun, and the hour of the day can be set off. In the solar attachment to the theodolite the latitude arc is found unnecessary, as this is formed by the vertical arc of the theodolite; therefore the hour and declination arcs need only be described.

330.—*The Hour Circle* Fig. 137 *H* is fixed upon the centre of the telescope upon a socket axis *S* which is placed perpendicularly to the optical axis and to the transverse axes or pivots of the theodolite. This circle is divided to read five minutes of time and is figured I. to XII., the index being a fine line carried down on a plate from the lower arm of the *declination arc*, which is fixed to the socket *S*. The hour circle when set to any reading may be clamped to this position by means of the milled head placed over the socket *M*.

331.—*The Declination Arc* is of 5 inches radius, divided to read on the same plane with a vernier *V* to single minutes of arc. The vernier arm is fixed by a clamp at *C*, which carries tangent adjustment *T*. At the back of the vernier arm two spur-pieces are carried out directly from it *L* and *I*. These are blocks of metal about $1\frac{1}{2}$ by $1\frac{1}{4}$ by $\frac{1}{4}$ inches, which carry each a lens of a focus *L* to *I*, and a silver plate to be presently described, upon which the sun's image is received in one direction or the other.

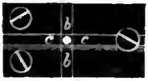


FIG. 137A.—*Image plate of solar attachment.*

332.—*The Image Plate* Fig. 137A is marked with two sets of lines intersecting each other at right angles. The lines *b b* are termed *hour lines*, the lines *c c equatorial lines*, these lines having reference respectively to the hour of the day and the position of the sun in relation to the equator. The intervals between the lines *b b* and *c c* are just sufficient to include the circular image of the sun formed by the solar lens on the opposite end of the vernier arm. The axes of the solar lenses and corresponding image plates are placed parallel with each other and with the direction of the vernier arm. Below the lower line *c* three other lines are cut at 5 minutes apart. These are useful in making allowance for refraction. The following description of the use of the instrument is partly extracted from Messrs. Gurley's manual.

333.—When the instrument is made perfectly horizontal, the equatorial lines and the opposite lenses being accurately adjusted to each other by a previous operation, and the sun's image brought within the equatorial lines, his position in the heavens with reference to the horizon will be defined with precision.

Suppose the observation to be made at the time of one of the equinoxes; the arm *R* set at zero on the declination arc *V;* and the polar axis, represented by the axis of the telescope, is placed exactly parallel to the axis of the earth. Then the motion of the arm *R*, if revolved on the spindle of the declination arc around the hour circle *H*, will exactly correspond with the motion of the sun in the heavens on the given day and at the place of observation; so that if the sun's image is brought between the lines *c c* on the image plate in the morning, it will continue in the same position, passing neither above nor below the lines as the arm is made to revolve in imitation of the motion of the sun about the earth.

In the morning as the sun rises from the horizon, the arm *R* will be in a position nearly at right angles to that shown in the cut, the lens being turned towards the sun and the silver plate, on which his image is thrown, directly opposite. As the sun ascends, the arm must be moved around, until when he has reached the meridian, the graduated side of the declination arc will indicate XII. on the hour circle; and the arm *R*, the declination arc *V*, and the latitude arc, that is the vertical arc of the theodolite, will be in the same plane.

As the sun declines from the meridian the arm *R* must be moved in the same direction, until at sunset its position will be the exact reverse of that it occupied in the morning.

334.—*Allowance for Declination.*—Let us now suppose the observation made when the sun has passed the equinoctial point and when his position is affected by declination. Then by referring to the *Nautical Almanac* and setting off on the arc his declination for the given day and hour, we are still able to determine his position with the same certainty as if he remained on the equator.

When the sun's declination is south, that is from the 22nd of September to the 20th of March in each year, the arc *R* is turned towards the plates of the compass in the opposite position to that shown in the engraving, using the solar lens at *I*, with the silver plate opposite at *L*.

The remainder of the year the arc is turned from the plates, and the lens at *L* and plate at *I* are employed in the position shown in the figure.

When the solar compass is accurately adjusted and its plates made perfectly horizontal, the latitude of the place and the declination of the sun for the given day and hour being also set off on the respective arcs, *the image of the sun cannot be brought between the equatorial lines until the polar axis is placed in the plane of the meridian of the place, or in a position parallel to the axis of the earth.* The slightest deviation from this position will cause the image to pass above or below the lines and thus discover the error.

We thus, from the position of the sun in the solar system, obtain a certain direction absolutely unchangeable, from which to run our lines and measure the horizontal angles required.

The transit theodolite will, without the solar compass, perform the same functions; but by means of this instrument the calculation for position is said to be much more simple.

335.—**Curve Ranger**, the invention of Mr. H. H. Dalrymple-Hay, C.E.,* provides a means of setting out railway curves from tangents given, by means of the mechanical construction of the instrument instead of by reference to the tables of tangents found in Molesworth's and other pocket-books. The apparatus is applied to the vertical axis arrangement of the theodolite, which requires modification for the purpose. It consists principally of an angular bar fixed directly radial with the axis, which carries a roller that may be clamped upon the bar at any position from about 4 inches to 10 inches from the axis, and a horizontal plate projected from the body-piece, upon which the roller may traverse a circumference of 20° to 30° of the horizontal circle during this movement of the upper part of the theodolite. The motion of the roller is communicated to a dial at the end of the bar, by which the amount of its displacement, shown by its rotation, is indicated by divisions which give the direction consecutively of tangents 1 chain apart on the curve. The bar is divided and figured for placing the roller at different distances from the axis proportional to the radius of the curve to be set out. There is much ingenuity in the construction of the instrument. An objection may be made that if it is used as a part of a theodolite it adds greatly to the bulk and weight of the instrument. It may be also observed that it is very generally more practicable to range curves by the method

* Patent No. 2527, February, 1886.

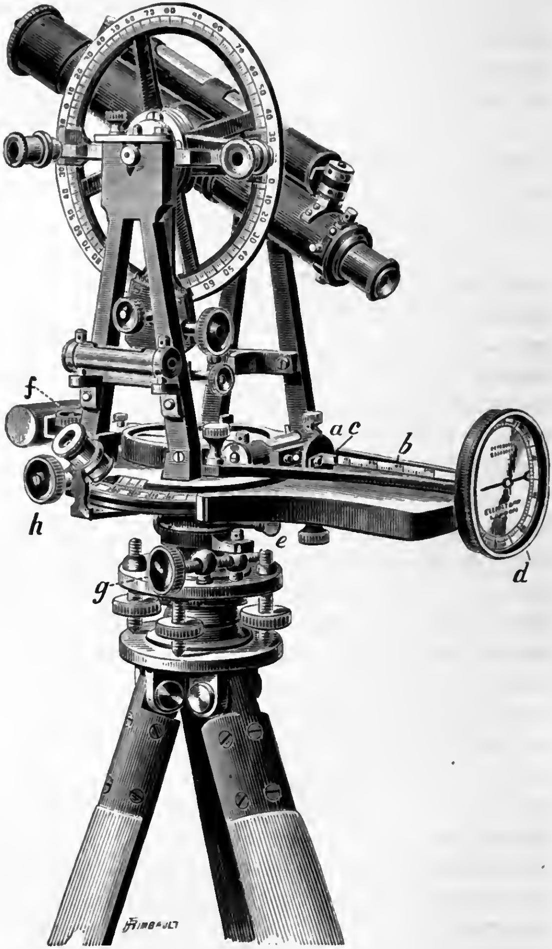


FIG. 138.—*Curve ranger adapted to a theodolite.*

of off-sets in equal chords than by tangents,* as the instrument very frequently cannot be set up conveniently

* See Molesworth's "Pocket-book," page 215.

at the end of the curve. Messrs. Elliott Bros. are the makers of the instrument, who have kindly given the use of the engraving, and who supply printed instructions with the instrument.

336.—**8-inch and Larger Portable Vernier Theodolites.**—It is not common to make portable theodolites of over 6 inches. Even with an 8-inch instrument, to render this portable, it is necessary to separate its parts and pack them in two cases, so that each part may be a fair load for one person. In this separation the body of the instrument is placed in one case, and the vertical axis apparatus, with its fittings and telescope, lantern, striding level and supplementary parts, as also the tribrach, in another. 8-inch and larger instruments are only necessary for superior triangulation. There are generally some refinements introduced, but these do not materially change the construction already described for the 6-inch instruments.

With the 8-inch instrument it is usual to have three verniers to the horizontal circle, which is divided to 15′, the vernier reading to 20″. These verniers have each a microscope mounted over it of higher power than that of the 5-inch or 6-inch instrument, generally of three diameters. Reflectors or shades are placed over the verniers to give a dull, soft reading. The transverse axis is counter-balanced by a weight, shown dotted in Fig. 130 *W*, which is placed to ensure perfectly equal pressure upon the pivots.

The telescope is also generally balanced by an internal collar, which permits it to stand at any position in solar focus without clamping or putting any strain from the clamping screw or pressure on the pivots greater than the weight of its connected parts. These additions ensure greater precision but add very much to the weight, so that such instruments may be regarded more as stationary instruments than portable ones.

When instruments exceed 10 inches the capabilities of the divided circle exceed the steadiness of any form of portable stand; therefore these larger instruments should be set up if possible on masonry, or at least on framed metal or solid wooden stands, with all proper provision for protection from wind and weather. The higher class of instruments, which are used only for geodetic surveys, will be briefly considered further on.

337. — The most important difference generally between 8-inch or 10-inch instruments and those under these dimensions is, that the tribrach system is entirely adopted and that the tripod stands are framed, the convenience of portability of these stands being entirely disregarded. The stands are generally made to detach from the tribrach, and this from the instrument, on a plan designed by the late Sir George Everest, of the Great Trigonometrical Survey of India, which is termed in the trade the *locking plate system*, which will be now described.

338.—**Everest's Tribrach.**—The upper part of the engraving Fig. 139 shows the tribrach that supports the upper part of the instrument directly upon its vertical axis. The three arms of the tribrach carry each a milled-headed adjusting screw, the nut of which is formed in the arm. The arm is sawn up to admit of adjustment, that the milled head may turn softly but without any shake. The lower points of the milled-headed screws, technically *feet*, fall into V-grooves in the head of the tripod. The V's are not shown in the engraving. Above the upper surface of the tripod head a thin, three-armed plate of metal, termed the *locking plate*, is centred upon the hollow axis of the head so that it will move laterally. The locking plate has a *hole and slot* at the end of each of its arms, the holes of which admit the *toes* of the feet of the tribrach into the V-grooves formed in the head of the tripod. The locking plate when moved laterally afterwards locks all the toes in at once, so that the instrument is held firmly and secured by this means from accident. This locking plate has commonly a milled-headed screw clamp which fixes it in its locked position. The head of this screw is under the tripod head, and consequently cannot be shown in the engraving.

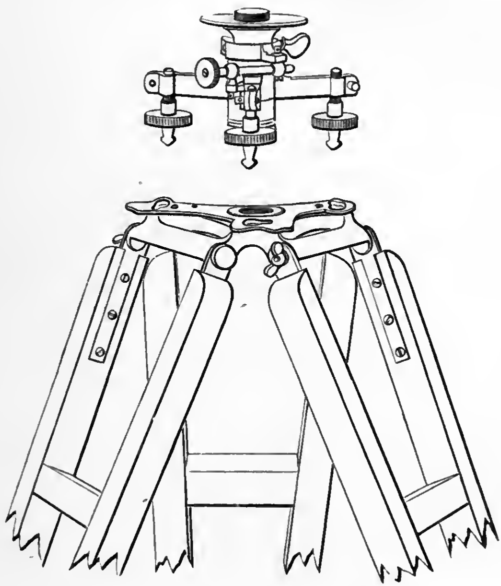


FIG. 139.—*Everest's locking plate tribrach adjustment.*

339.—**The Framed Tripod**.—The head, which is shown Fig. 139, is generally made in straight-grained mahogany, each leg being formed of two *side-pieces*, with one or two cross-pieces. The engraving shows the tripod for an 8-inch transit. The side-pieces are spliced together at the lower ends, where they form a rather obtuse point, which is shod with a gun-metal shoe.

The upper ends of the side-pieces carry *strap plates* that receive a bolt which holds them firmly by a winged nut to the tripod head. The legs are detached after use, and the tripod head is placed in the case with a part of the instrument, as already mentioned.

340.—*Mining Theodolites.*—When a 5-inch or 6-inch transit theodolite is fitted with lamp, as shown Fig. 132, and with a tripod jointed so as to separate for use at half its ordinary height, the instrument is termed a *mining theodolite*. Mining instruments will be considered in the next chapter, to which the reader may refer as to jointing of the legs, and other matters connected therewith.

341.—**The Plain Theodolite** is constructed in the same manner as the 6-inch transit just described. For all parts of the instrument below the vernier plate, and for the compass-box above the vernier plate, the construction of the instrument varies from the transit in having a half vertical circle only, with a single vernier; and in differences in the arrangement of the fittings connected with the telescope, a single microscope is used on the horizontal circle, which passes in a groove from one vernier to another, instead of having two microscopes on arms jointed upon the vertical axis, as in the better construction before described.

342.—*The Standards* or A-frames in the plain theodolite are firmly attached to the vernier plate, but are not generally attached to the compass-box. The pivots of the transverse axis, which are made exactly equal in size, rest on coupled bearings on the tops of the standards, which are at first made together exactly alike. As the transverse axis is not adjustable, as in the transit theodolite previously described, the standards have to be adjusted to height by filing, with the application of a special striding level, until the transverse axis is exactly perpendicular to the vertical axis.

343.—*The Vertical Arc* is fitted over the transverse axis, which is constructed with a turned flange to which the arc is firmly screwed. The arc is divided to 30′ and reads with a vernier to minutes Fig. 103. The vernier is fixed directly to the vernier plate, and reads

FIG. 140.—5-*inch plain theodolite.*

sometimes with a microscope jointed on the transverse axis, but sometimes with a loose magnifier for economy. Difference of hypotenuse and base is generally divided on the back of the arc. The vertical arc has a clamp and tangent placed at the back, therefore this cannot be shown in the engraving.

344.—Along the bar of the vertical arc a stout plate is attached by screws. From this a pair of Y's with clips and eye-pins, as described for the Y-level art. 165, support the telescope.

345.—The telescope is of the same construction as that described for Y-levels, with turned collars. The diaphragm is cross-webbed. For economy a simple cap is generally put to the telescope instead of the better plan of a ray shade. The principal level is fixed to collars round the telescope, to which are attached one slot-piece for lateral adjustment of the level, and one screw-piece for lineal adjustment by means of two capstan nuts. The level is placed under the telescope for compactness.

346.—The parts of the plain theodolite below the standards are the same as those already described for the transit theodolite arts. 302 to 311, except that the vernier plate carries one level only at right angles to that of the telescope. The telescope is therefore set to zero by the vertical arc, and the two levels are then used as the pair upon the vernier plate of the transit. The means provided for the adjustment are the same as those provided for the adjustment of the Y-level, but the Y's are adjusted firmly by the maker by fitting them down upon the Y-plate.

347.—The plain theodolite appears to be going gradually out of use, being superseded by the transit. It has had a long day since its first conception by Sisson about 1730. For 4-inch and 5-inch instruments the makers still find a small demand. The 6-inch is rarely enquired for. The plain theodolite cannot compete with the transit for perfect utility, but it has the merit of less weight and of greater portability. The weights of the three sizes in general use are as follows:—

Weight of Plain Theodolites.

	Instrument.	Case.	Outer Case.	Tripod.
4-inch, ...	7 lbs.	7½ lbs.	3½ lbs.	8 lbs.
5-inch, ...	11 ,,	8½ ,,	4 ,,	9 ,,
6-inch, ...	17 ,,	10 ,,	5 ,,	11 ,,

Very light 3-inch and 4-inch plain theodolites are made occasionally for travellers of from 7 lbs. to 10 lbs. complete.

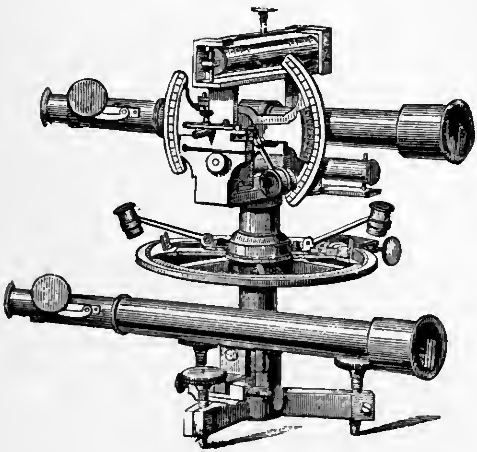


FIG. 141.—*French model theodolite.*

348.—**French and German Instruments** very generally have the standards carried up direct from the central axis, the vernier plate then being very light or with open arms only. In this case the standards are frequently made in one casting with a transverse base upon which the vertical axis is fixed. This system has certainly merits in ensuring a solidity of work in the upper part of the instrument, with less weight than any form of instrument joined up in pieces by screws;

but the axis cannot then be made of bell-metal. The compass, when one is used, in this case is either placed under the limb or upon the telescope. The variations into which the system runs are too great to be followed here in detail within our limited space. Fig. 141 is an engraving of an old French instrument of the type described. In this it will be noted that the tribrach system is used which is general upon the Continent. There are two telescopes, one upon the axis which is common to the *théodolite répétiteur* of the French. The second telescope was formerly placed upon English instruments before the importance of a rigid, well-made tripod head was fully recognized. The double telescope permits two observations to be made without risk of disturbance even with a poor tripod.

349.—**Everest's Theodolite**, designed by the late Sir George Everest and used for details of the great trigonometrical survey of India, is built very much upon the French model. In service in India it has been proved an excellent instrument. The horizontal circle or limb of this instrument consists of a single plate, upon which the silver is inlaid flat upon the surface, upon the plan shown Fig. 101. In place of the ordinary vernier plate three arms are extended from the central axis, which carry each a vernier at its end, reading to a fiducial edge Fig. 108. The verniers trisect the circle and are marked *A*, *B*, and *C*. A fourth arm proceeding from the same relative position of the centre as the arms of the vernier, carries a clamp and tangent which is similarly constructed to that of the ordinary theodolite described. The instrument has also under clamp and tangent for setting the telescope to bearing, or for repeating, as in the ordinary theodolite.

350.—*The Horizontal Axis* carries the telescope in a cylindrical fitting as in the transit theodolite, terminating in two pivots which are set to permanent position as in the plain theodolite. The pivots rest in bearings upon short standards carried out from the centre upon a flat horizontal bar to which a spirit level is attached for adjustment of the pivots to horizontality. Vertical angles are read off upon two arcs which have a horizontal axis as their centre attached to the telescope (so as to move with it in the vertical plane) and clamp and tangent adjustment. An index upon the same centre carries two

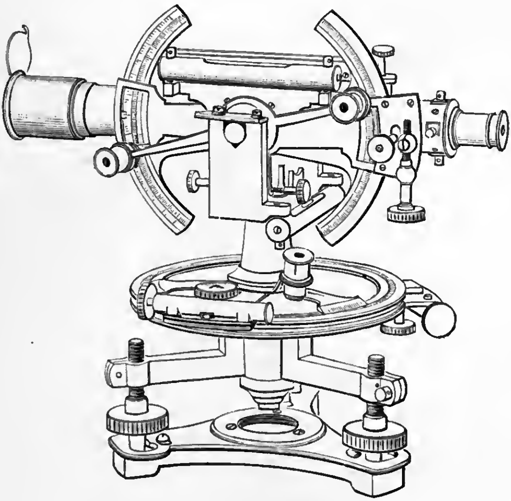


FIG. 142.—*Everest's theodolite.*

verniers and has a spirit level attached to it. The verniers are read by a pair of microscopes. Upon the upper side of the telescope a trough needle is placed alongside the spirit level. The tribrach, which is one of the most important and original parts of this instrument, was described art. 338. The tripod is sometimes made of the ordinary solid section art. 148; but for India, where carrying labour is cheap, a heavy, framed stand is used.

The Setting-up Adjustment is the same as that described for the level with tribrach art. 203. Other adjustments will be considered generally further on.

351.—Objections that civil engineers have made to Everest's theodolite are that the parts are made very open, so that wet and dust intrude in the working parts; otherwise it lacks the general convenience of the transit principle, which is necessary for astronomical observations.

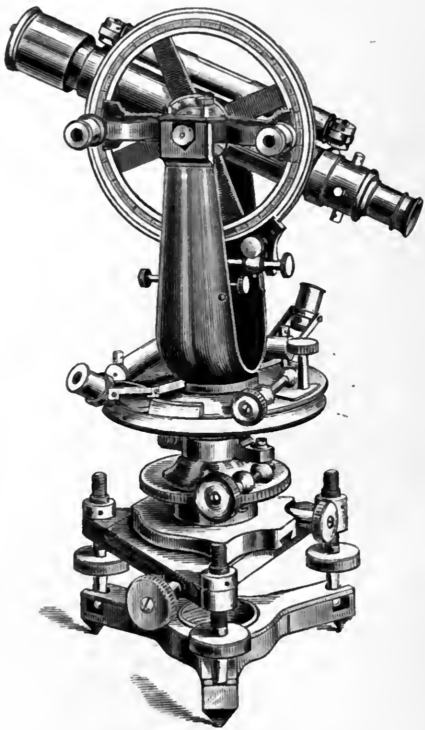


FIG. 143.—*Stanley's patent new model theodolite.*

352.—**Stanley's New Model Transit Theodolite.**—In this instrument the principles of construction are the same as in the ordinary transit theodolite fully described, but the distribution of materials and details is very different. The general arrangement is shown in Fig. 143 of a 5-inch instrument. One important difference is that the work is not built up so much in separate castings and pieces as is usual, but every possible casting is shaped out of the solid to the finished form. This principle, carried out as far as practicable, produces lighter work of greater rigidity and with less risk of accidental imperfect attachments by screws, or the risk of the screws jarring loose in conveyance.

353.—In this theodolite the vertical axis is of nearly the same construction as the ordinary transit, except that the central axis is about double as strong, being of once and a half the diameter. It is made in one casting with the upper framework. The vernier plate is formed of thin, hard, hammered metal, which is screwed upon the axis. This plate has not to support the superstructure as in an ordinary theodolite, but has only to hold the two axis bubbles, which are thereby brought distinctly in view, and the clamp and tangent motion, which is also placed conveniently for use upon this plate, in a position where there is less risk of accident than when it is placed upon the outer edge of the limb.

The Readers to the horizontal limb are double jointed to turn up against the standards and adjust for reflection, as shown Fig. 112. In this manner the readers do not need detachment to place the instrument in its case.

354.—*The Central Axis* and the standards are made in one casting in hard gun-metal. They are of light cylindrical section. This construction, although of only about one-half the weight of the A-frame arrangement with its attachments, was found upon testing to have more than double the rigidity in resisting deflection, with perfect certainty of avoiding the accidental occurrence of imperfect fitting of parts. The making of the vertical axis and the standards in one piece is in a certain sense an experiment. It will give, no doubt, much greater resistance to all ordinary strains and jars and ensure the instrument keeping in order and adjustment, just as the same principle acts in the dumpy level; but at the same time, in cases of violent accident, as the fall of the instrument from a height, it renders repairs more expensive, as this entire part would have to be reinstated instead of the axis only, the axis of the theodolite being generally made very weak that it may go first.

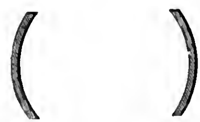


FIG. 144.—*Section of standards of new model transit.*

355.—Instead of carrying the clips on the clipping arm, in this instrument double clips are placed on the standards: this enables the instrument to be set down in its bearings with more certainty.

The transverse axis is adjusted by one direct-acting vertical screw and two lateral screws instead of a Y adjustment. This axis, for compactness of the instrument, is made shorter than is usual—4 inches only. The axes are better long; but the most important axis, the vertical one, is made only 3½ inches in portable instruments, and the transverse axis, which has a much more perfect bearing, may be consistently made only equal to this. The defect of this part in the general construction is not want of length of axis but want of equilibrium, caused by throwing the weight more on one bearing than the other, under which conditions a long axis is of advantage.

356.—*The Compass-box* in this instrument is attached under the limb, the magnetic north being set to its zero.

This is not shown attached in the drawing. The box is tubular and only a slight modification of that shown Fig. 33, page 75.

This theodolite has screw adjustment to the eye-piece, and stadia points in the telescope. Stadia points will be presently described with other schemes of the same kind chapter IX.

357.—**The Tribrach** of this theodolite is made adjustable for centre and of quite a new form, as will be seen by the illustration Fig. 146. The upper plate is triangular with rounded corners. The nuts of the foot screws Fig. 145 are sawn down on one side so that

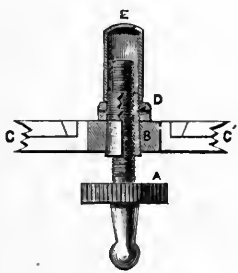


FIG. 145.—*Foot screw Stanley transit.*

they spring tightly upon the screws. These nuts are turned conical upon the exterior surface at the lower part, and are cut with a male screw at the upper part. Each nut is fitted into a conical hole *B* in the upper plate, so that it may be drawn up by a capstan-headed nut *D*, which closes the slit upon the screw at the same time and thereby tightens it. This plan gives the screw about $\frac{3}{4}$ inch of thread, and permits adjustment for comfortable movement and for wear without any risk of shakiness. The screw has a cap *E* to exclude dust. The foot of the screw *A* has a ball joint which rests on a flat surface upon which it is sprung tightly by a spring plate above the ball, upon the plan described for a level tribrach Fig. 68, page 128.

358.—**Mechanical Tribrach Stage.**—The upper plate of the tribrach with this stage is shown in Fig. 146. A dovetail slide *B B* is fitted upon the base of the stage adjustable for wear by a slip-piece with two screws at the narrow part of it. The slide is adjusted to position in the direction of its dovetail fitting by the screw *B′* so as to move the whole instrument above it for centring in this direction. A slide acting in the same manner, with dovetail fitting pieces at each end only *A A*, moves the slide for an equal distance for centring transverse to the slide *B* by the milled head *A′*. This gives the same kind of motion of displacement that we have in the slide rest of a lathe or the mechanical stage of a

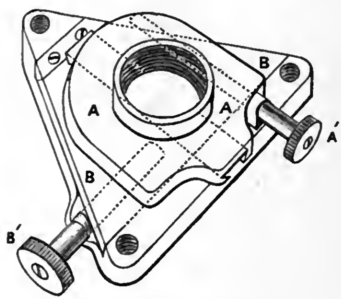


FIG. 146.—*Stanley's tribrach mechanical stage.*

microscope, except that in this case we have a kind of three-point bearing surface. The motion given the screws *A′* and *B′* permits the perfect adjustment of the theodolite over a point on the ground by means of a suspended plummet, after the instrument is set up to nearly its true position by movement of the tripod-legs. The range of motion is about $\frac{3}{4}$ inch, a quantity quite sufficient for final adjustment, but which does not materially affect the equilibrium of the instrument upon its rigid tripod, as it has in this case a broad, solid base even in the extreme positions of the slide.

359.—**Larger Theodolites** employed upon geodetic surveys. Where the complete survey of a country has to be made, a system of large triangles is formed over the country from convenient positions which are naturally or artificially elevated so as to obtain distinct views with the telescope. These triangles are correctly measured by angles subtended from a very carefully measured base or bases set out upon approximately level planes which are generally of a mile or more in length. Where measurements are derived from such bases by constant intersection of angular positions extended therefrom to large triangles or other polygons, it becomes important that the theodolite employed should measure angles with great accuracy. In this case the vernier reading does not possess sufficient refinement, and the divisions representing the degree have to be made wider apart and to be more finely subdivided, and the reading to be taken by means of a micrometer microscope capable of subdividing the divisions made upon the instrument to single seconds of arc. Theodolites used for the superior triangulation of Great Britain were Ramsden's 36-inch and 18-inch, which, although constructed in the last century, remain excellent instruments. A modern 14-inch instrument which Colonel Clark selects for illustration in his excellent article on "Geodesy" in the ninth edition of the *Encyclopædia Britannica*, will be presently described. The author is indebted for the loan of the illustration to the publishers of that famous work.

360.—The construction of large instruments is varied very considerably according to the conditions of the country to be surveyed. This subject would extend, if carried into detail, much beyond the intended limits of this work; therefore two historical instruments for geodetic work only will be given by single illustration and verbal description.

361.—**14-inch Theodolite.**—This instrument, as shown in the illustration Fig. 147, is shown as a combined ordinary theodolite and altazimuth instrument, one

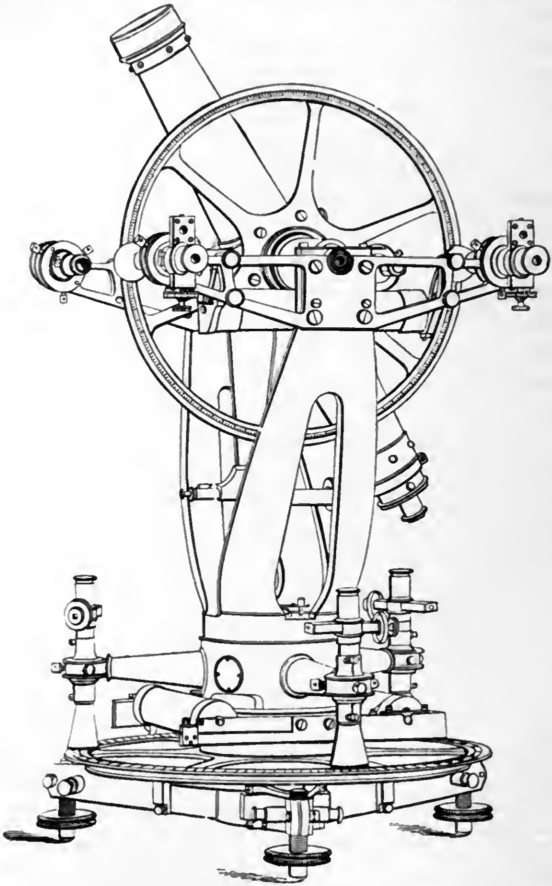


FIG. 147.—14-*inch altazimuth theodolite.*

side of the vertical circle being divided to place the zero in a direction coincident with the polar axis; but the construction as that of a simple transit theodolite, for which its structure is well adapted, and which will be discussed here. The telescope is of 18 inches focus, with 2 inches clear object-glass. The axis pivots are of hard steel: one is perforated for illumination by a lamp. The vertical circle is placed almost directly upon the side of the telescope, and the axis adjustment on the opposite side is of nearly equal weight, so that there is no counterbalance necessary to give equal weights upon the pivots. There are three Ramsden eye-pieces giving powers of 17, 35, and 54, and one diagonal eye-piece. A level is attached inside the standard, divided to read 10″ of arc: this has cemented ends, art. 152, and is enclosed in an outer tube for protection. Two other exactly similar levels are attached to the exterior axis of the instrument. The circle is divided to 5′ of arc and reads by two micrometer microscopes to single seconds. The vertical axis of the instrument is of steel. It is placed with the apex of the cone upwards, and terminates on a triangular spring with three adjusting screws by which any portion of the weight of the upper part of the instrument can be relieved from the axis, so that the whole instrument moves quite freely. The horizontal circle reads with three micrometer microscopes on the upper circle to single seconds. Originally the light was thrown down on the divisions by three ivory cones placed over the fronts of the microscopes, as shown in the illustration; but these have been changed in the present instrument for concave, swivelled reflectors which may be set to any angle convenient to throw sufficient light upon the circle. The microscopes are supported from the body of the instrument upon hollow conical arms upon the same excellent plan originally used by Ramsden. The microscopes have adjustments in three directions, so as to bring them exactly into place for trisection of the horizontal circle. The clamp and tangent motion is placed directly upon the divided circle and has adjustments to secure freedom from strain; but this is not perfect—it is perhaps the worst feature in the instrument, some modification of the plan shown Fig. 126 being much better for large instruments.

The whole instrument is mounted on a tribrach frame which is adapted to stand upon a portable table or upon masonry. The screws have lateral adjustment to prevent loss of time by wear.

362.—It is a common custom with this class of instrument to make the axes of hard steel. This plan is no doubt very satisfactory as it leaves the optician's hands; but the author very much prefers good, hard bell-metal. In the present instance, when the author saw the above-described instrument at Southampton, there was quite sufficient evidence of rust on the pivots to destroy all perfection of centring, and this could scarcely have occurred with bell-metal. Of course the brittleness of bell-metal would be objectionable where the instrument might be subjected to severe jar in carriage from place to place; but the author has obviated this by a plan he would strongly recommend for general adoption—of having the axis of good gun-metal, and to silver-solder a ring of bell-metal thereon where the fitting surfaces occur. If the gun-metal is pure it will bear the average reliable strain of hardened steel, which in hardening and tempering is not with certainty always free from flaws; and the average wear of pure bell-metal is perhaps quite as good as steel.

363.—**36-inch Theodolite**, Fig. 148, was designed by the late Colonel A. Strange and constructed by Messrs. Troughton & Simms for the Great Trigonometrical Survey of India. It is probably the most complete and perfect theodolite ever constructed. The leading characteristics of this important instrument only will be given. It has a horizontal circle 36 inches diameter, and a vertical circle 24 inches diameter. The telescope has a focal length of 36 inches: the aperture of the object-glass is 3·25 inches.

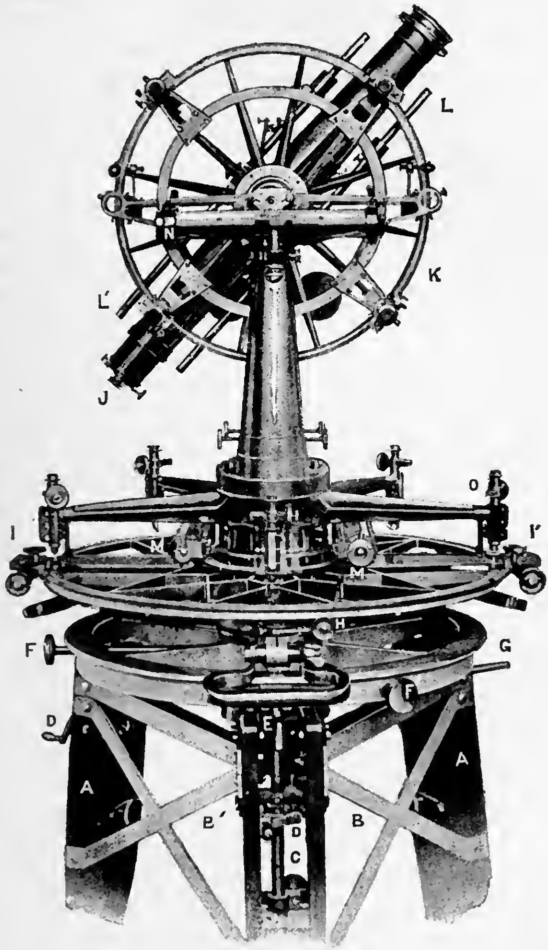


FIG. 148.—36-*inch theodolite—Great Indian Survey—from a photograph.*

364.—*The Stand* has three massive mahogany legs *A A* braced together with horizontal and oblique wrought-iron bars *B*. Each leg is divided vertically, and contains a long, gun-metal, square-threaded screw *C* which is made to rotate by means of a worm-wheel and endless screw worked by a winch handle *D*, and capable of being firmly clamped after adjustment at points about 15 inches apart *E*. The upper ends of these screws are conical, and fit into three inverted radial grooves formed in the lower side of a cast-iron circle or table, which is thus supported by the three screws without being attached to them, and is therefore free to accommodate itself to expansional changes without restraint. The upper surface of the cast-iron circle is turned flat and true to receive the tribrach of the instrument. The three screws *F* which pass through the side of this circle are intended to adjust the centre of the instrument over the station mark. A lever *G* also passes through the side of the circle and actuates three rollers, which when in action, support the greater part of the weight of the instrument, and enables the horizontal zero to be set without difficulty. As the instrument weighs over 400 lbs. it will be seen that some such arrangement is absolutely necessary to enable it to be moved on the cast-iron circle. When the correct position has been obtained, the lever is thrown out of action and the instrument remains immovably seated upon the circular frame.

365.—*The Foot Screws* are tapped through the ends ot the tribrach arms in the usual way, but have a range of motion not exceeding $\frac{1}{10}$ inch. This range may appear small, but it is really much more than is required, as the upper surface of the cast-iron circle can be levelled by the long screws in the mahogany legs before the instrument is placed on it, so that not more than about $\frac{1}{100}$ inch of motion is required. The foot screws do not rest directly on the cast-iron circle, but on the extremities of an intermediate three-armed plate which is securely bolted to the centre of the instrument, the distance between the tribrach and the plate being about $\frac{1}{10}$ inch. The object of this arrangement is to obviate the disturbance of level and azimuth which arises from clamping foot screws of the ordinary construction after adjustment, as well as that due to looseness of the foot screws in the tribrach arms. The arms of the spring plate, being of considerable width, have great horizontal rigidity, but being comparatively thin are easily bent vertically. The outer ends of the arms rest on the cast-iron circle or stand; the foot screws pass through the tribrach arms, but not through the spring arms. It is evident then that when the foot screw is turned inwards with the screwing motion, the solid end of the tribrach will be raised and the slit between the two arms widened; but since the end of the screw does not rest on the stand, but on an intermediate arm, which is actually a portion of the tribrach itself, it is clear that if a lateral pressure be applied to the tribrach, no motion will be caused thereby, however loose the screw may be, so long as the pressure is less than the lateral rigidity of the intermediate arm. The lateral pressure generated by turning the instrument in azimuth when taking observations is greatly within this limit. This plan is perfectly successful, but it is only available where a moderate range of vertical movement is needed. In the present instance, as the cast-iron ring or stand on which the instrument is supported is always first made sensibly level, the vertical range of the foot screws need not be more than a small fraction of an inch. Another point with regard to the foot screws is their delicacy and certainty of action. This is attained by applying to them a clamp and tangent screw arrangement *H* very similar in principle to that sometimes applied to circles. Although the foot screws themselves are rather coarse, having only about eight threads to the inch, the arrangement is such that one entire revolution of the slow motion tangent screw alters the level only about one second of arc. Hence the foot screws, though coarse and strong enough to bear the great weight of the instrument, are thus probably for the first time in this instrument, made in keeping, in point of refinement, with its most delicate parts.

366.—*The Horizontal Circles.*—The inner or working circle is 36 inches in diameter. It is very finely divided on silver to 5 minutes, and is read by five equidistant micrometer microscopes to tenths of a second of arc. It is fixed at the centre to the tribrach, but everywhere else it is perfectly free. The outer or *guard circle* consists of a second horizontal circle exterior to and concentric with the inner circle. There is a space of about $\frac{1}{10}$ inch all round between the two circles, and the upper plane of the outer circle stands about the same quantity above that of the inner or principal circle. The guard circle is supported by radii of its own, quite independent of those of the inner circle. This circle has several functions. It protects the working circle from accidental injury; it helps to distribute changes of temperature uniformly over the circumference of the working circle; it receives the clamp and tangent screw, leaving the working circle absolutely free from contact at all times; and it bears a strongly cut set of divisions, more visible to the naked eye than those of the working circle, which are exceedingly fine, and therefore inconvenient for setting the instrument approximately in azimuth.

367.—*The Horizontal Tangent Screws.*—It will be seen at *I I'* that there are two clamps and two tangent screws to the horizontal circle. It is necessary to have both, on account of the large size of the circle. In use, of course, they are not both used at the same time. In the present position of the instrument the clamp and tangent screw on the left-hand side of the illustration would be employed; but on reversing the telescope this clamp would be released and the one on the opposite side made use of. It is necessary with this, as with smaller instruments, to avoid loss of motion in the tangent screws. Many methods have been employed to obviate this loss of motion, but while they are suitable to small instruments they are not so effective with large instruments such as that under consideration. The plan adopted in this case is that known as the *divided nut* principle. The block into which the tangent screw is tapped is divided transversely and the two halves are forced asunder, and therefore act against the contrary sides of the screw threads by four internal spiral springs. The tension of these springs is necessarily constant, and therefore not subject to the disturbance and slow recovery of elastic force unavoidable in an external spring. Means are supplied for regulating the tension of the four springs, which must be a little in excess of the force necessary to move the revolving mass, without taking the parts to pieces.

368.—*The Vertical Axis* is a truncated cone of steel with its base downwards. It is about 6·5 inches high and 3·3 inches and 2 inches in diameter at the base and summit respectively, the flange being about 4·5 inches in diameter and constructed on the isolated principle. The vertical axis socket and the five horizontal microscope arms are cast in one piece of aluminium bronze, the elliptical table carrying the telescope supports being bolted to the central boss in which the socket of the vertical axis is formed. The vertical axis and the elliptical table are both perforated in the centre so as to allow of a look-down telescope being employed in adjusting the instrument accurately over the station mark.

369.—*The Telescope* is furnished with two separate eye-ends, carrying respectively a vertical and a horizontal parallel wire micrometer *J*. It is also supplied with both bright and dark field illumination, the latter being employed when faint stars are observed. The vertical circle *K* is divided on silver similar to the horizontal circle, and is read by two opposite micrometer microscopes when the instrument is used for terrestrial work; but when required for astronomical purposes four micrometers can be used, and they can be shifted to any part of the circle on which they are clamped. In the illustration the four micrometers are shown in position. The two rods or handles seen parallel with the telescope at *L L'* are attached to the middle of the transit axis where the telescope passes through it, and are intended to raise or depress the telescope without touching it by hand. These rods are also used for carrying adjustable counterpoises, the instrument being so balanced in every part that the equipoise is as nearly perfect as practicable through any diametrical section through the vertical axis.

370.—*The Spirit Levels*, both horizontal *M* and vertical *N* are very delicate. They are constructed so that the divisions on their scales represent as nearly as possible 1 second of arc. The scales are divided to twenty per inch. The glass bubble tubes are mounted on V bearings, and are kept in position by light springs in such a manner that they are free to adapt themselves to changes of temperature with perfect freedom. They are also enclosed in external cylindrical glass covers to protect them from sudden changes of temperature. The arrangements for adjusting the levels are such as to obviate strains without risk of shake and to ensure delicacy of action.

371.—*The Five Micrometer Microscopes O* for reading the horizontal circle are carried by the same number of equidistant radial arms branching from the central boss which carries the whole of the instrument above the horizontal circles. These micrometers are made on

Robinson's principle Fig. 149, that is, with a short bow spring S having a central nut tapped through it to keep the tension between the bearing of the micrometer screw on the end of the outer box and the slide which carries the webs constant with whatever part of the screw may be in use. The radial arms each carry a vertical socket which is bored out cylindrically to receive the microscope. These sockets are slotted vertically and have three clamping screws at the side to hold the microscopes firmly in position when they are once adjusted. The two webs in these micrometers are placed parallel to one another, and at such a distance apart that when in proper adjustment they are a trifle wider apart

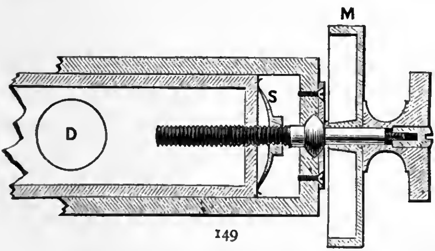


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FIG. 149.—*Robinson's micrometer.*

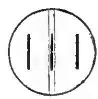
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FIG. 150.—*Webs of micrometer.*

than the width of one line on the circle, as shown in Fig. 150. The micrometer heads are divided into sixty parts, and the whole is arranged so that in practice ten revolutions of the micrometer screw traverse the webs over ten minutes of arc or two divisions on the circle. Each division therefore on the micrometer head represents one second of arc; and as the divisions are clearly cut on silver and about one-tenth of an inch apart, there is no difficulty in reading to the tenth of a second, which on a circle of 36 inches in diameter is equal to the ·00000872 of an inch, or the three-thousandth part of one division of the circle, which, as before stated, is equal to five minutes of arc or the ·02616 of an inch.

The illumination of the microscopes, or rather of the divisions of the circle, is a most important matter. When such exact measures are to be taken it is effected by means of perforated silver reflectors attached to the micrometer arms and mounted quite independently of the micrometers themselves. The axis of each reflector coincides with the axis of its microscope. All the reflectors have both vertical and horizontal movements, and are therefore readily adjustable to the best position for securing effective illumination under the varying conditions in which the instrument may be employed.

372.—*Relieving Apparatus.*—It will be readily understood that the moving parts of so large an instrument must necessarily be very heavy. In this case the telescope, vertical circle, pillars, elliptical table, horizontal micrometer arms, and vertical axis socket weigh nearly 300 lbs. It would of course be impossible to take horizontal angles with so much friction on the flange of the vertical axis as this weight would produce, hence the necessity for some form of relieving apparatus. The apparatus employed in this case is a system of forty spiral springs, each of a definite length, which when adjusted support about 6·25 lbs. The spiral springs are mounted on a flat ring in two circles with projecting pins to keep them in position. The upper ends of the springs support a steel ring with a circular groove on its upper surface, between which and a corresponding groove in the outer part of the vertical axis socket three equidistant, nearly frictionless steel rollers run; so that by this means about 250 lbs. weight is taken off the flange of the vertical axis, the remaining weight being sufficient to allow of the instrument moving with the necessary freedom, and at the same time giving all the stability requisite for accurate levelling.

373.—**Simple Theodolite.**—For surveying in level countries the vertical arc is seldom used; therefore this part is sometimes omitted for the sake of economy or for lessening weight. For laying out small estates in building ground, local sewage, gas, and water works, and many other cases of small surveys, a simpler construction of theodolite than any of those previously described will be found sufficient, with saving of about half the cost. The instrument shown below Fig. 151 was designed by the author to meet the above cases. In

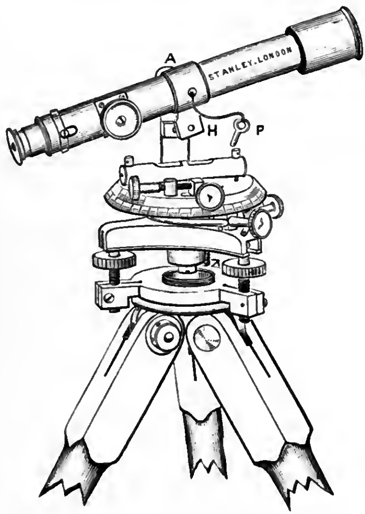


FIG. 151.—*Simple theodolite.*

this instrument there is no vertical arc. The telescope has a socket axis carried upon a single standard. The axis cannot be seen in the figure from interference of the telescope placed in front of it. The telescope may be fixed in a level position by means of the loose pin P being pressed in a pair of holes at H, and then be used as a level by means of the spirit level shown on the vernier plate. The horizontal circle is divided to read with a single vernier to 2′ by means of a hand magnifier which is placed in the case with the instrument. There are internal and external axes, each provided with clamp and tangent motions to the horizontal circle, as with the plain theodolite. It is supported on a tribrach. The legs are upon the American plan, art. 211.

If the instrument is made with two verniers and divided upon silver it becomes a useful, light instrument for filling in details of superior triangulation. Weight, with tripod, 6 lbs.

374.—**Mountain Theodolites.**—This term is applied generally to very small theodolites with 3-inch to $3\frac{1}{2}$-inch circles, which may vary from a miniature transit to one of the simplest possible construction. They are made for travellers to take angles and altitudes for making descriptive maps, and even for astronomical observation to obtain approximate latitude, longitude, and time with the aid of a chronometer. They are made as portable and as light as possible, generally from 4 to 7 lbs. A slight modification of Fig. 151, but with two verniers and vertical arc, forms a very good instrument of this class. These instruments are generally made to order, and vary according to the requirements of the user. Occasionally they are made with the telescope eccentric, after the manner of some mining-dials to be described. There are not a great many instruments of this kind in use and the variation of patterns is great, so that their importance does not warrant a more lengthy description in our limited space.

375.—**Examination and Adjustment of the Theodolite.**—The description given of a transit theodolite arts. 301 to 318 will show that this instrument is provided with means of adjustment in every requisite direction. Larger transit instruments have been shown to possess the same means of adjustment, but in some parts these have greater refinement. The plain theodolite possesses also the like methods of adjustment, except in the case of the transverse axis, which is adjusted once for all by the maker. It will be necessary therefore, to limit our space, to discuss the examination and adjustments of the transit theodolite only, of which we have a full description (arts. 301 to 318), noting only where variations occur from partial differences between this and other theodolites.

376.—A theodolite as it comes from a respectable maker is usually carefully adjusted in all its parts. If it has gone a long journey it is, however, well for an experienced surveyor to put it through its various adjustments. The corrections, if any are required, will be generally very small, and these in all probability will be of the same kind as will occur in the use of the instrument and in the accidental conditions to which it may be submitted in conveyance from place to place upon a survey; therefore it is well to be familiar with them.

377.—If a new instrument is received from the maker, it is necessary to observe attentively the manner of its packing as it lies in its case. It is well at first to lift the parts a few times gently out of the case and replace them, so that this may be done at any future time with certainty and without any risk of strain upon the instrument, remembering always that an instrument is much more liable to be thrown out of adjustment by carelessly replacing it in its case than from ordinary use art. 37.

378.—For examination or adjustment of the theodolite the tripod stand should be at first firmly fixed with its legs extended to an angle of about 70° to the ground, which should be solid and hard. As the telescope has to be brought to the height of the observer's eye, it is well to mention his stature in ordering an instrument. The tripods are made for tall men, and are often awkward and unsteady if the legs are extended to bring the telescope down to the height of a person of short stature. They may always be cut down and refinished by the maker. When the tripod is set up, the toes should be each separately pressed down, so that future slips are impossible. This being done, the instrument is taken from its case and grasped firmly by the body part under the horizontal circle, and is placed on the tripod at once, and screwed firmly but not too tightly down upon its bearing surface. With a transit theodolite the upper part is generally detached and packed separately in its case. Where this is so, after the body part is fixed on the tripod, the cleats on the top of the standards must be opened out, and the upper part of the instrument, lifted by its telescope, be slowly lowered into its bearings, being particular at the same time that the clips under the telescope embrace their stay-piece on the standard. The cleats must then be closed over the pivots. The instrument being set up to position, all levels may be adjusted to the centres of their runs, and every part clamped sufficiently to make the instrument firm, but in no case using violence to produce a strain in any part. The clamps or other fittings are afterwards separately released as they are required for examination or adjustment of the separate parts to which they relate.

379.—*Examination for Coincidence of Exterior and Interior Vertical Axis.*—The theodolite being set up solidly, and all clamps fixed as above described, unclamp the lower or exterior axis clamp and set the vernier plate levels parallel with opposite pairs of parallel plate screws if the instrument adjusts on the parallel plate system art. 166, or one level parallel with one pair of foot screws if it is made on the tribrach system, art. 199. Now adjust both levels. Turn the instrument half round (180°) and observe if the levels keep the centre of their runs. If they do so they are in adjustment to the exterior axis. If found imperfect, the adjustment by the capstan heads of the levels are set, by means of the *tommy* or pin which is provided in the instrument case, for half the error as it appears by the bubble, the other half being given by readjustment of the parallel plate or tribrach screws. In these adjustments it is necessary to be particular *always* to observe the bubbles after the hands have left the instrument, *not during the adjustment*, which produces strain upon the instrument. Now clamp the lower clamp and note if this clamping has disturbed the levels. If the levels are very sensitive it will do so in a slight degree, but the disturbance should be very small if the clamp is perfect. Now unclamp the vernier plate and note again if this clamp disturbs the levels: this should also disturb them very little. Now observe the levels if they stand exactly as they did when the exterior axis was unclamped at their present position, and also at right angles to this. If they remain as before the axes are truly concentric. If they are not so, there is no remedy except at the hands of the maker. The vertical axis to which the above examination applies is considered the most important part of the instrument, and the work should be thoroughly well done; nevertheless if the levels are very sensitive, which they seldom are, such minute faults may be detected, that a small allowance may be made for imperfection of work, and the instrument still be considered a sound one. In the use of the instrument it is always well, after the circle is set either by the magnetic compass or by sighting a distant point for direction, to clamp the lower clamp and readjust the levels to the vernier plate. In this way the axis that will afterwards be used for triangulation will be vertical, and small errors due to want of coincidence of axis be eliminated.

380.—*Examination of the Azimuthal Level.*—This level, which is placed over the telescope, being made of superior sensitiveness to the vernier plate levels, is much more accurate for adjusting the vertical axis, but much slower.

in operation for testing. The verniers of the vertical circle should be accurately set to zero, in which position the run of the bubble should exactly agree with those on the vernier plate when placed parallel with them in any direction. But this level may also be considered by itself. Assuming the circle and verniers correct, or otherwise, it may be reversed over the axis by half turns in all positions over the parallel plate or tribrach screws, and adjusted by the capstan heads half the error, as before described, for the vernier plate levels.

381.—*Examination of the Divisions and Centring.*—The vernier plate being unclamped, the verniers, if two, should be brought approximately to 0° (360°) and 180°, and then the plate be softly clamped. The microscopes or readers are then to be set truly radial with the zero reading of the verniers, and the tangent screw adjusted to make one of the readings, say the 360°, exact. The opposite reading, 180°, is then carefully examined, and the error, if any, discovered is due to the imperfection of centring, assuming the division perfect. At this point it is well to record the amount of difference. The same examination is then repeated with the 90° and 270°. In a properly centred and accurately divided 5-inch or 6-inch theodolite this difference will not amount to more than 1′ error, in larger instruments proportionally less. From the difficulties at all times of reading the circle correctly from difference of direction, of light, and what is termed personal error, it is well to entirely repeat this examination, turning the instrument half round. It is also well to repeat the examination at what are termed the *half points*, 45°, 235°, and 135°, 315°. This will sometimes detect the error of centring, if there is one, in its true direction. The purpose of the two verniers is to discover this error. In practice the two readings are always taken, and the mean is considered as the true reading. Where there are a greater number of verniers exactly the same principle is followed, but the mean of three or more readings is taken, which of course assures greater accuracy.

Examination of the telescope has been discussed arts. 89 to 95.

382.—*Testing an Instrument for its Stability.*—The stability of an instrument will depend principally upon the quality of the workmanship; but the same test will also indicate whether the instrument has been submitted to sufficient wear to need the repair of the optician at any time. For this examination the eye-piece of the telescope requires to be focussed against a piece of white paper held obliquely in front of the object-glass so as to throw a soft, white light into the telescope. After the eye-piece is focussed, any distant point may be taken for a sighting object upon which to direct the telescope. This point should be focussed by the telescope so that its image falls centrally upon the intersection of the webs. The eye should then be shifted up and down or sideways within the range of clear vision of the webs in the eye-piece to ascertain that there is no parallax, that is, that the adjustments of the eye-piece and the telescope are in true focus upon the webs. This preliminary arrangement being made, which will serve for future examination for other adjustments, all parts of the instrument should be examined to see that the clamps are firmly clamped. The object to be used as an index or sighting point should be brought by the clamp and tangent motions exactly upon the intersection of the webs as they appear in the telescope, when the following examinations are to be made.

383.—*Tripod Head Examination.*—The telescope being sighted upon an index point, and all clamps screwed down and the tripod firmly fixed on the ground, take the tripod head of the theodolite in both hands and give it a twist of about a pound pull in one direction;

then examine the telescope to see if the index point is displaced in the telescope. If it still stands correct give a like twist in the opposite direction and again examine the telescope. If it stands these opposite firm twists retaining its position the stand is good and in good order. If it does not, assuming good construction of stand, the remedy may be found in tightening up all its screws; but if its construction is bad it will not even after tightening keep in order. There is no doubt that more defective triangulation is caused by defective tripods than from any other cause whatever. A perfect instrument is useless on a bad tripod.

384.—*General Examination of Fixed Parts.*—The stand being found good by the above process, the general fittings of the instrument may be examined, after clamping all parts of the instrument and directing the telescope upon a distant point, by taking a quill pen by its root or pipe and pressing its feathered end upon one side of the eye-piece of the telescope sufficiently to bend the quill, and afterwards examining the telescope to see that the webs are not displaced from the index point. This may be done first to the right hand and then to the left. If the webs still cut the same object it is clear that the whole of the centres, fittings, clamps, and tangent screws of the horizontal circle are correct. If there be displacement discovered, the amount of difference between the right and left handed twists will be the total error due to imperfection of work or wear as the case may be. In exactly the same manner, but by pressing the eye-piece upwards and downwards, the transit axis and its fittings may be examined. If the instrument is not generally sound enough to bear the above tests, other critical adjustments become necessary. For the correction of faults that may be included in the above operations, the parts of the instrument must be separately examined.

385.—*Examination of the Transit Axis.*—The best means of adjusting this axis in a theodolite is by a *striding level* art. 325. Where this is not provided with the instrument, and it is often left out for economy, the axis is generally better to be left as it is adjusted, in this particular, by the maker. To adjust the transit axis the vernier plate bubbles are set exactly true by reversing angles of observation. The cleats are opened and the striding level is mounted above the instrument resting upon the pivots. The telescope is placed exactly over an opposite pair of parallel plate screws, or parallel with two screws if the base adjustment is on the tribrach principle. The striding level is then carefully observed and reversed on the pivots. If there is any difference in the run of the level bubble the transit axis is adjusted by raising or lowering the movable V on which one pivot rests by turning the capstan nuts until it is quite correct. This adjustment is almost superfluous, as the axis is generally set right at first and is not subject to change.

For larger theodolites of 12 inches and over, the transit axis is much better adjusted by means of an artificial horizon, which will be described further on. By the use of this instrument in the northern hemisphere the pole star is first observed directly by the telescope, and then by its reflection from the horizontal surface of clean mercury placed on the ground at 12 feet or so from the instrument. If the star and its reflection cut the webs equally in directing the telescope by movement of its transit axis only from the one to the other, this axis must be truly horizontal. If the vernier plate be then turned a quarter of a revolution and the exterior axis a quarter of a revolution, the telescope transited and observation be repeated, the verticality of the principal axis may be adjusted with perfect certainty. The principal axis should be moved one-eighth revolution all round, and the bubble examined at every position to assure perfect adjustment. With the plain theodolite, Everest's and some others, the transverse axis is fixed to position by the maker.

386.—*Examination and Adjustment of Webs.*—The ordinary manner of webbing the diaphragm of a theodolite was shown Fig. 23. Horizontal angles are taken by the upper intersection of the nearest to vertical webs. A single web is placed horizontally for taking vertical angles: it is necessary that this should be nearly true. When the theodolite has its axis vertical, as shown by the vernier plate bubbles being in the centre of their runs, if one end of the horizontal web be set to cut a small distant object by sight in the telescope, the same object should keep on the web while the tangent screw of horizontal circle is moved a distance sufficient to traverse it, the hand being always taken from the screw while the observation is made. If it does not do so, the collimating screws should be lightly tapped with the back of a penknife in the direction to set it right. These screws have a slot in the body of the telescope, under the loose covering plate, sufficient to permit of this small adjustment.

387.—*Adjustment of the Telescope to Vertical Collimation.*—The eye-piece is first focussed as before against a piece of white paper held obliquely in front of the object-glass until the webs are sharply seen. The axis of the telescope is then examined for vertical collimation error. The method of doing this has been already described for a telescope placed in Y's, as it is in the Y-level, and the plain theodolite art. 172. The only difference with the transit theodolite is that instead of turning the instrument in its Y's, the telescope is *transited*, as it is termed, over on the transverse axis exactly half a revolution, or 180° as seen by the vernier reading; and the horizontal circle is moved also half a revolution, so that the telescope points again on the same distant point which is used for an object. If the webs still cut the same point or small object, the webs are in vertical collimation, or truly in the optical axis of the telescope, as regards the vertical direction which this adjustment is intended to secure, presuming the circle has been correctly divided and centred and the verniers accurately set. If the webs do not cut the same point, half the error is corrected by the top and bottom collimating screws situate near the eye-piece. This process is repeated until it is exact, being particular to observe, as before mentioned, that there is no parallax. This adjustment cannot be made with the plain theodolite; but the zero of altitude may be examined on both sides of the arc.

For the transit theodolite, adjustment by means of a collimator art. 194 is much more convenient and exact, as lateral and vertical errors in the position of the webs can be detected in one operation. When a Y-level is at hand, this may be used as a collimator if set to solar focus.

388.—*Examination for Perpendicularity of Transit Axis and Telescope.*—The whole of the lower part of the instrument retaining its position with all clamps firm, open the cleats upon the top of the standards so as to release the transit axis. Now release one of the clip screws and gently lift the upper part of the instrument out of its bearings. Turn the telescope the reverse way upwards, which will be in this case bubble downwards. Release the clamp and turn the clips to the reverse position of the telescope, and reverse the position of the pivots in their bearings. If the telescope be now directed to the same point as before, if the webs still fall upon it, the telescope adjustment is at right angles to the transit axis.

389.—*Examination of the Magnetic Needle.*—If the needle is placed in a circular box, as shown in the engraving

Fig. 30, it admits of no adjustment. If it is placed in trough Fig. 134 it admits of adjustment generally by lateral screws to a portion of its division. If the needle is used for a survey, it is set to the zero of the horizontal circle by clamping the vernier plate and bringing the northern vernier to zero, then releasing the exterior axis and bringing the needle by the motion of the lower tangent screw to the zero of its circle. The corrections of the needle for giving true north have been discussed art. 111. It is difficult to read an ordinary edge-bar needle correctly, and it is difficult to mount it perfectly true. It may be read at both ends, and if the 0° and 180° points cut the line fairly it is considered correct; if not, the mean of the difference may be taken. In some German instruments a microscope is mounted over the needle point that the needle may be adjusted to a web; but British surveyors seldom feel confident of surveys by the magnet, and generally prefer for triangulation the employment of a certain number of distant fixed points, the bearings of which are at first as accurately ascertained as possible, for referring objects, than to refer frequently to the magnet. When the magnet is out of use the needle should always remain lifted off its centre. When the instrument is put by for a long period it is better to place it in a vertical position and free the needle, so that it rests in the magnetic meridian, to preserve its magnetism as much as possible.

390.—**Use of the Theodolite.**—In setting up a theodolite place the tripod nearly over the position in which it is to be used. This is frequently the socket hole formed in the earth by the removal of a ranging pole or *picket*, to be described chap. XIV. Then suspend the plummet from the hook which will be found inside the head of the tripod after it is set up. If the ground is solid and level, then by shifting the toes of the tripod slightly, and firmly pressing them down one by one, the centre of the plummet may be brought easily within about ·25 of an inch of its true position. The theodolite is then placed on its tripod, observing that the telescope is in a position easy to be used. The centre of the picket-hole, when this is used for a station, is generally taken by guess-work, which is considered near enough. It may be taken with a little more refinement by placing a short false picket of a foot or so in length, but of the same diameter as the ordinary picket, the top of which is cut off smooth and polished, and has cross lines sawn across its centre inlaid with ebony, described chap. XIV. The false picket is carried about with the theodolite. With Everest's and some other makes of theodolites the hook is fixed under the axis of the instrument. In this case it is general to set the theodolite before adjusting it to the station, as there is no separate hook to the tripod. This also occurs with all framed stands. This process is sometimes a little dangerous for the instrument.

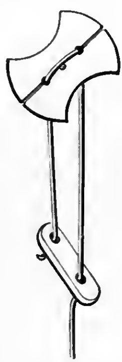


FIG. 152.—*False centre for a tripod head.*

391.—Where there is no hook to the tripod an excellent plan is to have a false centre, which may be a piece of turned wood with a hole through it, to fix on the top of the tripod head. The plummet cord adjusts through the hole. This false centre is also convenient where the axis adjusts to position by a mechanical stage. Fig. 152 shows a false centre formed of a piece of brass with two slots to permit the cord to loop over and yet hang centrally.

It may be observed that if the tripod is set up out of level, which it must necessarily be in many cases, the hook, if attached to the stand and following its inclination, will not hold the cord at a truly vertical position to the axis. Surveyors commonly allow a little for this inclination. It is much more accurate to have the cord suspended directly from the axis of the instrument where the instrument is constructed to admit this. Then if a false centre is used the plummet should be suspended a second time from the axis hook. With the kind of runner shown in the figure this need take little time, as it is detached and reattached in a minute.

392.—After the tripod is fixed with the theodolite upon it, the readers are set to exact focus. The horizontal circle is then brought to zero by the vernier plate clamp and tangent, and the compass brought to magnetic north, if all angles are taken in reference to this as a check, by means of the lower clamp and tangent. The vernier plate clamp is then released. The eye-piece is correctly focussed upon the webs against the northern sky, or upon a piece of white paper held obliquely if this is preferred. The telescope is then ready to be directed upon a picket or other station mark to be observed, and set correctly to focus this, after which the eye is moved to the right and left, to the extent of clear vision in the eye-piece, to see that the object appears to remain fixed upon the intersection of the upper V of the webs, or does not *dance*, as it is sometimes termed. The observation, if of a picket, should be taken as near the ground as possible, as this may not be set quite upright. If the telescope is directed to objects where the sun's rays would enter it, the ray shade should be pulled out sufficiently to quite shield the object-glass. The initial reading to be recorded is always taken on the *face* of the instrument, in which position the upper tangent screw is always on the right-hand side. When the observation is clear and satisfactory, it is recorded in the field-book. If the sight lines taken are to be measured by the chain, the amount of inclination is taken by the vertical circle reading to the top of the picket if this is the 6-feet ordinary length, or to a marked band if this is longer. The inclination may be taken exactly to angle by vernier, or roughly by scale of difference of hypotenuse and base as engraved on the vertical circle, or by both of these—the one as a check upon the other. It is common to take the upper inclination as a plus (+) and the lower inclination as a minus (−). Inclination observation is recorded at the same time as the horizontal position. Other observations of the various positions or pickets are taken in a similar manner at the same time. It is thought well when the theodolite is in position to take as many exact observations as possible in all directions of intended stations. It is also convenient to take a number of observations, which from the circumstances must be inexact, such for instance as the angles subtended by trees, gates, rough buildings, or even sometimes the corners of fields, as from such observations these objects may be placed nearly enough by the angles they subtend from this and another station upon the plan. In any case they form a check to positions if taken afterwards more definitely. These may be marked in the field-book *inx.* for *inexact*.

393.—**Field-book.**—This book is generally made 8 inches by 4 inches, covered with red leather, with elastic closing band and sheath for pencil, as an ordinary pocket-book. It contains about 100 pages of good stout writing-paper. Two lines are ruled in red ink, $\frac{3}{4}$ inch apart, longitudinally down the centre of each page. The column between the lines is used for distances measured by the direct chain line at which hedges are crossed, stations, offsets, or other measurements are taken. In the right and left columns observations are made of objects desirable to be recorded or triangulated.

394.—For superior triangulation, definite and prominent fixed objects are taken at as great distances as possible, so as to include the details of measured triangles within a superior triangle. A church steeple, for instance, is a favourite sighting object. This cannot generally be made, however, a station for future triangulation unless a scaffold is built up around it. Generally the most convenient method on fairly level ground, if the survey is large, is to have an ordinary scaffold pole, 20 feet or so in length, carefully straightened by a village carpenter with a stretched chalk line and then painted white. This may be squared at the end and fixed vertically in a socket formed of crossed boards to a depth of 3 feet or so in the ground, with long crossing tail-pieces rammed firmly with the soil to keep it steady. When this is used for a triangulating station the pole is taken out of its socket and its exact position is centred for placing the theodolite. Flags are sometimes used to indicate stations: their defect is that the wind may blow them from or to the observer and thus render them invisible. Other methods will be found in practical works on surveying. This subject will also be reconsidered in chapter XIV.

395.—*Elimination of Instrumental Errors during Triangulation—Changing Face.*—It is generally advised to *change face* with the theodolite after angles are taken in the ordinary way, that is, to take first the initial angles reading from the *face* vernier with the tangent on the right hand, and then to take the same angles with the back vernier, the telescope being transited. This of course gives a reading on a different part of the circle and corrects the error of position of the vernier, or centring, in the following manner:—In Fig. 153 let *a* be zero (360°), the reading of the face vernier. Let the

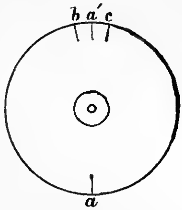


FIG. 153.—*Diagram bisection of circle.*

opposite reading (180°) be at *a′*. Suppose at 180° on the left-hand side of the instrument the 180° reads at *b*, then observe by the telescope an object that cuts this reading, or place a picket to do so. Change face; then the same arc will come to *c*, and the telescope must traverse *c b* to come to the first direction. The instrumental error is half *b c*, which bisected in *a′* gives 180° exactly. The same principle of repetition with changed face may be made on any part of the circle, and the mean will be the correct reading.

396.—*Repeating Angles.*—This is performed by taking all parts of the circle for reading a given angle, so that errors of division and centring of the instrument are eliminated. The process is as follows:—Take the angular position of two objects in azimuth, commencing with the zero of the horizontal circle, say the two objects subtend from the centre of the instrument 36° 10′; then turning the telescope back from its advanced position at 36° 10′ by releasing the lower or axis clamp, we may bring the first reading to the original zero position. Now clamp the lower clamp and release the vernier plate clamp and take again a forward reading.

If this reads $36° 10' + 36° 10' = 72° 20'$, the circle and centring appear so far correct; but it will probably read $72° 21'$, and the corrected reading would be the mean $36° 10' 30''$. If we continue this system round in ten pairs of readings the whole circle will be embraced, then the mean of the sum of the minutes divided by the number of pairs of observation will give the true reading of the minutes. By taking the readings separately of two opposite verniers the circle would be encompassed by five readings. This plan is followed in all important triangulations where the work is submitted to calculation. Such refinement is scarcely necessary for direct plotting with the protractor.

397.—It may be observed that if the horizontal circle is placed with its zero constantly to magnetic north—not necessarily for taking angles in reference to this—that the same part of the circle will always be used in the same direction; so that the sum of errors of the whole circle must necessarily tend to tie, even if the division is to a certain degree imperfect, provided also that the protractor used in plotting is also kept in one direction. This plan has otherwise no inconvenience, as any arc or angle may be taken by the difference of the circle reading in any position in which it may happen to fall. This does not say that it is advisable to survey by the magnet above ground—it is quite otherwise. It is best to have some distinct, sharply defined object to which all angles are referred, and therefore called a *referring object*, as the general index. The magnetic bearing need only be the initial position of the horizontal circle of the instrument.

397.—With large instruments constructive errors of injurious amount are not permissible; but these instruments are observed under altogether different conditions, suitable to the precision demanded. A large theodolite is generally fixed upon solid rock, or masonry with good foundation, or upon a very firm, solid framed stand, and the instrument is protected from wind, sun, and rain. Where it is necessary on level ground to elevate the instrument for more extensive view, a proper structure is built, in which the theodolite is isolated from the outer walls or enclosure which carries the stage upon which the observer works, so that no vibration or deflection of this caused by the wind or the weight of the body affects the instrument. Under such conditions angles are read on various points of the circle by micrometer microscopes so as to obtain a sufficient number of means, that personal and instrumental errors may be reduced to a minimum.

CHAPTER VIII.

MINING SURVEY INSTRUMENTS—CIRCUMFERENTERS—PLAIN MINER'S DIAL—SIGHTS—TRIPOD STAND—ADJUSTMENTS—HENDERSON'S DIAL — LEAN'S DIAL — ADJUSTMENTS — HEDLEY'S DIAL — ADDITIONAL TELESCOPE — IMPROVED HEDLEY TRIBRACH AND BALL ADJUSTMENT—REFLECTORS—CONTINENTAL FORMS—THÉODOLITE SOUTERRAIN—TRIPOD TABLES—STANLEY'S MINING THEODOLITE—PASTORELLI'S, HOFFMANN'S, AND DOERING'S ADJUSTABLE TRIPOD HEADS—MINING TRANSIT THEODOLITES—STANLEY'S PRISMATIC MINING COMPASS—HANGING DIAL—HANGING CLINOMETER—SEMI-CIRCUMFERENTER—MINING LAMPS.

398.—**Miner's Circumferenter.**—In the original form of theodolite, as it was at first designed by Sisson, open sights took the place of the telescope. The sights in this case were extended on arms. The compass-box placed over the axis was large and very free from obstruction, so that the needle upon which general surveying formerly depended could be read correctly by placing the eye vertically to the plane of the horizontal circle of division against which the needle read. After the introduction of the telescope to the theodolite this old form of instrument took the general designation of the *circumferenter;* and subsequently, being best adapted to underground surveying, it became the *miner's dial.*

399.—Upon this original circumferenter improvements have been made in the various mining-dials we possess, in all of which the large open compass is still preserved. This prominence of the compass does not indicate that the modern scientific mining engineer has any desire to depend upon it for taking horizontal angles, but that in close and tortuous workings it provides the nearest and often the only possible means of taking angles consistent with the extreme difficulties of observations of any kind. Where workings are open and fairly plane the telescope and circle with vernier reading can be used, so that at the present time the better class of instruments possesses the means also of taking observations of angular direction by vernier reading. Several other very important factors specialize mining from ordinary surveying instruments, which may be specified as follows:—1. That there shall be means of shortening the tripod for work in strata of small depth. 2. That the instrument shall be low and compact in itself, that the head of the surveyor may be placed above it, if possible, even in shallow workings. 3. That great extent of adjustment of the compass-box to horizontality shall be given in the fittings of the instrument, on account of the difficulty of extending the legs at all times for tripod adjustment and from the extreme inclination of the floor of the working in some cases. 4. That it is desirable in mining survey instruments that the telescope, if there is one, shall take sights at all angles upon the surface of the earth in the locality in which the instrument is used, as also about a vertical position, so as to be able to sight lines from the top to the bottom of the shaft, or *vice versâ*, to set off angles in the same azimuth as those taken at the surface by direction of stretched wires or otherwise. This last form of instrumental contrivance will also give the means of sighting a perfectly vertical point beneath the centre of the instrument placed at the top of the shaft, to make a concurrent station below during ventilation, when the plummet would be disturbed. The devices by which these various requirements have been met more or less perfectly will go far to explain the specialities of construction found in mining surveying instruments, which will now be described, commencing with the most simple form, upon which improvements have been made in many directions.

400.—**Plain Miner's Dial.**—The original simple form of specialized miner's dial is shown in Fig. 154.

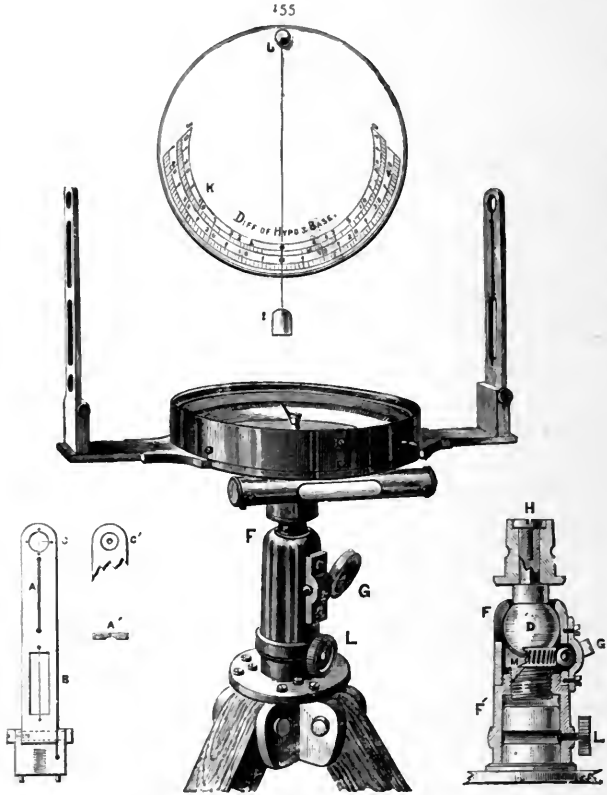


FIG. 154.—*Mining dial.* FIG. 155.—*Cover to the same.* FIG. 156.—*Sight.*
FIG. 157.—*Section of ball and socket joint.*

This dial consists of a compass, divided to single degrees, read by a finely pointed, edge-bar needle mounted on a jewelled cap. The needle has a sliding rider placed upon it, art. 110, so that it may be carefully balanced to horizontality in the locality in which it is used. The divided compass is raised on a step, and the upper surface of the needle is made to be quite level with the division when the compass is horizontal. In erecting the instrument with the needle correctly balanced, the compass may therefore be brought to horizontality by the coincidence of the upper surface of the needle with the plane of the divisions, without the necessity of having spirit levels.

401.—The compass-box is extended in one meridian, north to south, by strong arms that carry a pair of sights which are hinged to turn down to the surface of the cover for portability. The compass-box and arms together are termed the *limb*. The limb of the instrument is mounted upon a *ball and socket joint* to be described. The socket is slotted down on one side to permit the limb to be turned to a vertical position. In this position the level shown on the front of the instrument is used for levelling by means of the sights: this level is not, however, put on all plain dials.

402.—The cover of the compass-box Fig. 155 is fixed on the box to a given position by a stud and slot. It has an arc divided upon its outer surface, which is centred from a small hole placed near the outer edge. A line from the centre of the hole to the zero of the arc is made perpendicular to the central indices of the sights. A piece of silk or a horse-hair carrying a small plummet is fixed to hang from the hole. By this means, when the limb is turned down in the slot of the socket and the silk or hair stretched by the plummet to permit it to hang in front of the arc, it will then cut the divisions and thus form a reading index to the arc, giving thereby the vertical angle at which the sights are set.

The instrument is mounted on a simple jointed tripod to be described. It will be seen by the above description that this instrument is cheaply made, and is not designed for very exact work. It is now giving way for more exact instruments, but it forms the groundwork on which mining survey instruments are most generally constructed. The height of this dial with sights erect is 11 inches; weight, 6 lbs. Some of the separate parts above enumerated, which are common to many other forms of mining instrument, will be now more particularly described.

403.—**Sights** are common to mining instruments, one of which is shown separately Fig. 156. They are essentially constructed in two parts, termed technically the *slit* and the *window*. The *slit A* is a narrow parallel cut made through the metal upon the inner surface of the sight, which is turned towards the centre of the instrument. The thickness of the metal is hollowed away on the outer side which comes next the eye, so as to present a thin edge only for the sighting slit, as shown in section at *A′*. In some instruments the slit is formed of two thin plates that are fixed to the sight by screws in slots, which render the slit adjustable both to width and position: this is the better way if machinery is not used for cutting the slit. The *window B* is an oblong opening, across which a hair wire or a thin plate placed edgewise is fixed lineally with the slit. The hair or wire is laid in a deeply engraved line, so that it is in the same plane as the centre of the slit. The ends of the hair are held firmly by drawing them through small holes and fixing them therein by means of dry, conical, pinewood pins pressed tightly in the holes. When a thin plate is used edgewise, this is soft-soldered into the top and bottom of the window. In the pair of sights the window of one sight is placed at the lower position and the slit in the upper. In the fellow sights the position of these parts is reversed, the observation being always taken from the slit through the window. The duplication of parts in each sight permits it to be used in either direction.

404.—*In the Use of the Sight* the point or object to be observed from the slit should appear to be bisected by the hair in the window at the same time that it appears to the eye to stand in the centre of the slit. For this reason it is not necessary that the slit should be very narrow. It is generally more comfortable to take the sight with the eye at a distance of 10 to 12 inches in front of the slit to obtain clear vision of it. In this case if it is made too narrow it shuts out the field of view.

405.—**Universal Sight**, termed technically *hole and cross* sight, consists of a small hole *C′* Fig. 156 on the inner side of one sight that is hollowed away on the outer side which comes next the eye, so as to present a thin edge only of the hole. The fellow sight *C* has a hair cross placed centrally in a circular window. This is of occasional use for sighting angles approximately in altitude and horizon simultaneously; but the cross occupies so much of the sight space that observation with it cannot be depended upon where better can be obtained.

406.—**Ball and Socket Joint.**—This is shown in elevation Fig. 154 at *F* and in section Fig. 157 *F*, *D*. It is one of the oldest forms of adjustment and is common to many dials. When the clamping screw *G* is released the ball is free in its socket *F* to move about its centre, to the extent of the opening at the top of the socket, in any direction. A *plug E*, which really forms the lower half of the socket, is screwed into the part *F′* at the lower part of what is technically called the *socket-piece*. The plug is turned upwards by its screw so as to tighten the ball by means of a tangent screw *G* which works in a rack thread cut in a part of the circumference of the plug, thus forming a *screw and cross screw*, which, as the construction indicates, clamps the ball with great rigidity. There are several other ball and socket arrangements: these will be discussed in describing the special instruments to which they are affixed. The only objection to this form is that it elevates the dial very much.

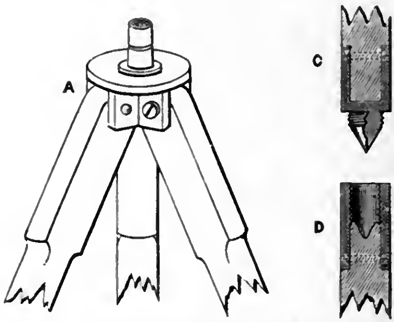


FIG. 158.—*Jointed tripod legs of a miner's dial.*

407.—**The Tripod Stand of an Ordinary Miner's Dial.**—The upper part is shown in Fig. 158. This form of tripod is common to many dials. The legs are made about $1\frac{1}{4}$ inches in diameter. The heads of the legs are fitted directly without brasswork between the *book-plates A*, to which they are held by cross screws or bolts which form the joint on which the legs move for extension. The book-pieces are screwed, unless the head is worked out of the solid, to a plate that carries a male plug centre to which the dial is fixed by a milled-headed screw shown at Fig. 154 *L*. The plug is grooved at the position of the point of the screw so as to permit rotation of the instrument on the plug when the screw is slightly released. This tripod head remains permanently fixed to the legs. Each leg is jointed to part in its centre by unscrewing, to present when disjointed a point to hold the surface of the ground, to form a short stand. The usual height of the full tripod legs is 5 feet; the upper part only 2 feet 6 inches. The usual form of joint is shown in detail in section Fig. 158: *C* the male screw which is fitted to the woodwork by a socket and cross-pinned to it. This piece has a point at its lower end. *D* the socket-piece is screwed over the point to extend the leg when the tripod is required of full length. The woodwork of this lower piece has a conical metal point to bite the ground when it is set up full length. Occasionally for close work shorter legs are provided, or the legs are jointed in three parts. In the common dial shown, the legs are left exposed when out of use; with superior instruments they are packed in a deal case that protects the socket fitting to which the instrument is attached. Another form of tripod will be discussed further on with the instrument to which it is attached.

408.—*Examination and Adjustment of the Plain Miner's Dial.*—The tripod should be first set up to full length and each leg separately twisted to right and left to see that its socket fittings are good and free from shakiness. The legs should each be separately pressed in and out at its centre to see that the screws clamp the parts firmly and are free from shakiness. The instrument should then be set up and its socket fitting be felt to see that it is free from shake, and also be turned round to see that it moves freely. The ball fitting should be clamped and its rigidity be tested by fair pressure on the two ends of the limb separately. The sights should be examined to see that they are quite lineal with hair and slit. The compass-box should be levelled by the coincidence of the upper surface of the needle with the plane of the division, and be reversed in every direction by turning the compass-box, the reading being observed with the N. point of the needle at N. E. W. S. to see that it bisects the graduation by angles 180° apart.

The compass-box being level, the sights should be ranged with an external object at a distance—a plumb-line is best—a piece of string suspending a stone answers—to see that they are vertical and that they cut the same line with the position of the sights changed fore to back. If the sights are coincident but do not range with the plumb-line, the needle is out of balance, and this may be corrected by shifting the rider. The general examination will also test the adjustment. If there are faults, or the instrument is not generally adjustable, these faults can only be remedied by a maker.

409.—**Henderson's Dial.**—This is an improvement upon an old form of circumferenter,* in which four sights are centred in opposite pairs so as to revolve about the vertical axis, so that one pair of sights may take any angle to the other pair. In Mr. J. Henderson's dial the improvement consists in making the compass larger, the needle being made to read by a vernier placed upon one end to 3′ of arc. Mr. Henderson prefers plain slit sights instead of slit and window sights, which avoids the accidental derangement of the horse-hair.† The instrument combines some of the parts of Lean's dial, to be next described. Illustration of this instrument is given in Mr. B. H. Brough's "Mine Surveying," page 61.

410.—**Lean's Dial.**—The inventor of this instrument was Mr. Joel Lean, a Cornish mine manager, who was well known for his important improvements in mining apparatus at the end of the last century. This dial is still popular in Cornwall and other mineral districts. In general construction the sights and limb on which they are mounted are the same as in the plain dial just described. The legs are also the same—other parts are additional or modified. In the engraving Fig. 159 the

* Plate XIV., Fig. 5, "Geometrical Essays," Geo. Adams, 1803.

† "Proc. Min. Inst., Cornwall, 1883," vol. I., page 317.

sights and vertical arc with its telescope are shown mounted together on the limb. This is done to show the relative position of these parts: they could not in practice be used simultaneously upon the instrument. They are separately attached to the limb by the same pair of milled-headed screws. As a general rule the

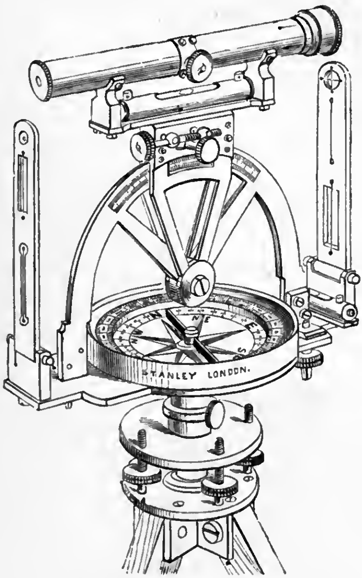


FIG. 159.—*Mining circumferenter or Lean's dial.*

telescopic arrangement, which will be described further on, is used above ground and the sight arrangement below. The details of construction are as follows:—

411.—**The Tripod** of the mining circumferenter, in common with many other forms of dial, has the legs fitted directly between *book-pieces*, as shown Fig. 159, which are fixed to the lower parallel plate, thus dispensing with the separate tripod head, common to levels and theodolites. Otherwise the parallel plates are in every way similar to those described for levels and theodolites art. 166, and are used in the same manner. The upper parallel plate in this dial carries the male axis, which fits into a socket attached below the centre of the limb in the manner just described for a plain dial. The tripod stand, with its parallel plates attached, is generally packed when out of use in a pinewood case. The motive for attaching the legs directly to the lower parallel plate instead of having a tripod head, is that it saves the extra elevation of the instrument by the depth of one screw fitting. At the same time it must be observed that it exposes the axis to the air by separating the instrument at this part when it is put by, which renders the axis difficult to be kept lubricated and in smooth working order. On the Continent and in America it is general to detach the legs only, on a plan shown Fig. 74. This keeps the axis attached, and is probably the better plan, although it may be found a little more troublesome to erect the instrument.

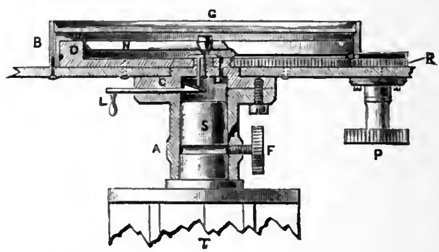


FIG. 160.—*Section of compass-box and axis of Lean's dial.*

412.—**Revolving Compass** forms a part of Lean's dial and many other dials. It is shown in section Fig. 160. As the axis is constructed in this instrument the socket-piece *A* is ground to fit the male axis *S*, and at the same time it is shouldered to fit the surface of the parallel plate *T* to prevent excess of friction on the axis fitting, so that it may move easily to set the needle to magnetic north of the compass if desired. The socket-piece is attached to the compass-box through a collar. The compass has a step *D* which is divided to degrees on its inner edge to read to the point of the needle, and similarly to degrees on its outer edge to read with a vernier scale, shown above *D*, to 3′. The vernier is set off on each side of the zero line in ten divisions, which are figured 30, 45, 0, 15, 30, art. 263. The upper surface of the needle is made level with the upper surface of the step. The bottom plate of the compass-box is divided to 10°: in some difficult positions in the use of the instrument this last is the only reading that can be sighted. The compass-box, which carries the vernier *B*, is fixed centrally on the arm plate. The arm plate is centred upon a step fitting between the compass and the socket-piece, so that the arm plate carries the whole superstructure of the instrument around the compass, its relative position being read by the vernier. The edge of the compass plate is formed into a toothed wheel, as shown in half section in the figure on the right-hand side, into which a small wheel or pinion *R* is fixed in a box upon the arm plate that works by means of a large milled-head screw *P*. By means of this milled head the instrument may be rotated about the compass, so that the line of division on the compass step reading into the vernier performs the functions of the horizontal limb of a theodolite. In this manner angles may be taken by means of the vernier, quite irrespectively of the reading of the needle. When the compass is set to the zero of the vernier at north (360°) it may be fixed in this position by means of a pin fitting in opposite holes to the arm plate and bottom plate of the compass, not shown; and when thus fixed the needle only is used as in the plain dial. Between the collar-piece *C* and the socket-piece *A* a wedge-shaped lift raises the needle off its centre by pressing in a slide shown at *L*.

413.—*The Vertical Arc* is erected upon the limb as close as possible to the compass-box, so as to leave room for a level to be placed between the seatings of the arc and sights. The axis of this arc, which is a simple hinge joint, is brought down nearly to the surface of the cover which protects the glass of the compass-box: this is done to keep the instrument as low down as possible. The telescope, which is of the same kind as that used for the theodolite, traverses the arc tangentially, permitting it to be adjusted for reading the arc by its vernier by means of a clamp and tangent motion at any position. The arc is divided on one side to degree, and reads by the vernier to 3′ in the same manner as the horizontal circle. On the opposite side it is divided with a percentage scale of difference of hypotenuse and base which reads to an index line. A spirit level is placed under the telescope, lineal with its axis, to which it is adjustable by means of capstan-headed screws. The telescope when fixed is placed just sufficiently above the arc to permit it to be brought to a vertical position at 90°, or a degree or two over this, with the full aperture of the object-glass beyond the extreme edge of the horizontal circle. By this construction a bearing may be taken of any object upon the surface from the top of a shaft, and a line may be sighted at the bottom of the shaft in exact azimuth with this without changing the horizontal adjustment of the instrument. In the same manner, if the vertical axis be perfectly adjusted by the level on the vernier plate, the telescope at $90° + n$ will indicate a perfect vertical to the station of the instrument above, the $+ n$ being allowance to be made for the eccentricity of the telescope, provided the collimation is perfect. If this is not perfect, the vertical may still be taken accurately by means of three observations taken from equal division of the entire horizontal circle, say at 360°, 120°, and 240°.

It will be noticed that the vernier to the compass circle comes directly under the vertical arc, therefore it can only be read obliquely when this arc is mounted: with open sights the vernier can be read directly. This is a defect in this instrument, as the vernier is mostly required for exact work when the telescope is used.

414.—Lean's dial possesses the qualities pointed out in art. 399 as important to dials 1 and 4, in 4 the power of setting the telescope to the vertical with great facility being the most important. This quality has kept the dial a favourite with many mining engineers in mineral districts for so many years. Otherwise for general work the compass is most inconveniently obstructed by the arc above it, and the instrument is too high to be used in shallow workings, although, of course, of less height than the theodolite, some of the functions of which it performs. The height of a 5-inch Lean's dial is 9½ inches to central apex of the telescope, 8 inches to the top of the sights placed in a level position; weight of instrument only, 6½ lbs. The 6-inch instrument is about 1 inch higher and weighs 1 lb. more.

415.—A number of variations have been made in Lean's dial; but none that the author is aware of have proved successful improvements. In an instrument of this class designed by Mr. J. Whitelaw,* the vertical arc is brought down to the compass-box by placing pivots on each side of the box after the manner of Hedley's dial, to be next described. This lowers the instrument about an inch, which is an improvement; but this is effected at the expense of placing a striding bar across the compass-box, which is a great impediment to the clear sighting of the compass.

416.—*Examination of Lean's Dial.*—As regards the stand and sights and parallel plates, particulars have just been given upon plain dial just described. The

* Patent No. 1592, April, 1878.

revolving compass should be turned round by the milled head *P* Fig. 160 of the pinion wheel *R* to see that the compass-box revolves steadily at all points without disturbance of the needle. It may also be particularly observed that the needle does not oscillate at any part of the circle, to be sure that the compass-box is quite free from iron. The vernier should be examined at four opposite positions of the needle to see that the needle is truly centred and is in accord with the vernier. The lift should be tried to see that it lowers the needle gently on the centre, and that it holds the needle firm off the centre. The telescope should be set up and directed to an object, and all parts of the instrument clamped and the needle observed. The telescope should then be detached and the sight set up, to see that they range fairly with the telescope. If they do not do so the difference should be noted and treated as a constant in any case of change from telescope to sights on the same survey. The difference should be very small, otherwise the instrument should be returned to the maker.

417.—*Adjustment of Lean's Dial* is the same as that of the plain theodolite, so far as this can be carried out; but generally the adjustment is depended upon as it leaves the manufacturer. For the general use of this and other dials some notes will be made further on, but as regards vertical position and the taking of azimuth angles, for which this dial is specially adapted, notes may be made here.

418.—*To Set a Line in Azimuth with one taken above Ground.*—This is necessary where there is local attraction to the needle below, or there is suspicion of this, so that the needle cannot be depended upon with certainty. The instrument is placed on staging over the pit and a vertical is taken to its centre either by the means briefly discussed, by the instrument, or by suspending a plummet, a ball, or a bullet from the centre of the instrument by a thread and burning the thread when the ball is free from vibration. The ball is allowed to fall upon a smooth horizontal surface formed of earth or otherwise, in which it makes a dent which will be vertical to the axis of the instrument if the ball has not been deflected by ventilation currents. Two lights, as distant as possible to be seen to range lineally with the dent, are placed at the bottom of the pit. The lights, if thought desirable, may range north and south with the needle; but in whatever direction this may be set the correct azimuth of this may be taken by cutting them by the webs of the nearly vertical telescope of the dial; and this azimuth may be correctly set out on the surface by a pole or other station mark, or its true direction by a pair of these, one on each side of the pit's mouth, the second station mark being set out after a shift of the horizontal vernier exactly 180° on the circle. A straight-edged flooring board painted white may be made to cut the line from light to light, which is more definite for bearing than the lights themselves.

419.—**Hedley's Dial**, the invention of John Hedley, H.M. Inspector of Mines, in 1850, has now become the most popular form of miner's dial, modified however from its original form in various ways. The peculiar feature of this form of dial is that the sights move upon a framework centred upon a horizontal axis, so that they may by a rocking motion take horizontal angles within wide azimuth without obstruction to sight of the compass.

For consideration of the general features of Hedley's dial, the tripod and ball and socket are the same as that described for the plain dial; but the socket is not cut down on one side to change the position of the axis, as the compass-box in this instrument is required to be kept uniformly level. The general appearance is shown

Fig. 161. For districts in which the working strata are fairly level, parallel plates are put to this instrument in place of the ball and socket joint. The compass-box revolves as that just described for Lean's dial; but it is more general in this instrument to have a clamp and tangent motion as in a theodolite than the rack and pinion motion described. Two levels for setting the compass horizontal are sunk into the plane of the compass dial low enough to miss the edge-bar needle.

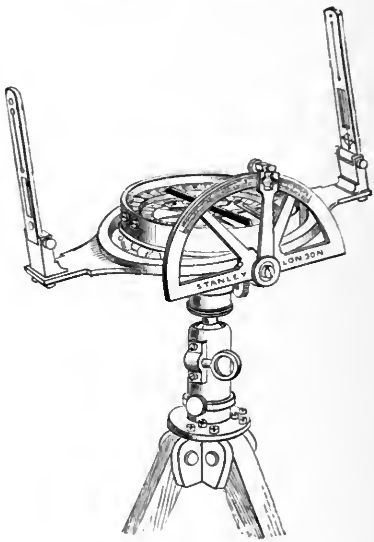


FIG. 161.—*Hedley's dial.*

The step of the compass is divided into degrees and the plane of the dial to 10°. The vernier, which is placed on the opposite side of the box to the vertical arc, reads to 3′, as described for Lean's dial.

420.—*The Rocking Centre* forms the peculiar feature of this dial. From opposite points of the under side of the compass two pivots are projected. These are set perpendicular to the vertical axis, which is placed above the ball and socket. The pivots are placed central with the vernier and lineal with E. to W. of the compass when this is set to *zero* (360°). The pivots form the axes of a stout ring — *rocking ring* — which surrounds the compass-box, with space sufficient to clear it when the ring is rocked about its axis. The ring has two extended arms which carry sights as shown. These turn down upon the compass-box when out of use. One of the pivots is prolonged for about $\frac{3}{4}$ inch beyond the outer circumference of the ring. The prolongation is made generally of triangular section. This forms a fitting to the vertical arc which is attached by a milled-headed screw when required, the arc being an encumbrance when this dial is used for making horizontal plans only.

421.—*The Vertical Arc* with its index arm forms a separate piece. The arm is centred upon the arc with a ground fitting which is retained in its position by a collar fixed with three screws. The arm-piece forms the axis, through the centre of which a triangular hole is made to fit the triangular prolongation of the pivot, so that the index arm remains fixed, and the arc moves with the rocking ring, to which it is held by a pair of dowels. The arc is divided into degrees on the outer edge of its surface, and a scale of difference of hypotenuse and base upon its inner edge. The graduations read to a single index line upon a fiducial edge carried down from an opening in the index arm.

Hedley's dial can be locked by a pin which is attached to the under side of the compass-box, so as to work by the compass only. The ring can also be locked level with the compass by a sling *latch-piece* so as to convert it into a plain dial.

422.—The great merit of Hedley's dial is that the rocking centre permits a greater range of open sighting than any other dial, and the instrument is so low that it permits its use in shallow workings. Further, that it is a very strong instrument to resist accidents and is very portable. The height of a 6-inch Hedley's dial above the tripod head, in a level position, is 9 inches to the top of the sights. Weight of instrument, 7 to 10 lbs.

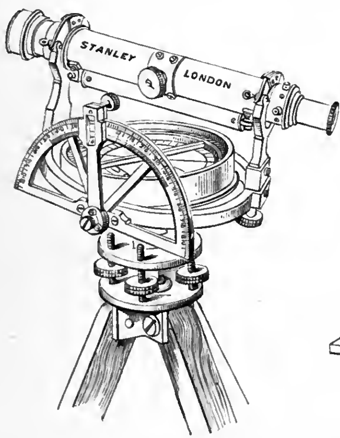
423.—There have been many variations made and proposed for Hedley's dial. Mr. Casartelli, of Manchester, places the arc over the centre of the compass-box.* The plan is intended to make the rocking centre firm; but the arc interferes a little both with the sights and the view of the compass-box. Messrs. Davis & Son connect wheelwork with the arc, so as to magnify the scale of motion. Other less important variations in Hedley's dial are common.

424.—*Examination and Adjustment of Hedley's Dial.*—The general examination of the stand and of such parts of the instrument as correspond with Lean's dial are the same as just given. The rocking ring should be lifted and pressed down at one end alternately to see that there is no *loss of time* on the axis. The arc should be examined in like manner. The dial should be set up in front of a plumbed line to see that its sights range properly when the instrument is set level by its bubbles. A point in the sights should be observed, say through hole and cross webs at the top of the sight; and with this point kept in view the rocking ring should be moved upwards or downwards so that the point traverses the plumb-line to the extent of the rocking motion. If this does not do so, possibly the transverse level in the plane of the compass-box may be adjusted to make it do so; but in this adjustment it must be particularly observed that the balance of the needle remains so that it still reads the graduation with its upper edge, and that the sights traverse the same plumb-line when turned about, as it is possible to set the level right

* Patent No. 1857, J. L. Casartelli, May 1874.

with one pair of sights and throw other parts out. There are no simple means of adjustment provided, so that if the instrument is not correct it should be returned to the maker for correction.

425.—**Improvements in Hedley's Dial** *by Addition of Telescope.*—Surface work being generally performed with the theodolite, surveying with open sights following this cannot be effected with sufficient accuracy; therefore there becomes a necessity for the use of the telescope,



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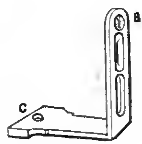

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FIG. 162.—*Hedley's dial with telescope.* FIG. 163.—*Bracket sight.*

which was first placed on this instrument by the author, at the suggestion of Mr. W. Preece. In mines also, although sights present often the only possible means of directing angular positions in cramped and tortuous workings, on the other hand, better work can very often be done and the telescope be conveniently used. Under these conditions this addition forms an important improvement in the instrument, to be at hand to apply when desired. The telescope of this instrument detaches exactly as with Lean's dial, but the sights are made with an angle-piece, so as to extend them to a distance of about 12 inches apart for sighting. Fig. 163 is of one cranked sight. The instrument illustrated has parallel plates, art. 158, suitable for fairly level workings. A ball and socket joint is sometimes fitted to this instrument in place of these.

426.—*The Telescope* is placed on Y's and is of exactly the same form as that described for a plain theodolite. The Y's in this instrument offer a great convenience for reversing the telescope for back sights in range when the vertical axis is fixed. The level under the telescope is sufficiently good to convert this instrument into a level for drainage, etc., when the rocking ring is locked with the compass. *Its examination and adjustment* are the same as those last given, except for the telescope, which is the same in all particulars as that of a 5-inch plain theodolite.

427.—**Improved Miner's Dial.**—The illustration given Fig. 164 is of the form of dial the author now most generally makes—a part of the arrangement only being of his own design. The telescope is the same as that just described with Y supports, and the sights, not shown, are cranked in the same manner as shown Fig. 163. The horizontal circle, instead of being placed in the interior of the box, is placed on the exterior rim, and reads with two verniers—not for correction, but for convenience of reading in different positions. The compass is divided upon the upper surface of the step to degrees, and in the same manner on the interior cylindrical surface of the step. This last often permits the compass to be read in a close working when the upper surface could not either be lighted or sighted. This plan was used on old circumferenters.* The plane of the compass is divided to 10° as usual. The compass

*Illustrated plate XV., Fig. 1., "Geometrical Essays," John Adams, 1803.

adjusts by clamp and tangent motion. The axis of the instrument is supported upon a ball and socket arrangement for roughly bringing the compass to level, and a

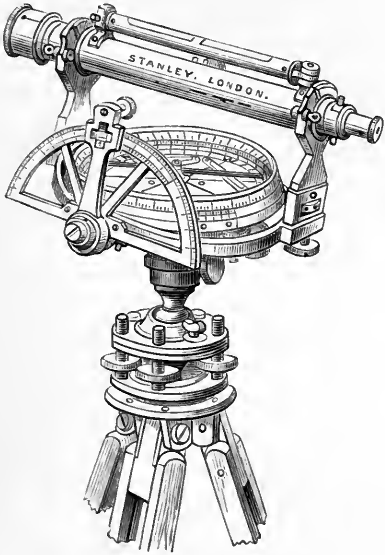
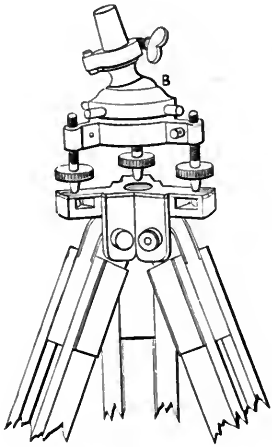


FIG. 164.—*Improved miner's dial.*

parallel plate adjustment for final setting. The ball is fixed by clamping a pair of plates together by thumb-screws. Each plate is hollowed in the centre to hold nearly half the ball. When fixed, the instrument is found to be very rigid.

428.—A plan of clamping by the author, of equal rigidity to the above described, is shown in elevation Fig. 165 *B*. In this the upper half of the socket is screwed down outside the lower half socket by means of four projecting handles or pins. This is a somewhat neater arrangement than that shown in Fig. 164. Either of the above-described ball arrangements elevate the instrument, and are better omitted for close working, if there is a special adjustment in the tripod attached to the instrument, as that to be described presently, which will be found sufficient in most cases. The height of the instrument is about 6½ inches from the tripod; weight, 11 lbs.



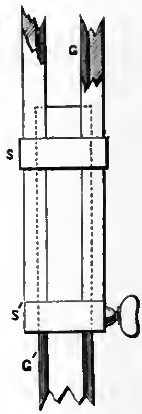


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FIG. 165.—*The author's adjustable ball joint and socket tribrach stand.*
FIG. 166.—*Adjustment to leg of tripod.*

429.—**Adjustable Tripod for Dials.**—The author's latest improved form of tripod is adjustable to all heights between 30 inches and 57 inches Fig. 165. Each leg is formed of two stiff bars of ash, shown in detail Fig. 166 *G*, of section about 1¼ inches by ⅝ inch, and a third bar or leg *G'* of about 1¼ inches square, which slides between the other two. The sliding surfaces are grooved and tongued together in the solid. Two strap-pieces of brass *S S'* are fixed near the ends of the bars. One of these *S'* is firmly soldered to a boss-piece that takes a thumb-screw which has quite sufficient power to hold the leg *G'* firmly at any position of extension. It is a rigid stand which may leave the tripod head nearly vertical upon any inclination of the floor surface.

430.—**Reflecting Cup.**—The only disadvantage in any way of the improved forms of Hedley's dial, in comparison with Lean's, is that the telescope cannot be placed vertically to range a line at the bottom of a shaft in azimuth with one taken above, or even cut the nearly vertical angles of some mineral veins. To obviate this the author has made a reflecting cup Fig. 167 to place over the end of the telescope. The cup is formed of a tube which fits the outer surface of the object end of the telescope. This is prolonged sufficiently to lock the telescope against revolution by a dowel when the points that are used for index in the diaphragm of the telescope

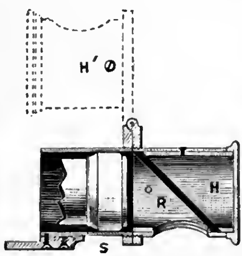


FIG. 167.—*Reflecting cup to miner's dial.*

are vertical. The tube is cut in two and hinged to turn up, as shown in two positions *H* and *H′*. When turned up it leaves the tube open for direct vision. A reflector *R* is placed in the cup, and there is an opening below it equal to the full aperture of the telescope. It is easy to see that by this means a pair of lights or a line may be sighted up or down a shaft, and the azimuth of its direction be reflected to follow a line by slightly rocking the telescope upon its pivots. This may be done, however, with more refinement if there is a clamp and tangent motion to the vertical arc, which is placed only on first-class instruments.

431.—**Illumination of the Axis of the Telescope** for observing the webs or a point, may be conveniently effected underground by employing a conical ring reflector in front of the object-glass. The aperture through the cone leaves the field of the object-glass nearly free, as it is only necessary that the cone should project in front of this for a very small distance. This reflector is placed over the object end of the telescope when it is required, just the same as the ray shade. The vertical reflector Fig. 167 goes on the same fitting. The reflector Fig. 168 *R* may be made of silver or platinum. A light

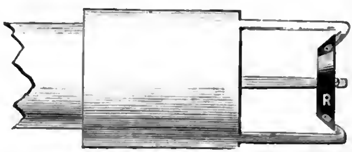


FIG. 168.—*Conical reflector to illuminate axis of telescope.*

placed anywhere opposite this and perpendicular to the axis of the telescope will throw sufficient light to see the webs or point. Sometimes a simple, plain mirror placed on an arm bent over to the centre of the front of the object-glass, in which the mirror stands at 45° to the axis, is used; but this plan is not so good as that shown Fig. 168, as the light has to be brought to face the mirror quite perpendicular to the axis of the telescope, and this process is frequently difficult to accomplish underground.

432.—**Continental Forms of Miners' Dials.**—On the Continent generally sights have been abandoned for miners' dials. The telescopes are made generally of short form, with large object-glass and wide field of view. The telescope is generally placed eccentric, which permits the instrument to be made of very low form. There is a certain amount of disadvantage in the eccentricity of the telescope, as angles cannot be taken direct from the centre of the instrument; but this is compensated for in the plotting by making each station a small circle equal to the amount of the eccentricity to scale, and setting off angles tangentially to this, which may be done with very little more trouble than that of taking the angle from a point.

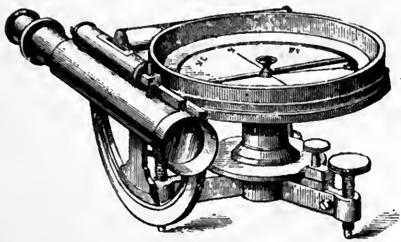


FIG. 169.—*French form of miner's dial.*

433.—**French Miners' Compasses.**—Fig. 169 shows the simpler form of this instrument. The needle is open and quite free from obstruction. The telescope is centred about level with the compass-box. The vertical axis has clamp and tangent adjustment. The transverse axis is set entirely by hand as with the plain dial. The instrument is set up level by its tribrach adjustment. The height of an instrument with 5-inch needle in a level position, without tripod head, is about 5 inches; weight about 11 lbs. without tripod table. The extreme squat form of the instrument permits its use in very close workings, with a short tripod, if the workings are fairly level. This instrument is used also as a cheap form of surface surveying instrument, consequently it is not generally very carefully made. As a good instrument it cannot compete with that to be next described.

434.—It will be seen by Fig. 169 that the instrument has no direct connection with its stand or tripod. This is general with all French and German instruments;

even with theodolites and surveying levels, it being the rule that the top of the tripod should form a kind of table upon which the instrument is set up. The table is almost uniformly made of wood, and is somewhat bulky and clumsy in construction, therefore not very well adapted to mining surveying, particularly in wet mines. Neither is the tribrach system of adjustment very well adapted for mines unless it is supplemented by some form of ball and socket arrangement or with adjustable stand. This subject will be further discussed in description of superior instruments presently.

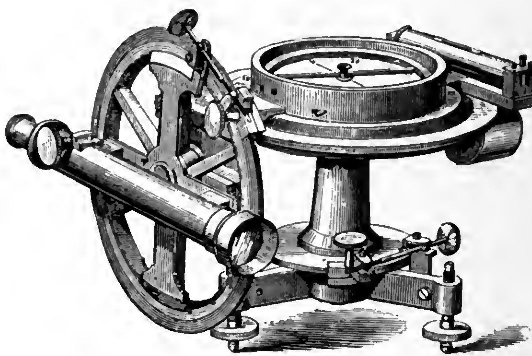


FIG. 170.—*Miner's transit survey instrument.*

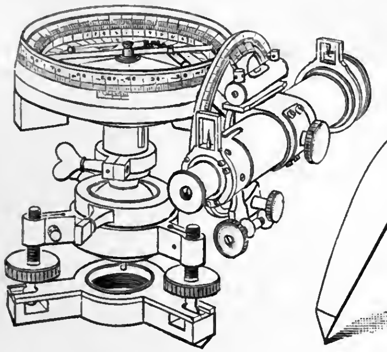
435.—**Miner's Transit Instrument.**—This is the *théodolite souterrain* of the French, and is of a construction very general throughout the Continent—Fig. 170. The compass is placed clearly in view. The vertical axis has a clamp and tangent motion to bring the compass to exact bearing if desired, or to permit surveying with the compass only. The axis has also a clamp and tangent to the exterior divided circles, which reads with two verniers. The telescope is placed on the side of the instrument, and has clamp and tangent motions to read the vertical circle which the vernier traverses in transit.

All the divisions are made strong to be read clearly by lamp light, either to 1′ or 3′ by the vernier, as desired. A second level is generally placed on some part of this instrument at right angles to the one shown. The instrument is balanced by a counterpoise weight to keep its vertical axis in equilibrium. The height of an instrument with 5-inch needle is about $6\frac{1}{4}$ inches; the weight without the tripod table is about 14 lbs. The tripod table is constructed in various ways by different makers.

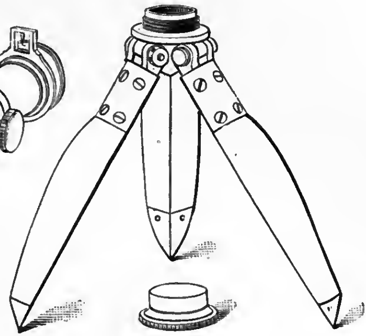
436.—The value of the transit principle applied to mining instruments, for taking back and fore sights for hanging lines in undulating strata, by simply turning the telescope over on its axis, cannot be overrated for exact work such as the telescope alone can perform. Further, with this construction the inclination and difference of hypotenuse and base for correction of the chain measurements may be taken. But it is important in the use of this instrument to observe the side upon which the telescope is situated at the time of observation, *right* or *left*. For this a column should be placed in the field-book. As a rule fore sights are taken with the telescope *left;* back sights, with the telescope *right*, remembering that in plotting all angles are taken eccentric from the axis of the instrument, that is, tangential to a small circle which represents the eccentricity of the telescope according to the scale used in plotting.

437.—*The Tripod Table* of a superior class of Continental instruments, whether this is used for surface or mining surveying, is usually made with some form of adjustment to bring the upper surface approximately level before setting up the instrument. In this case the table is made a combination of wood and metal; and the only difference between mine and surface plane tables is that in the former case there is a jointed arrangement for shortening the legs, in the latter there is not. The table surface for superior work is generally adjusted to approximate level either by a ball and socket joint or by a pair of knee joints placed at right angles to each other, with clamps to hold it firmly when it is adjusted. Radial V-grooves are commonly made for the points of the tribrach, and a hole is sometimes made in the centre of the table for suspension of a plummet from the axis of the instrument. There are many forms of tripod tables in use, a modified form of one of which in metal will be described further on in the chapter on plane tables. There are certain merits in this table arrangement over connective stands, as the table is convenient to set up fairly level, and the instrument need not be exposed until the operation is complete. On the other hand there is more risk of upsetting and injuring the instrument by accident when loosely placed on the table. There are, however, schemes to prevent this more or less complicated, as by a screw fixed in the tripod head acting against a spring which draws the instrument constantly down when attached, and other contrivances, none of which are perhaps equal in simplicity to Everest's arrangement for the tribrach Fig. 139 on this particular point.

438.—**Improved Mining Survey Transit.**—The author has modified the form of instrument last illustrated, retaining the general principles. In Fig. 171 the compass is made larger and reads in the inside of the step as well as upon the surface, which is the only way in many cases that it can be read in a close working. The reading of the horizontal circle is placed nearly vertical, so that it may be seen clearly when the instrument is near the roof of the mine. The vertical circle is made smaller than the horizontal, as this circle, although it is, as a rule, of less importance, can generally be read more exactly, from its convenient position. This arrangement also permits greater freedom for use of the tribrach. The telescope is made with a much larger object-glass than is usual, so as to take a wide field of view.



171



171A

FIG. 171.—*Stanley's improved mining survey transit.* FIG. 171A.—*Stand for the same.*

Two pairs of sights are placed upon the telescope, either for roughly sighting an object or station, or to be used in difficult positions. These are made on a new principle, shown Fig. 172. The sights are placed in two windows, each of which is formed of a needle point of platino-iridium. In sighting, the points are brought

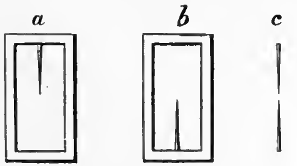


FIG. 172.—*Stanley's miner's dial sight.*

over each other, the distant lamp or object appearing between them. A sharp point gives much clearer definition than a hair, as it subtends of itself no angle to the axis of the eye. *a b* represent the pair of sights,

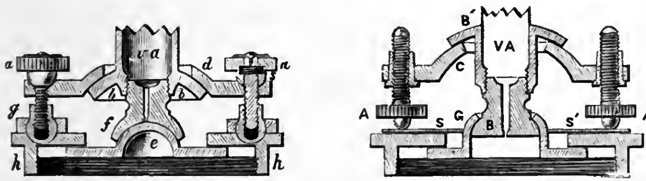
c as they appear superimposed. This instrument is very conveniently fitted with subtense points in the telescope, by which distances may be taken without actual measurement with the author's staff Fig. 88, for the particulars of which see next chapter. The subtense points are arranged to measure the staff either vertically or horizontally. As a rule it will be found with this instrument better to take rough positions first with the points, and afterwards by the telescope. The height of the instrument is 6 inches; weight, 13 lbs.

439.—Fig. 171A is an ordinary tripod, like that used with a level. This is preferred by many mining engineers as being firmer than any jointed arrangement, and is sufficient for working in a seam of fairly equal thickness. The legs vary from 9 inches to the full height, 5 feet 4 inches. An ordinary set of three tripods would be 2 feet, 3 feet 6 inches, and 5 feet 4 inches.

440.—**Pastorelli's and Hoffmann's Ball and Socket Arrangements.**—By these arrangements the ball and socket is clamped by the same adjusting screws that bring the instrument to final position. In Pastorelli's arrangement* the socket is drawn down upon the ball by the adjusting screws. In Hoffmann's arrangement† the ball is pressed up towards the socket. Messrs. Davis & Sons, of Derby, have carried out Hoffmann's arrangement very successfully. The two arrangements are mechanically equivalent in either case. When the screws are lightly clamped, the ball can be moved with moderate force, or even quite loosely by careful adjustment; and in either case, when the ball is once set, care must be taken to keep pressure constantly upon it during the final adjustment by the screws. The general arrangements are shown in two figures, 173, 174, which are taken from the drawings of the respective patents.

*Pastorelli's patent, No. 2714, 1863.
†Hoffmann's patent, No. 2084, 1878.

In Fig. 173, *va*, the axis of the instrument terminates in a ball *e* which works in a cup *f*. The axis has also a portion of a ball of greater radius *b* concentric with the lower ball *e*. The upper parallel plate *d* is cupped over this ball. When the parallel plate is moderately free on *b*, the axis *va* may be set to any angle within the range of the central opening of *d;* and as the friction upon *bd* is greater than that upon *fe*, the axis moves by the adjustment of the parallel plate screws *aa*. In Fig. 174 the action is precisely the same, except that the pressure is upwards instead of downwards. In Fig. 173 there are springs *s* under the parallel plate



173 174

FIG. 173.—*Pastorelli's ball and socket adjustment.*
FIG. 174.—*Hoffmann's ball and socket adjustment.*

screw heads to keep contact when the screws are loosened. In Fig. 174 the spring is a plate under the screws *s*, the action being the same in both cases.

Some objections have been made to this class of arrangement, over the simpler one of clamping the ball independently and then adjusting by the screws, as being more complex. On the other hand this compound arrangement has the merit in underground instruments of being lower and more compact. From the author's experience he prefers Pastorelli's arrangement to Hoffmann's as being smoother working.

441.—**Doering's Setting-up Adjustment.**—In this arrangement the axis is mounted on a gimbal with arcs concentric to the axes. The arcs may either move by clamp and tangent arrangement, or be racked on their edges so as to move with pinions and large milled heads. One or both the arcs may be divided. In Fig. 175* one pair of axes are shown B B, the arc of which is moved by the pinion, not shown, connected with the milled head D. The other axes and arc are transverse to this. This plan permits of a larger angle of adjustment than any other. The defects are that it elevates the instrument too much and is a little complicated to

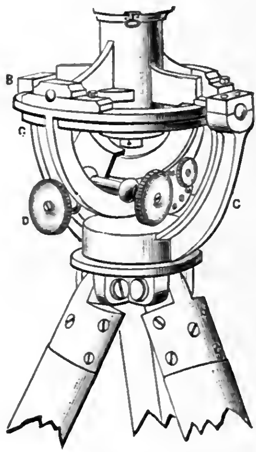


FIG. 175.—*Doering's adjustment.*

make and somewhat heavy. It is discussed here as being quite a speciality which may be well adapted to a certain class of work.

442.—*Mining Survey Transit Theodolites* have been sufficiently described arts. 301 to 321, and they have very limited use for ordinary mining work, but are efficient for working in thick seams or for stone and marble quarrying where there is good opportunity for lighting and plenty of head room. The general employment

*Patent No. 2987, November, 1864.

is, however, restricted almost entirely to tunnelling in railway workings in combination with surface work. The defects of the ordinary form of theodolite under conversion into a mining survey instrument is its inconvenient height, great weight, general delicacy, fine division, and insufficiency of adjustment of vertical axis. Therefore it does not fulfil the special conditions required (2, 3, 4 of art. 399). The height of a 5-inch mining theodolite above the tripod head is 13 inches to the centre of the telescope; weight, 12 lbs.: a 6-inch height, 15½ inches; weight, 16½ lbs.

443.—The author some years ago made an attempt at converting the theodolite into a generally useful mining survey instrument—into an instrument he termed a *geodolite*. Very few of these instruments were made and sold: they had defects which rendered them suitable for special work only, which the theodolite will perform equally well; therefore no description will be given.

444.—**Prismatic Mining Survey Compass.**—This arrangement is designed by the author for very close workings. The entire depth of the instrument being only 4 inches, any reading may be taken with the instrument from one point of view simultaneously with the observation. The 5-inch compass Fig. 176 has a floating ring divided to half degrees, and the reading of this is reflected through a prism so that it appears directly under the fore sight, to be seen at the same time. The prism has a slight magnifying power, so that by estimation a bearing may be easily taken to ¼ degree or nearer. The principle of the compass is described art. 116, the prism art. 126; but in this case the prism is raised and has a second lens under it, so that it forms a kind of prismatic Ramsden eye-piece. This elevation of the prism permits sighting under a certain amount of downward inclination, regulated by the height of the prism and the length of the back sight, as well as the upward inclination which is common to the use of the prismatic compasses. The most important feature in this compass is the mode of lighting, which is effected by means of a large prism Fig. 177 *R* placed under the compass-box in a square tube, and a small movable lamp to throw light into it Fig. 176 *L*. The floating ring Fig. 177 *C* is made of celuloid quite transparent, so that the divisions upon it are clearly read through the small window in the cover

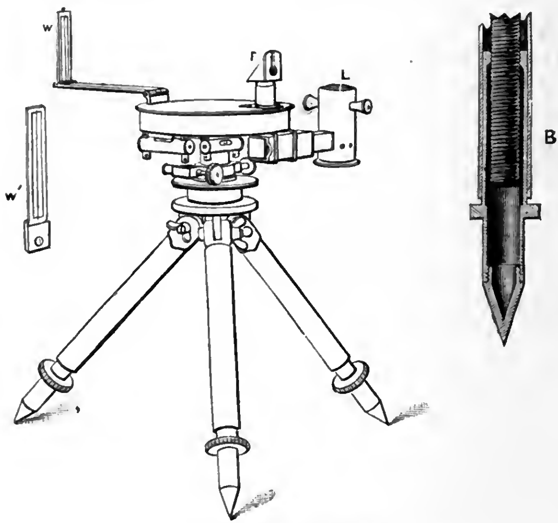


FIG. 176.—*Stanley's patent prismatic mining compass.*

of the compass-box. The fore sight *W* is jointed in two folds *j j*, so that it extends the distance of sights to about 10 inches apart in use and yet folds away closely to the compass for portability when out of use. On the near sight a cut is made transversely to the slit. A second similar cut on the fore sight is made level with this, to take levels roughly. About 20° are set off on each side of the cut on the fore sight, so that angles of altitude may be approximately taken—although the instrument is not well adapted to this. The cover of the compass-box, which is permanently fixed, carries two levels set at right angles to each other, to be used in setting up the instrument; these are omitted in the engraving. Weight of instrument, $4\frac{1}{4}$ lbs.; tripod stand, 9 lbs.

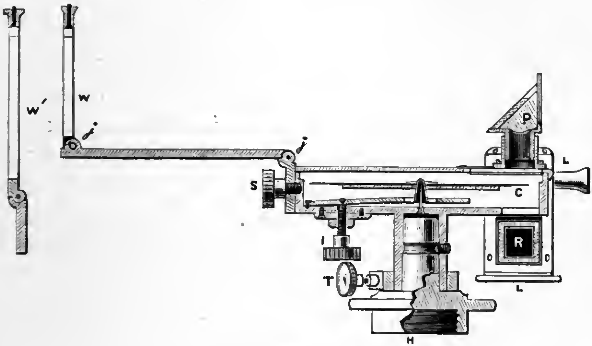


FIG. 177.—*Section of prismatic mining compass.*

445.—**Tripod Stand for Shallow Workings,** shown in Fig. 176, which was designed for the above-described instrument by the author, is arranged so that it may be brought down very low, so that the whole instrument with its tripod may work in about 15 inches of height, the stand alone when extended being only about 10 inches. This dimension may be varied more or less to demand, to suit the work it has to perform. The legs of the tripod are attached on the American plan, art. 211, and have of themselves a certain amount of firmness at the jointing. The adjustment to level the compass-box is effected by screws placed longitudinally up the legs. These screws work in tubes, as shown in section *B*. They are moved outwards or inwards to lengthen or shorten the legs by means of large milled heads. The point of the leg is made of very hard gun-metal capable of biting upon any moderately soft stone. The covering tubes of the screws are arranged to keep the joint water-tight, and at the same time to keep the toe of the leg firm. This tripod may be adapted to any of the before-mentioned dials although it was especially made for that just described.

446.—**Hanging Compass.**—A very general method of underground surveying in mineral districts upon the Continent is by means of the *hanging compass;* this instrument is therefore generally found in catalogues of surveying instruments in France, Germany, and Italy. The original hanging compass was invented by Balthasar Rössler about 1660.* It appears to the author to be a valuable instrument for surveying in tortuous mineral veins where sighting is difficult. The measuring line upon which it is used is either a hempen or copper cord or a chain. The compass is hung upon the cord or chain, which may be stretched to any point out of sight, and the compass will then indicate the bearing of the line. In Germany two instruments are used simultaneously—the hanging compass for taking the bearing, and a clinometer composed of a light brass semicircle graduated to degrees with a small plummet for taking inclination Fig. 179.

447.—**Hanging Dial.**—Fig. 178 represents a modification of the hanging compass designed by the author, by which inclination may be taken simultaneously with bearing, if the dial can be suspended near the centre of the line or chain where the catenary curve is parallel with its points of support.

448.—In the construction of the instrument a circle of brass about 6 inches diameter, ½ inch wide, and ⅛ inch thick, has two arms extended to 12 inches at the upper part, on the end of each of which a hook is formed for hanging the instrument upon a cord or chain. Upon

* "*Geometria Subterranea,*" Voitel, 1686.

the lower part of the circle a *fork-piece*, with a bearing clipping the circle, is attached with two screws. The fork-piece is constructed to support two axes concentric to the vertical circle in which the compass-box is suspended much above its centre of gravity, so that it

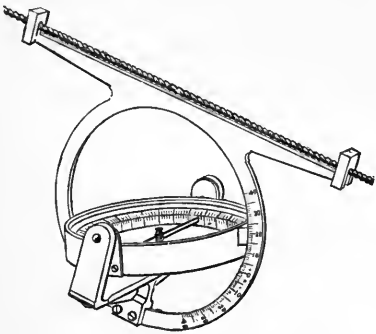


FIG. 178.—*Stanley's hanging dial.*

falls by its own weight in use to a level position. Upon the edge of the compass-box an index is brought up nearly to the interior surface of the vertical circle, which reads into graduations upon this circle into degrees and half degrees.

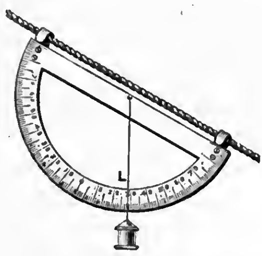


FIG. 179.—*Hanging clinometer.*

449.—**A Light Hanging Clinometer,** Fig. 179, is the same as used in Germany, of 5 inches diameter, graduated to degrees, made of thin brass, is packed in the cases with the above-described instrument. The ends of the semicircle are formed into hooks for hanging on the line. The plummet has a horse-hair line which cuts the degrees. The clinometer is used only when the hanging dial Fig. 178 cannot be suspended near the centre of the line, in which case this light semicircle will cause less deflection of the line and give the inclination approximately. For further details of the use of the hanging compass the author refers the reader to Mr. B. H. Brough's admirable work on "Mine Surveying."

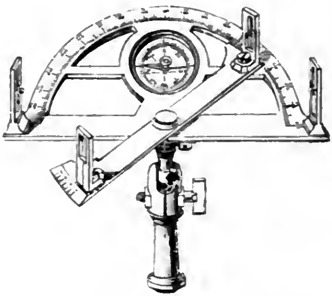


FIG. 180.—*French semi-circumferenter.*

FIG. 181.—*Tripod head.*

450.—**Semi-circumferenter.**—This simple instrument can scarcely be enumerated with mining surveying instruments, as it is much more used for surface work; but as it is of the class of circumferenters to which miners' instruments generally belong, this is the most convenient place for its description. It has very general use on the Continent. Its construction is very simple Fig. 180. It is supported on a ball and socket joint. The socket is formed in two pieces which are clamped together to hold the ball by a winged-headed screw. One pair of sights are mounted upon the extreme ends of lugs upon the limb. The limb is divided to half degrees. When the ball is loosely clamped the fixed pair of sights may be adjusted to cut any desired object. A second pair of sights are jointed upon an axis to move centrally between the first pair. These are made shorter to pass within the first pair to any angle around the arc, except the small angles with which the sights themselves interfere when they are superimposed. The movable sights carry verniers to read on the limb to 2′. There is a small compass attached to the limb. As a cheap instrument for taking angles approximately it is found very useful, particularly for the use of workmen in carrying out work from drawings plotted from a survey by a better instrument. The weight of the instrument with 6-inch circle is about 2 lbs.; height above tripod, 7 inches.

451.—The tripod of this instrument is made of wood. The head is shown Fig. 181. The legs are simply extensions of the upper parts, which are shown attached with wing-nut screws. The point of each leg has a brass ferrule and a stiff steel peg driven up the end of the wood to prevent it slipping in use. The head is turned to a cone which fits into the socket-piece of the instrument and permits it to be rotated with moderate friction. The head block is made of triangular section that the legs may be clamped firmly to it. Where used for underground work a separate set of short legs is provided, which attach to the head by the same wing nuts.

452.—The old underground station, formed of a lighted candle or lamp, is not now considered good in practice where surface land is exactly defined by boundaries held by legal clauses and rights. The system of underground surveying now very generally followed is that first recommended by Mr. Thomas Baker, C.E., and afterwards fully developed by Mr. H. Mackworth,* by which a station taken for angular directions is formed

* "Subterranean Surveying," by Thomas Fenwick Lockwood, 1888, page 44.

by the position of the centre of a tripod. For this system three tripods are provided to each instrument, with head adjustment complete. These are made in such a manner that the instrument can be placed on either tripod in a level position. Two lamps are provided, the flame of either of which will take the position of the vertical axis of the instrument when the lamp is placed upon the tripod formerly occupied by it. It is easily seen that by this system fore and back sights or angular positions can be extended with all the accuracy that the uniformity of the flame of the lamp will permit.

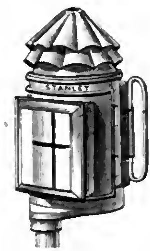


FIG. 182.—*Mining survey lamp.*

453.—**Mining Survey Lamp.**—The author constructed this lamp from an idea given to him by Mr. Geo. Kilgour. It is somewhat different from the ordinary form. Its accuracy does not depend upon the regularity of the flame. A vertical axis is formed under the lamp, which is made to fit the same fitting on which the mining survey instrument is placed. The lamp is placed entirely eccentric to the vertical axis in such a manner that a vertical line formed by a wire upon its face may stand central and lineal with the axis. A cross line is also placed at the same height above the tripod head as the centre of the axis of the telescope or cross sight. By this means, although the lamp throws its light broadly in one direction only, the cross is a perfectly defined object, easily picked up and brought to exact bearing to the instrument when placed upon another tripod. In converting this lamp from a fore to a back sight it has simply to be turned half round on its axis, which is done without any displacement of the relative position of the cross in vertical or horizontal directions. Where this lamp is required in mines liable to fire-damp, it is made on the safety principle of the Davy lamp.

Electrical Station Lamp.—Electricity has been applied to lamps for surveying, but the system has not heretofore, so far as the author can ascertain, proved satisfactory.

CHAPTER IX.

INSTRUMENTS TO MEASURE SUBTENSE OR TANGENTIAL ANGLES TO ASCERTAIN DISTANCES—HISTORICAL NOTES OF THE METHOD—PRINCIPLES INVOLVED—STADIA MEASUREMENTS, DIRECT AND BY THE ORDINARY TELESCOPE—CORRECTIONS FOR REFRACTION OF THE OBJECT-GLASS—ANALLATIC TELESCOPE OF PORRO—THE CLEPS—TACHEOMETERS — STADIA — FIELD - BOOK — WAGNER - FENNEL TACHEOMETER—CO-ORDINATE PROTRACTOR—OMNIMETER—FIELD-BOOK—BAKEWELL'S SUBTENSE ARRANGEMENT.

454.—**Direct Subtense Measurement of Distances** *by an Instrument* depends upon our powers of measuring the image of a distant staff or stadia, or the divisions marked thereon as they appear at the focus of the telescope. If the stadia is placed at right angles to the direction of one of two sight lines which subtend a given angle, the number of units divided upon the stadia cut by these lines will be proportional to units of length of base or cotangent for a constant focus of the telescope; so that if we can measure at a fixed angle the number of equal units of measurement of a stadia correctly, we can obtain its exact distance; and whether this method is more or less exact than chain measurement will depend entirely upon the perfection with which either of these operations may be practically performed.

455.—*The Origin of the Invention of Subtense Surveying* is due to Wm. Green, an optician of Great Moulton Street, London, who published a pamphlet giving a description of his method in 1778.* This subject he pressed upon the notice of professional men at the time, and his

* "Description and Use of an Improved Reflecting and Refracting Telescope and Scales for Surveying," by William Green, 1778.

method has continued in limited use in this country ever since. His refracting telescope, which alone has remained in use, formed part of a theodolite. A micrometer was placed in the focus of the eye-piece of the telescope, which revolved a quarter turn in its axis to read angles vertically or horizontally. He constructed his micrometer with lines fixed at a given distance apart, and by a second method with the lines adjustable. For this adjustment a fine line was ruled upon one side of two pieces of glass. The ruled sides were placed face to face, so as to be at the same focus. One of the lines was adjustable by a micrometer screw. His staff was 20 links in length by 4 inches in width, divided decimally into 1000. His description of the manner of using his instrument will give a general idea of working the various instruments which may have been derived from it—tacheometers, omnimeters, etc.—and this is worthy of note, as the invention is not generally attributed to him:—

"To find the contents of a field with either of the instruments described, let the telescope be placed so that the observer may see all its angles from his station. If near the centre of the field the better. The person who carries the scale *(staff)* is to go all round the field, stopping at every angle, and to place the scale at right angles to the axis of the telescope *(passing)* from corner to corner (from right to left if required) with the help of a signal by the observer. After the distances all round the field are taken *(by measurement of the image of the micrometer)* and all the angles included betwixt them, with the theodolite, plot it out in the usual manner, *e.g.*, with a nonius protractor. Describe a circle, and on this circle set off all the angles from the centre through each point upon the circumference. Set off the length of every line by a scale of equal parts. These points will give the limits of the field, which may be laid out in trapeziums, triangles, etc., and measured from the same scale of equal parts. The surveyor will comprehend how easily the contents of the field are found by trigonometrical calculation, since by this method there are two sides and one included angle given."

"The common method of measuring with the chain, besides the inaccuracies to which it is liable, does only give the length of the surface of the ground between two objects, and therefore not its proper distance unless the surface be straight and no object to hinder its being measured from one end to the other. How often this is practicable I leave to the consideration of those who are most accustomed to measure lines, and doubt not that upon the whole they will find the telescopic method has besides ease, accuracy, and universality, necessity itself to recommend it."

He points out the utility of the system for levelling, as "both distance and inclination may be taken at the same time." He finds by experiment that the accuracy of the method exceeds what he could reasonably expect from calculations deduced from theory, from several circumstances in its favour being inseparable from it.

"The observer's station is the centre of circle whose radius is the distance required, which is obtained by measuring the length, that is, the tangent or subtense, of the small arcs whose limits are defined by viewing their image in the focus of a telescope between two points there placed, and moving them up and down until they appear to touch the very extremities of said limits exactly. The manner of seeing is natural and by practice will become habitual, and therefore continually approach nearer to perfection."

"Thus may any surveyor in less than two hours take all the dimensions of an irregular polygon necessary for obtaining its area, if it be as much as 80 or 100 acres and limited by twenty or thirty unequal sides."

Green points out that if the subtense angle is taken horizontally, atmospheric refraction error is eliminated. He proposes to use both reflecting and refracting telescopes. With the reflector he possibly obtained accurate results, but with the refracting telescope he does not appear to have recognized a constant correction which is necessary and important.

456.—**Subtense Instruments**, as that originally made by Green, are of some form of theodolite, the telescopes of which are constructed to measure either the angle subtended by the chord of a small arc or the tangent of the same. For convenience the tangent is more generally taken upon a graduated stadia or staff which is erected for measurement perpendicularly to the horizon, the principle of which is shown in the following scheme.

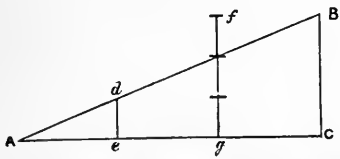


FIG. 183.—*Diagram of tangential angle measurement.*

Let $A\,C$ be a horizontal line; $B\,C$ a stadia is set up vertically. Then if the angle $B\,A\,C$ and the height $B\,C$ are known, the distance $A\,C$ is known. For any intermediate distance between A and C a vertical will be in length proportional to this distance. Let $d\,e$ be at one-third the distance from A; then the line $d\,e$ will be one-third the length of $B\,C$. If we divide $B\,C$ into three parts and place the stadia at $f\,g$ two-thirds the distance from A, the angle $d\,A\,e$ given by an instrument subtending a fixed angle will cut the staff at the second division, equal to two-thirds the staff, which demonstrates the principle of tacheometers, cleps, etc., to be described.

If the tangent be made a *constant* equal to the length of the stadia BC, and this stadia be placed at another position, say de or fg; then the angle subtended by its entire length will vary in a manner that can only be estimated by trigonometrical calculation.

In case of reading two distant marks on the stadia only for the subtense, the single central web of the telescope being directed first to one and then to the other of these webs, the distance is calculated out as follows.

457.—Given the tangent BC and the angle BAC, required the distance AC. Let the angle BAC be represented by D; then—

$$\frac{CA}{CB} = \text{cotan } D, \text{ or } CA = CB \times \text{cotan } D.$$

Reducing by logarithms, we have—

$$\log CA = \log CB + L \text{ cotan } D - 10$$

For example, make CB 14 feet, and the angle D 2°, 45′, 50″, thus:—

$$\begin{aligned} \log CB &= 1{\cdot}146128 \\ L \text{ cotan } D - 10 &= \underline{1{\cdot}316265} \\ \log CA &= 2{\cdot}462393, \text{ or } CA = 290 \text{ feet.} \end{aligned}$$

The above gives the principles followed with instruments of the theodolite class simply; but arrangements are made in omnimeters and similar instruments to read the tangent directly and determine the height CB in equal parts, so that observation of the heights BC gives rectangular co-ordinates which save reduction from degrees of arc.

In practice the staff or stadia is made of the greatest length convenient for portability. With a telescopic staff, 14 or 16 feet is commonly used. If a unit tangent is not employed, the foot is divided into 100 parts, each of which parts, with the tacheometer, represents 1 link or 1 foot of the base, and the whole staff 14 or 16 chains, or 1400 or 1600 feet. The ordinary Sopwith staff art. 218 answers the purpose.

458.—*Measuring Distances by the Ordinary Telescope by Measurement of its Focal Image.*—When we apply a refracting telescope to measure a subtense angle by webs fixed in the diaphragm, vision is not direct, as in the scheme Fig. 183, but subject to bending caused by the refractive quality of the lens art. 46, the telescopic focus varying with the distance from the staff. Thus with a 12-inch telescope there will be a difference of about ·25 inch in the focus, whether the staff is held at 50 or 500 links from the telescope; and this difference of focus is equal to a difference of base or cotangent between the points A and C in the last figure, so that these distances do not remain proportional to the fixed unit of the tangent or stadia. It is important to go carefully into this subject of the use of subtense webs in the ordinary telescope, as the necessary correction does not appear to have been recognized by English writers on instruments, and no doubt this is the principal reason that subtense measurement has not been more practised in this country.

459.—At the commencement of the century, Riechenbach, a Bavarian engineer, pointed out a method still in use on the Continent. The author is indebted to the kindness of Lord Rayleigh for the following demonstration of Riechenbach's formula:—

FIG. 184.—*Subtense diagram.*

Let $AB = s$, $ab = i$, $OA = d$, $Ob = r$. O is the optical centre of the object-glass; ab a pair of webs at variable distance r from O according to telescopic focus; f focus for parallel rays. Then by similar triangles $\frac{s}{d} = \frac{i}{r}$

or $d = \frac{r\,s}{i}$, r is found by optical laws to vary in the proportion of $\frac{1}{r} + \frac{1}{d} = \frac{1}{f}$. We may therefore eliminate the variable r by substituting its value $r = \frac{f\,d}{d-f}$, by which we find $d = \frac{sf}{i} + f$, which gives the true correction; and the distance from the axis of the instrument will be $d = \frac{sf}{i} + f + c$ when c is the constant distance of the object-glass from the axis of the instrument. It is usual to place the vertical axis of a theodolite central between the object-glass and the diaphragm at solar focus, so that the constant c becomes $\frac{f}{2}$.

460.—It is seen that $\frac{sf}{i}$ represents the direct subtense, whereas the refraction, which is a constant, gives f and the position of the object-glass $\frac{2}{f}$. Riechenbach's formula being true for parallel rays is evidently also true for any subtense with refraction for the staff at any distance. We may therefore adopt a plus constant of $1\frac{1}{2}f$, which added to the apparent subtense is found to produce no error. Thus with a telescope of 1 foot solar focus and using the decimal system of notation, as before mentioned, if a stadia or distinct scale be placed at $301\frac{1}{2}$ feet distance from the centre of the instrument, and the webs on points of the diaphragm be adjusted to read 3 feet = 300 divisions, every subtense may be taken as number of divisions + $1\frac{1}{2}$ feet for distance in feet. If the subtense is to be taken in links or metres the adjustment of the webs or points will be to these measures, but the constant remains the same $1\frac{1}{2}f$ always.

461.—When the line of sight is inclined to the horizon and the stadia is held erect—a convenient method commonly followed upon the Continent—the reading becomes in excess of the true reading, in the ratio of the cosine of the angle of the stadia, represented by a line tangent to the sight-line subtended to the foot of the stadia, as shown in the following diagram.

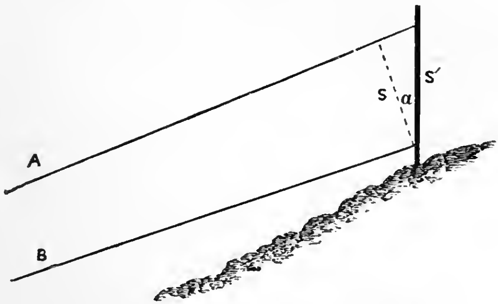


FIG. 185.—*Diagram of vertical stadia on incline.*

Thus Fig. 185 let the portion cut by the lines A B, S' be the reading of the stadia; then

$$S' \cos a = S.$$

The inclined distance is then equal to

$$\frac{f}{i} S' \cos a + f + c,$$

and the horizontal projection of that distance or

$$a = \left(\frac{f}{i} S' \cos a + f + c\right) \cos a;$$

or as $f + c$ is small and the angle generally small, also $f + c$ may be taken equal to $(f + c) \cos a$. Then

$$a = \frac{f}{i} S' \cos^2 a + f + c.$$

462.—**The Anallatic Telescope.**—In this telescope the focus is constant, and consequently the tangential measurements indicated by the numerical quantities subtended by a constant angle are directly proportional to the base, so that there is no constant to be added. The invention of this instrument and its modern application to subtense measurement was due to Professor J. Porro, of Milan, who put it to practical test in 1823,* in an instrument termed a tacheometer. The telescope will be best understood by the following details:—

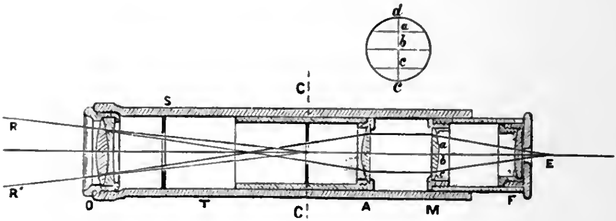


FIG. 186.—*Diagram of anallatic telescope.*

463.—The object-glass O Fig. 186 is made of a focus that falls well in front of the axis of the instrument $C\,C'$, so that the rays cross before falling upon the anallatic lens A, the optical arrangement being such that if the rays fell direct without any refraction they would reach the axis and subtend angles therefrom inversely proportional to the distance of the stadia. The object-glass and the anallatic lens are of the same focus, so that the rays after crossing from equal refraction may emerge parallel in the space A to M. The stops at $S\,S'$ and at the axis $C\,C'$ cut off eccentric rays that would otherwise give internal reflections from the telescope tube. The eye-piece, represented by MF, may be made to pick up the image of the stadia in front of it upon an ordinary webbed diaphragm or upon ruled glass; but in some modern instruments the better plan is adopted of having these lines engraved upon the field glass of the eye-piece M. In this case it is necessary that the

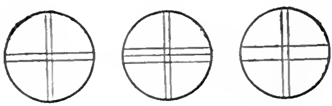
* "*La Tachéometrie, ou l'Art de Lever les Plans et de Faire les Nivellements.*" Paris, 1858.

pair of lenses forming the eye-piece should adjust to distance to suit the differences of natural vision. For this purpose a screw is placed at *F*. The diaphragm webs are fixed, or the glass surface engraved with three or five horizontal lines and one vertical. The outer horizontal lines are used generally as the subtense lines, and the central line for levelling and taking altitudes. The vertical line is used for triangulating on the surface of the ground.

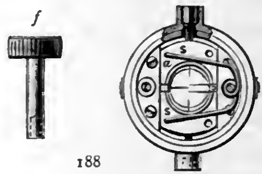
There is an adjustment made by sliding tubes to bring the object-glass and anallatic lens within mutual focus to ensure the parallelism of the emergent rays and to adjust magnification. This is commonly effected by means of a rack and pinion, moved by a separate key kept in the instrument case, but which is not necessary to be touched after the instrument is once adjusted by the maker, except in the case of accident. The eye-piece adjusts to distance from the object-glass in the ordinary manner of the surveying telescope—by rack and pinion.

The eye-piece of the anallatic telescope is generally made of much higher power than those ordinarily employed for levels and theodolites—25 to 30 diameters is usual. Where a diaphragm is used the subtense lines are commonly placed on a slip of glass in two or three sets, so that greater magnitude of image may be taken for objects at distances of from 2 chains to 7 chains with the 14-feet staff, or that the staff may be read at greater distances than 14 chains. This series of lines are distinguished as 50, 100, and 200, Fig. 187 A B C. In the 50 two divisions of the staff read for the unit, in the 200 half a division; so that with this as great a distance as 28 chains on a 14-feet staff may be estimated, but this is beyond the safe power of the instrument. An intermediate line, as shown Fig. 187B, is valuable in all cases for levelling.

464.—Where the civil engineer is satisfied with a single percentage pair of subtense lines the author much prefers using the needle point system, arts. 201, 202. In this case the diaphragm, as made by the author, possesses two systems of adjustment; that shown Fig. 188 at *a* for the single point for altitudes, and the pair of points separated by the spring *s s* for subtense angles. These points adjust by separate screws top and bottom with a large milled-headed key *f*. The two verticals are fixed permanently. These points are all made of platino-iridium, which possesses the hardness and elasticity of spring steel, which is at the same time, as far as is known, perfectly non-corrosive. In case of any light dust or



187A 187B 187C



188

FIGS. 187A, 187B, 187C.—*Subtense lines ruled on field-glass of eye-piece.*
FIG. 188.—*Adjustable point diaphragm with stadia points.*

moisture resting upon the points, it is perfectly safe to brush them lightly with a soft camel-hair brush to clean them. Where the 200 factor is required a mean may be taken of two observations above and below the central point. Where 50 is required the vertical points may be adjusted to this.

In adjusting the lines, webs, or points to a given subtense, the anallatic lens may be moved to give more or less angular displacement or magnification of the image. When adjustment is made upon a distant stadia, the subtense of the small arc will vary so little from a tangent to one of its radii that the one or other may be taken without sensible error. The plan originally proposed by Green of placing a sight tube through the stadia at right angles to its face, as a means of keeping it in the chord of the arc, is as good as any other plan. The vertical stadia is, however, generally preferred; and this may be set up by the small level, Fig. 93, page 155.

465.—It is well to note that with the anallatic telescope the closeness of the stadia to the staff must not be so near that the rays from the object-glass *do not cross* in front of the anallatic lens or the subtense will appear much increased, so that there is a fixed nearness at which this form of telescope can be used, say 50 feet. For this reason American engineers prefer an ordinary telescope, making use of the addition of a constant. The author also prefers the plain telescope, as being more correct according to his experiments where the constant is correctly allowed. The ordinary telescope possesses the important advantage that there is not an extra inner glass to be kept clean with difficulty, which glass also decidedly decreases the light received by the eye-piece. Where the anallatic telescope is used it is customary to use a much larger telescope and of higher power, and this is in all cases of great advantage in subtense measurement with any telescope. The tacheometer the author has lately made has a plain open telescope, but this is of the same size and power as that used upon the Porro system, and consequently it gives more light.

466.—**Tacheometers** consist essentially of some form of theodolite possessing generally the anallatic telescope of Porro. The graduation of the arcs and circles of these instruments is now almost uniformly made upon the centesimal system, the circle reading 400 grades, which are subdivided to half grades to read with the vernier or micrometer to centigrade minutes of ·01 grade. The centesimal system greatly facilitates calculation, and permits a free use of a logarithmic slide rule of a special kind which is now generally supplied with the instrument. In France, where working with the tacheometer is becoming general, we have very complete centesimal trigonometrical tables adapted to the tacheometer published in stereotype.* The theodolite Fig. 143 the author made specially for a tacheometer, but it is really quite indifferent to what form of theodolite the subtense system is applied; therefore any theodolite will alter into a tacheometer when the centesimal division is not desired, as all calculation may be made on the ordinary sexagesimal system, although with much greater labour. A modern tacheometer should be a high-class theodolite in which every refinement possible is placed. The instruments to be described are those which have secured the greatest popularity in Europe.

467.—**The Cleps.**—This name was given by J. Porro to his tacheometer (1824), which was the first practical instrument applied directly and successfully to geodetic work. The author is indebted to the eminent engineer and manufacturer of instruments of precision, A. Salmoiraghi, successor to Porro of Milan, by correspondence and extract from his pamphlet for the following description.

The leading idea of Porro, beyond the anallatic telescope already described, in his cleps, which is otherwise in principle the same as the theodolite, is that the graduated circles may be made very small if the magnifying power upon them be great; and that if these circles are entirely enclosed when in adjustment, no interference with them afterwards is likely to occur to cause derangement. Figs. 189, 190 represent elevation and cross section of one of these instruments. The anallatic telescope is placed upon one side of a cubic box. This box is fixed centrally upon the top of a column which rests upon a base supported by three adjusting screws. The telescope turns upon a horizontal axis which is placed in the cubic box. The box is supported by a vertical

* "*Tables Trigonométriques Centésimales,*" by J. L. Sanguet. Paris, 1889.

column in two concentric parts so arranged that the exterior column to which the cubic box is fixed turns upon the interior, which acts as a vertical axis. The central column also turns upon an axis projected from the base, all parts moving by clamp and tangent motion. This is similar to the theodolite, only that the corresponding parts are inverted. The graduated circles are

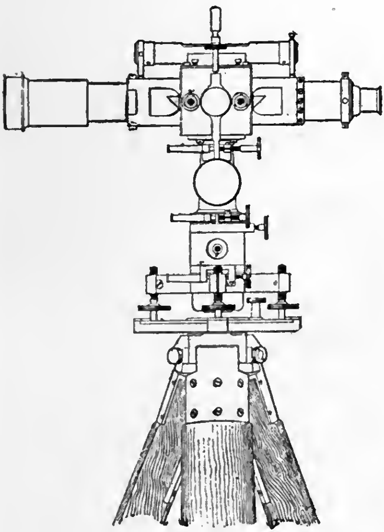


FIG. 189.—*Side elevation of the cleps of Porro.*

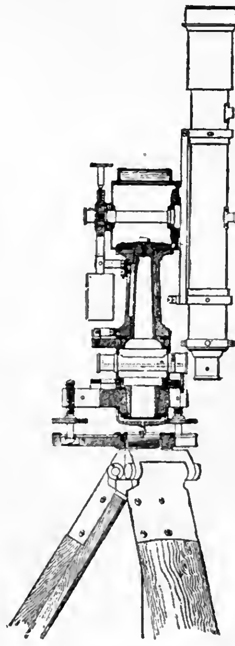


FIG. 190.—*Cross section of the same.*

contained within the cubic box which supports the telescope. The vertical circle is placed upon the axis of the telescope. The horizontal circle is placed upon the top of the inner axis so that it remains in position while the telescopic arrangement with the cubic box turns about it. These circles, which are very small, are read by a micrometer microscope to centesimal minutes by estimation. They are lighted from windows placed conveniently in different parts of the cubic box. A level is generally placed upon the telescope, and a loose level is separately supplied in the case for levelling normal to the vertical axis.

468.—In medium-sized instruments the body of the anallatic telescope is 35 centimetres long, with an object-glass of 4 centimetres. The eye-piece is of the Ramsden type, but of a special construction termed *orthoscopic*, which is designed to give a large field without loss of magnification. The telescope magnifies 30 diameters, and at the same time presents a field in the diaphragm which covers several webs placed at a distance of ·02, ·01, ·005 of the focus apart. It is general with the instrument to take the reading of the stadia at double the centesimal angle and divide this for the mean.

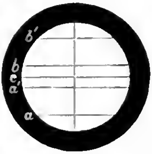


FIG. 191.—*Diaphragm of cleps.*

469.—Fig. 191 represents the diaphragm of telescope with the ordinary cross; the four measuring lines by $a\,a'\,b\,b'$. Using these letters as four corresponding readings upon the stadia, the formula for distance D, with the telescope level and the height H above ground at the point which cuts the central web, will be as follows:—

$$D = 2\,(a - b + a' - b');$$

and by making $a - b = a' - b'$ and $H = 0{\cdot}01\,(a + a' + b + b')$ we obtain D by the formula following:—

$$D = 10\,(a' - b).$$

This formula is not employed except for great distances in which a stadia 4 metres long cannot cut the extreme webs *a b*, or even not more than two *a b* or *a' b*, in which case we may have $D = 4\ (a-b)$ or $4\ (a'-b')$. We may otherwise employ the four webs under normal conditions within 300 metres distance.

With the magnification of 30 before stated, the mean error found is stated to rest within the limits of 0·002 for distances within 250 metres. With large instruments a power as great as 80 has been employed, and the error, it is stated, has been found to have been as low as within ·0005 of the true distance.

470.—Several hundred cleps have been used successfully not only in Italy but in many parts of the world. The instrument was used in the admirable work of the Mont Cenis tunnel. The most important feature of the anallatic telescope has been generally accepted and adapted in France, Germany, and England; but the principles of the construction of the cleps otherwise have not been generally approved out of Italy or imitated in other countries, the open structure of the theodolite being preferred, which lends itself conveniently to adjustment, and the repairs of which from accident are understood by any practical optician. The eccentricity of the telescope in the cleps is also objectionable. This matter of principle, or perhaps of opinion, does not in any way detract from the excellency of the work of Porro and of his successor Salmoiraghi.

464.—The staff used for reading the subtense by the cleps is made of pine of triangular form, of about $2\frac{1}{2}$ inches on each face. The three sides have three systems of gradation—one in very fine lines for near observations; one in equal blacks and whites for moderate distances; and one with metres and decimetres only for great distances, with large figures at the metre marks only.

472.—**Tacheometer.**—This instrument, although manufactured for many years by Messrs. Troughton & Simms for export, has been very little used in this country. The instrument to be described, shown Fig. 192, is the author's latest pattern of this instrument. It is constructed nearly as the theodolite described page 240,

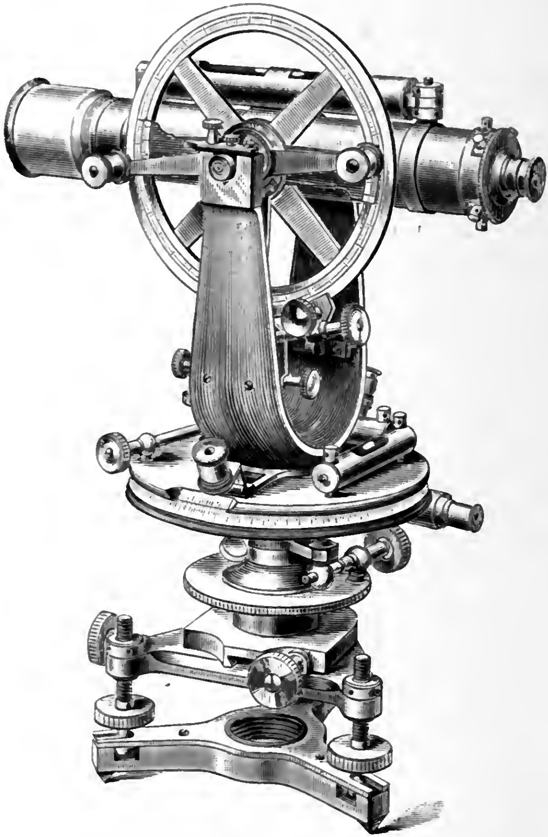


FIG. 192.—*Stanley's 6-inch tacheometer.*

the most important difference being that the divisions are in grades, page 169, which read by the vernier to ·01 or centigrade minutes, and in the telescope being of much larger and of higher power. The compass is of the cylindrical form, page 34, but the needle reads in the eye-piece of a small telescope. This enables the compass reading to be set exactly in the zero reading of the limb by looking alternately through both telescopes at a definite, distant object. The telescope has the adjustable point diaphragm Fig. 188. For a 6-inch instrument the telescope is of 11 inches focus, with an object-glass of $1\frac{3}{4}$ inches aperture. The eye-pieces are of the Ramsden form, page 41, of powers of 18 and 25. The points in the diaphragm are permanently set to cut 100 divisions of the stadia at 100 units + constant of the measurement intended to be taken, links, feet, or metres. This precludes distant measures, say of over 15 chains, where a 16-feet stadia is used. On the other hand it is somewhat doubtful whether the subtense method can be considered as reliable at a distance of over 1500 links; or at anyrate we must assume that much greater accuracy can be obtained by dividing distances greater than this into two by an intermediate station for observation, independently of the additional convenience of having the staff holder within easy distance of communication. This instrument is also made with the anallatic telescope if required, but the author prefers the open telescope as being generally more satisfactory in continuous use, as before stated.

Where points are not used or where lines are preferred, these are better divided upon the outer surface of the field glass of the eye-piece in fine lines as Fig. 187. In this case the glasses of the eye-piece are made adjustable, so as to bring the divided surface in focus to the eye of the observer.

473.—**Stadia.**—Any accurate levelling staff will answer for the stadia, but the ordinary Sopwith Fig. 82 is slightly confusing. A more open reading is generally recommended—that shown Fig. 85 answers perfectly. It is better to read the stadia low, as there is less vibration; but it is not often possible or at any time advisable to read it from the bottom—1 foot up is generally most convenient. Readings are taken and recorded of each subtense, web, or point separately, and the difference of reading subtracted for the subtense of tangent. With a point diaphragm for taking the subtense angle a fair certainty of accuracy of measurement of distance within ·001 may be assured, which is much nearer than can be attained by average chaining, taking six times the labour.

474.—*The General System of Working the Tacheometer*, to be given with sufficient detail for practice, would take too much of our limited space to be given here. We have no works published in Great Britain except the able paper by Mr. Brough before mentioned, and "The Tacheometer: Its Theory and Practice," by Mr. Neil Kennedy.* There is a small work published in New York giving some details.† There are more complete works in French, Italian, German, and Spanish. In French, "*Levés de Plans à la Stadia*," by M. J. Moinot, Engineer to the Paris, Lyons, and Mediterranean Railways, gives very complete instructions for all conditions of country upon surveys, which he has personally carried into practice with this instrument.

475.—**Field-book** for the tacheometer is ruled in various ways upon the Continent in columns, which vary in different books from twelve to twenty columns. In Moinot's we have fourteen columns, giving number of station, time, heights of line of collimation above point levelled, numbers of points selected, horizontal and vertical angles observed, reading of subtense webs and their differences, height of staff by reading central web, and columns for calculations and remarks.

* "Proc. Inst. C.E.," vol. XCIX., part 1, 1890.

† "Manual of the Theory and Practice of Topographical Surveying by Means of the Transit and Stadia," by J. B. Johnson. New York, 1885.

476. — **Wagner-Fennel Tacheometer.** — In this instrument the calculations of the co-ordinates of points above or below the horizon is avoided by these calculations being effected by mechanical contrivances connected with the instrument, so that a part of the ordinary office work is performed in the field.

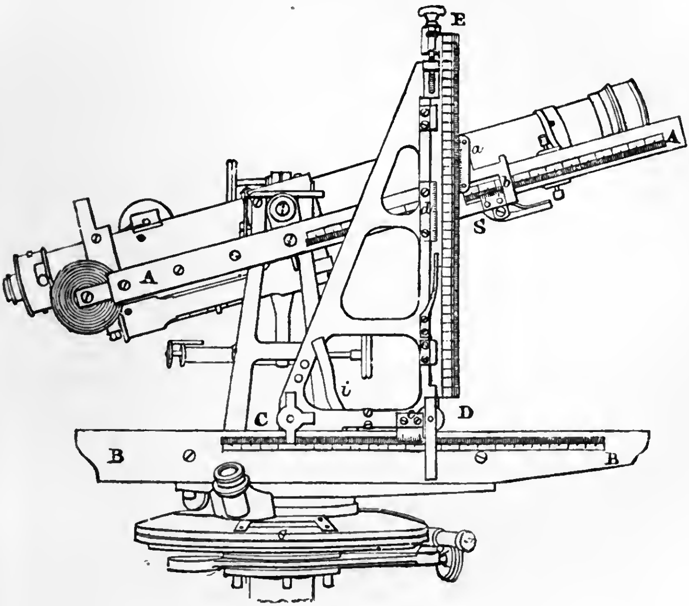


FIG. 193.—*Wagner-Fennel tacheometer.*

In general structure this tacheometer is similar to a theodolite in all that concerns the tripod, horizontal circle, and supports for the telescope, with all clamp and tangent motions connected therewith. The vertical arc of the ordinary theodolite is replaced by a tangent scale of equal parts, which reads into similar scales of base and inclination, thereby giving rectangular co-ordinates directly. This part is the characteristic of the instrument, which is termed its *projection apparatus.*

477.—*The Projection Apparatus.*—Fig. 193 a rule *A A* carrying a scale of equal parts is fixed at its two ends upon arms projecting from the telescope. The edges of this scale are fixed parallel with the axis of the telescope, so as to take its exact inclination in azimuth.

The slider *S* consists of two light frames pivoted together, which slide respectively upon the inclination scale *A A* and the vertical scale *E D*. Each of the frames carries a vernier whose reading edge is radial to the axis of its mutual pivot. The verniers move softly upon the scales by the contact pressure of light springs. By this construction the sliders move in a manner automatically upon elevation and depression of the telescope, so that the verniers are always in contact upon their respective scales.

The scale *B B* is fixed horizontally upon projections from the standards which support the telescope, so that its upper edge cuts a line perpendicular to the vertical axis of the instrument. This scale is adjusted by a spirit level at its back (not seen in the engraving), and is kept uniformly level when the instrument is in use.

The triangular frame *C D E* which supports the vertical or tangential scale *D E* moves upon the base scale *B B* on accurately turned rollers. The amount of displacement of the vertical scale from a line perpendicular to the axis of the instrument, which forms the zero of the base scale, is read off by a vernier. The vertical scale adjusts by the screw at *E* so as to bring its zero coincident with the axis of the instrument. In a 6-inch modern instrument before the author, the telescope is of $12\frac{1}{2}$ inches focus, the object-glass $1\frac{1}{8}$ inches. The scales are divided about 8 inches into 2000. The whole of the screws are of steel. There is no compass. The axis is not illuminated for tunnel work. The whole structure appears to be light, from the careful distribution of the metal; but from the bulk and necessary stability of the projection apparatus the instrument becomes very heavy. The weight of the instrument in its case with the tripod is $58\frac{1}{2}$ lbs. The size of the case, which is of thin wood covered with leather, is 20 by 18 by 10 inches. The stadia used with the instrument is 5 metres long and a decimetre wide.

478.—*Use of the Instrument.*—The setting-up adjustments are the same as in the theodolite—by means of levels fixed upon the vernier plate. The stadia used with the instrument is held in a position perpendicular to the axis of the telescope, in the manner proposed by Green, so as to give the subtense of a small arc represented by the divisions cut by the stadia webs of the telescope. The distance is read off directly by the telescope by the number of divisions cut by the subtense webs. This distance being ascertained, the telescope is then clamped to its position. The distance ascertained is then set off proportionally upon the scale $A\ A$ by moving the triangular frame CDE outwards till the vernier b on this scale cuts the representative quantity measured. The instrument is now ready for reading. The horizontal distance of the stadia is read by the vernier c on the scale $B\ B$, and the altitude from the horizon of the position of the telescope by the vernier a upon the scale $E\ D$. If the telescope is not anallatic the plus constant must be added.

479.—This tacheometer has been successfully used in some public works in Cassel, and a modification of it applied to the plane table (tacheographometer) in the survey for a railway in Roumania, according to the testimonials given to the makers, Messrs. Luckhardt & Alten, of Cassel. The objections found with the instrument by British surveyors are its inconvenient size and great weight, and general delicate structure from the number of loose parts in the projecting apparatus. Taken otherwise it is quite a question whether the co-ordinates are not quite as quickly taken in the office by other means, which saves important day-time work in the field and the uncomfortable work of moving loose pieces of metal by the hand in inclement weather.

With the Wagner-Fennel tacheometer it is seen the stadia is held directly in plane of the arc subtended from the axis of the telescope, which gives a scale uniform for the value of any number of divisions read upon it. With the ordinary tacheometer the stadia is held vertically, and the values of the divisions upon it vary with the obliquity of observation, which is calculated out trigonometrically.

480. — **Co-ordinate Protractor.** — The rectangular co-ordinates of sine and cosine, where the angle and radius are given from the field-book of any tacheometer, may be taken in the office directly by observation by means of the co-ordinate protractor of Voigtel.* This instrument consists of a square board, upon which a radius arm is centred upon one corner so that the arm may traverse the surface. The arm is divided to a scale of equal parts along its radial edge. The board is graduated as a protractor upon the two sides, which brings the 45° near the corner opposite the axis of the arm. The arm can be set to any angle upon the protractor. The entire surface of the board is ruled over with lines drawn to the same scale as the radius arm. One set of these lines are parallel with the edge of the radius arm when this is set to zero; another set are crossed at right angles to this, parallel with the radius arm, at 90°. The numbering of the lines is along the edges of the board where the values of sine and cosine are read off.

* "*Geometria Subterranea,*" by Nicolaus Voigtel, page 127. Eisleben, 1686.

481.—**Brotherhood's Co-ordinate Protractor.**—Mr. R. Brotherhood, C.E., made a convenient modification of this instrument in making the base and vertical two equal scales, instead of ruling the surface of the board entirely over with lines which are somewhat confusing to read. The system is similar to that just described for the scales of the Wagner-Fennel tacheometer described before. Mr. Brotherhood's instrument is made of German silver about 9 inches square.

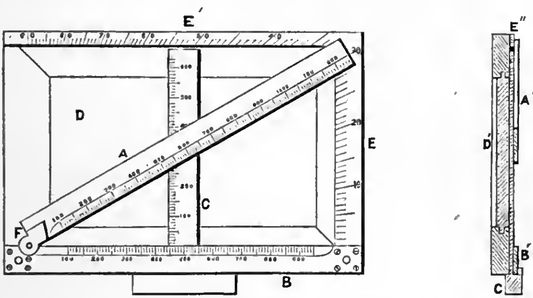


FIG. 194.—*Co-ordinate protractor.*

The author has made this instrument to larger scale and in a cheaper form, which is perhaps better for office use. This is shown in Fig. 194. *D* is a board about 24 inches by 16 inches; *C* is a T-square working upon one edge of the board and the edge of the base scale *B*, which it passes under; *E E'* are raised scales fixed upon the board, of the same thickness as the blade of the square *C*. These are protracted upon the edges *E E'* from the centre upon which the radius bar moves. The radius bar *A* is centred at *F* and has a fiducial edge direct to the radius line. This is divided 50 to the inch, so that 20 inches of it may represent 10 chains subdivided into links, or 1000 feet or metres. The base scale *B* is similarly divided, as is also the T-square, the scale of which has its zero coincident with the zero of the protractor when the radius arm is parallel with the edge of the base scale *B*. The square has a flat plane surface, the divided edge of which reads into the fiducial edge of the radius arm.

482.—*In Using this Instrument*, in calculating from the field-book, the angle of altitude is set out by the radius bar *A* reading into the protracted edge of the board *E E'*. The distance according to the reading of the stadia webs is set out upon the scale of the radius bar *A*. The edge of the T-square *C* is brought up to this reading. The reading of the T-square at the edge of the radius arm then gives the altitude and the position of its edge upon the base scale *B*. The same operation may be performed with the slide rule by taking the sine and cosine, but scarcely in so graphic and direct a manner, to avoid accidental error which may be made from the difference of decimal values, necessarily arbitrary, fixed for calculations by the slide rule, or traverse tables may be used.

483.—**Omnimeter** is one of the class of instruments in which the tangent to a radius proceeding direct from the axis of the telescope is represented by the stadia and remains of constant length, and the subtense angle varies with the distance art. 458. The omnimeter is the invention of Chas. A. C. Eckhold, a German engineer, described in the provisional British patent* as "a person living in Alexandria." The instrument as originally devised consisted of a kind of theodolite to which the subtense tangential system was added as an entirely separate part. The important part of the provisional specification shows that the principle of the invention consists in the use of two sights to the instrument, one a telescope to sight the object, and the other a powerful compound microscope to read divisions upon a tangential scale. The telescope and microscope are firmly united

* Patent, prov., No. 1859, June 1868; patent No. 3759, Dec. 1868.

together in parallel position with their axes exactly crossing the transverse axis of the theodolite, so as to move together through the same angle by the motion of the telescope in traversing the azimuth. A delicate level is placed upon the telescope, and when the bubble is in the centre of its run the scale is truly at right angles to the axis of the microscope. The scale in the

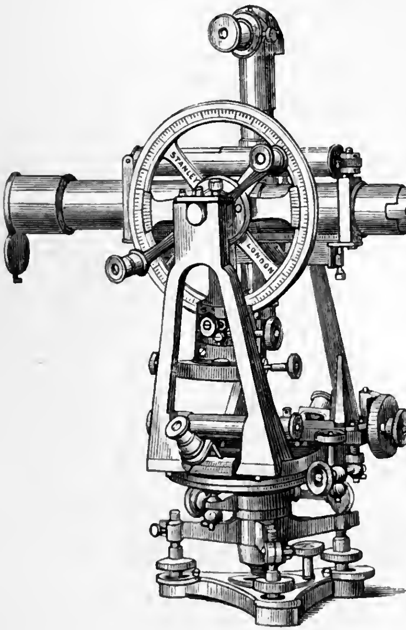


Fig. 195.—*Perspective view of 5-inch omnimeter.*

early instruments stood vertically at the extreme edge of the instrument in a position lateral to the object-glass of the telescope. It was finely divided to millimetres, and read the intervals of the divisions by means of a micrometer screw with a vernier.

484.—With the instrument as originally constructed it was found that the delicate scale, protruded vertically to the extreme edge of the instrument, was very liable to injury unless it was supported by heavy metalwork, which rendered the instrument cumbersome. A great improvement was made in this instrument, which brought

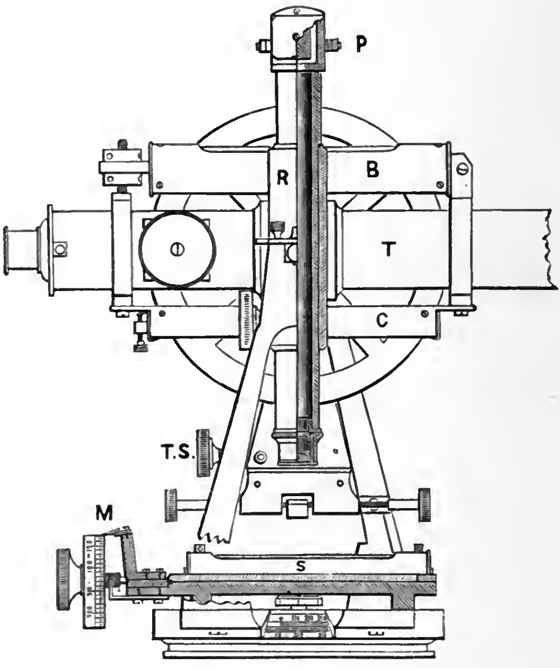


FIG. 196.—*Details of omnimeter, showing section of microscope and scale.*

it to its modern form, by placing the tangent scale in a horizontal position, where it could be firmly fixed upon the vernier plate, as shown Fig. 196 *S*, and reading the scale by means of a reflecting prism in the eye-piece of the microscope. In this improved instrument, as the microscope and telescope are still united on one axis so that they move at equal angles to each other, it is clearly indifferent whether the scale is placed vertically or horizontally, provided it is placed truly at right angles to the microscope when the axis of the telescope is truly horizontal. The scale, which is 4 inches long, is placed in a sliding fitting to adjust longitudinally to its position by means of a micrometer screw. In the English instrument the scale is divided into 100 parts for numerical calculation. The divisions are subdivided by shorter lines, making the actual division 200. The micrometer screw has fifty threads to the inch, and

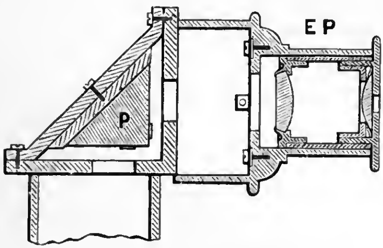


FIG. 197.—*Details of prismatic eye-piece.*

moves over one of the divisions of the scale only. The micrometer head is divided into 100, numbered at the tens; a vernier placed against the head subdivides each of these divisions into 5, making the total micrometer 500 for one complete revolution. The total division of the 4-inch scale therefore becomes: 200 (divisions of scale) × 500 (micrometer) = 100,000 in 4 inches. The scale is placed centrally to the instrument, so that when the telescope is level the microscope is vertical, and reads 50,000 when in perfect adjustment.

485.—The general appearance of the instrument, which resembles a transit theodolite, already described art. 301, in every way, except for the addition of the microscope and scale, shown in perspective in Fig. 195. The details of construction of the microscopic apparatus may be followed in Fig. 196. *T* telescope with sensitive level *B* mounted upon it; *R* body of microscope connected solidly upon the same axis as the telescope, shown in half section. The eye-piece is placed at right angles to the microscope and telescope, and reads through the reflection of a prism *P* to the face of the instrument. The details of the eye-piece are shown in section Fig. 197. The tangential scale is shown in section Fig. 196 *S* with the micrometer with edge reading vernier at *M*. The compass of the instrument *C* is of the trough form, and placed on the opposite side to the level to be used after transiting the telescope from the position in which it is shown in the figure. The axis of the connected telescope and microscope is exactly 6 inches above the surface of the tangential scale *S*.

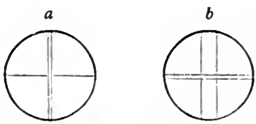


FIG. 198.—*Omnimeter webs; a telescope, b microscope.*

The telescope diaphragm is best webbed with two vertical webs and one horizontal Fig. 198 *a*, the altitude reading being taken from the top of the horizontal web and the horizontal angular position from the centre of the interval between the vertical webs. The microscope diaphragm *b* has two horizontal webs only, and reads from the centre of the interval, which is judged by the eye. Observed in this manner, there is no error due to covering angle subtended by the webs themselves.

486.—*Reading of the Tangent Scale.*—As the micrometer divides half a principal division into 500, the complete *figured* divisions are therefore divided into 1000. This is done for the sake of decimal notation. In reading it is only necessary to observe that the shorter or half division is 500, which must be added to the micrometer reading when it is past this division; as for instance $65\frac{1}{2}$ reading is 65·500, and say the micrometer reads 234 past this, the reading is then clearly $65·500+234=65·734$, just as before described for reading half degrees with the vernier.

487.—*Value of the Scale Taken in Rectangular Co-ordinates.* The radius from the transverse axis of the telescope to the tangent surface of the scale is exactly 6 inches. The scale is 4 inches divided into 100,000 parts, as it is read with the aid of the micrometer and vernier. The radius therefore in terms of the scale would be at 6 to 4, that is 150,000. By this we see that the divisions of the scale by the angle subtended give tangents, the value of each division of which is the reciprocal of this on 150,000 of the radius or base to any unit we may select. If we make the unit 1 foot, then one division represented by a unit of change of position of the vernier reading, and consequently of equal angular change in the direction of the axis of the telescope, would give a tangent of 1 foot upon a stadia placed at 150,000 feet distance. If the stadia were made 10 feet, as is usual, the same angular magnitude would be traversed in ten times this distance, or over 280 miles, making the value of the units of the vernier 1,500,000. This will give a general idea of the delicacy of the instrument so far as constructive principles are concerned.

488.—*The Stadia* is marked off in a number of feet, links, or metres, according to the unit taken for measurement of the surface of the land. The English stadia is generally formed of a 14-feet levelling staff, with the surface painted with a ground of plain white. At 10 feet apart two black bands about 2 inches wide are painted in, leaving in the centre of each band a clear white line of about one-tenth of an inch in width. These white lines are carefully set to 10-feet standard centre to centre. But a better plan is to have two equilateral triangles painted, with their apices meeting in the centre. An intermediate 5-feet line is drawn in black, which is found convenient for near measurements, to avoid too great angular displacement of the telescope. When the measurement is in chains, 15 links or 20 links may be taken for the distance of the lines apart to give the tangent. For metre measurement 4 metres are commonly taken for the stadia division. These are in each case subdivided. The lowest stadia reading should be 1 foot at least from the ground to avoid grass and other obstructions.

489.—*Field-book.*—The field-book as shown below is recommended by the inventor:—

<table>
<tr><th rowspan="4">Station.</th><th colspan="4">Base Line = 1,500,000.</th><th colspan="6">Departure Point at 500,010.</th><th rowspan="4">Remarks.</th></tr>
<tr><th colspan="2">Staff = 10 feet.</th><th rowspan="3">Difference.</th><th rowspan="3">Distance. Feet.</th><th rowspan="3">Difference.</th><th colspan="4">ALTITUDES.</th><th rowspan="3">Reduced Level.</th></tr>
<tr><th rowspan="2">Upper.</th><th rowspan="2">Lower.</th><th colspan="2">Back Sight.</th><th colspan="2">Fore Sight.</th></tr>
<tr><th>+</th><th>—</th><th>×</th><th>—</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

490.—*Examination and Adjustment of the Omnimeter.*—The parts which compose the theodolite proper have already been discussed art. 376. The most important adjustments are:—1. The distance of the scale from the axis. 2. True position at tangent to what is termed its *departure point*, that is, the point where the microscope reads when the axis of the telescope is level (about 50,000). 3. Freedom from shake in the screw and eccentricity in the microscope. The exact distance of the scale can only be measured in the complete instrument by testing a distance of a stadia to see that it works out correctly, according to the rule following, by careful measures upon the land by means of a chain or steel tape. The tangent of the scale agreeing with the microscope may be tested by taking two points of observation by the telescope, one level and the other at a considerable altitude above, say of 20 feet at 100 feet distance, carefully levelling the instrument for the first point and noting the reading on the scale. Then directing the telescope to the higher point and noting this reading on the scale, subtract the first reading from the second and the difference is found. Now return carefully to the level position and see that there is no change; and leaving the microscope at this position, elevate the telescope by means of one of its tribrach screws, which support the instrument, placed directly under it until the upper point is read by the same setting of the scale. Now move the microscope to the setting to sight the level object and note the difference on the scale. If the differences are alike in the two positions, which will be on each side of 50,000, the scale is at right angles to the microscope. If it is not so the scale must be adjusted by the maker of the instrument. The fit of the screw may be ascertained by bringing the scale up to a point or reading of one of the lines on the stadia, first by turning it in a right-hand direction, and then passing the point and turning it in a left-hand direction back to the same point. If the telescope and microscope agree through this change the screw and its fitting are perfect.

491.—*Mode of Operating with the Omnimeter.*—Carefully set the instrument up at its station in perfect adjustment as a theodolite, noting the departure point upon the scale reading through the microscope. Place the stadia in a vertical position at the point to which measurements are required. Direct the telescope so that the horizontal web cuts the upper line of the stadia, and lightly clamp it. Now read the microscope and record the reading as observed in the field-book. Unclamp the telescope and take the reading of the lower point of the staff and record this. Record the bearing of the instrument on the horizontal circle as with a theodolite.

492.—*To Determine the Horizontal Distance in Feet.*—Divide the constant radius given before of 1,500,000 by the difference of the two readings of the stadia mark, which are 10 feet apart. For example:—

First reading of scale	67,500,	micrometer	235	=67,735
Second ,,	64,000,	,,	450	=64,450
			Difference	3285;

then $$\frac{1,500,000}{3285}=456\cdot6 \text{ feet distance.}$$

The process is somewhat simplified by logarithms, as we have only the log. of the difference to extract from the constant of 1,500,000 whose mantissa is 1,760,913. Thus—

log 1,500,000	6·1760913
log 3,285,000	3·5165354
	2·6595559=456·6 feet.

To Determine Horizontal Distance in Chains the stadia should be marked as just described for feet, but at 20 links distance from line to line. Then the radius 150,000 × 20 gives 3,000,000. Taking, for example, readings as before with difference of 3285 we have—

$$\frac{3,000,000}{3285}=913\cdot2, \text{ or 9 chains } 13\cdot2 \text{ links distance.}$$

To Determine Horizontal Distance in Metres, the stadia is divided to 4 metres. Then radius 150,000 × 4=600,000. Taking, for example, difference of reading as before 3285,

then $$\frac{600,000}{3285}=182\cdot64 \text{ metres.}$$

493.—*Levelling—Taking Altitudes.*—To take the elevation of the staff above the level of the instrument, take the lower reading of the staff on the scale, and subtract the reading of the scale, when the axis of the telescope is level, from this, and divide by the distance difference, as found by the method discussed before, and multiply this by 10 feet. Thus taking the lower reading as before 64,450 and the constant for the level position of the instrument, say 50,010, we then have—

Lower reading		64,450
Level	,,	50,010
	Difference	14,440;

then $$\frac{14,440}{3285} \times 10 = 43{\cdot}96 \text{ feet.}$$

The heights, in relation to the position of the instrument, are *positive* or *negative* according as the scale readings are greater or less than the constant level reading, or departure point.

494.—*Work of the Omnimeter.*—The perfection of the principles of the omnimeter would lead anyone to infer that work might be done with it of the highest degree of accuracy. The testimony of the greatest authorities show by comparison that it is unable to compete in this respect with the best make of tacheometers. A large number of these instruments are employed in India. Colonel Laughton reports upon it—"It has been found to give very accurate heights of buildings, etc., also to be wonderfully accurate when used as a levelling instrument; *but it is not so accurate for measuring distances over* 600 *feet*, and even at this distance the error sometimes amounts to as much as 1 *foot*. It is recommended as admirably adapted for city surveys and traversing, also in hilly and jungly countries, and for railway and similar purposes." *

* "Report on Omnimeter," by Major G. A. Laughton, Superintendent Bombay Revenue Survey.

Wherein the instrument fails to give exact results is no doubt in the difficulty of its manipulation. For taking two readings, which is necessary for every operation in distance, the instrument has necessarily to be set twice, the hand being placed upon the micrometer for the second observation while the attention is upon the sighting of the telescope; and even when the readings are taken by the telescope, the microscope has to be separately adjusted to read the micrometer scale. In the repetition of these processes some slight disturbance of centre by pressure is almost impossible to be avoided. Further, in distant readings atmospheric changes giving difference of refraction occur quickly, so that there is more risk of error from two separate observations than if the observations of the subtense webs were taken simultaneously as with the tacheometer. On the other hand the wide angle subtended by the stadia with the omnimeter in short distances must be in every way an advantage.

Improvements in the Omnimeter.—During the time this chapter was in press the author had his attention directed to recent improvements in this instrument by Mr. W. N. Bakewell, M. Inst. C.E.; full details therefore cannot be given. One great improvement consists in turning the body of the microscope to a right angle at the position of the transverse axis of the omnimeter, and placing a reflecting prism at the angle. By this means the eye-pieces of the telescope and the microscope are brought side by side, greatly facilitating the joint readings. A second improvement is in making the scale 1,000,000 instead of 150,000, which much facilitates calculation.

495.—**Bakewell's Tangential Arrangement** *to a Theodolite for Measuring Distances.*—This arrangement, which gives the distances by direct reading without calculation, was devised by Mr. W. N. Bakewell to extend the power of an ordinary 6-inch transit theodolite fitted with subtense webs. The observations are made on marks at 3 feet and 13 feet on an ordinary Sopwith staff—a 10-feet base as is usual with the omnimeter. Any other base may be used if the distances registered are proportionally altered, or the scale may be divided to suit. It was first applied by the author to a theodolite that had been in good service, without the necessity of making any structural alterations in the instrument.* The measuring apparatus consists of a tangent screw impinging upon a radial plane, with micrometer and vernier. The details will be readily comprehended from the engraving Fig. 199 and the following short description.

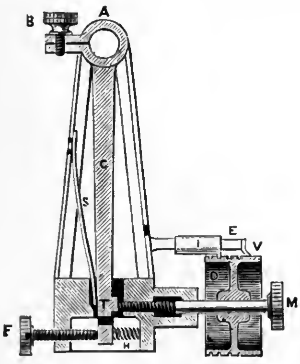


FIG. 199.—*Bakewell's tangential arrangement to a theodolite.*

496.—The transverse axis of a theodolite, upon the opposite side of the telescope to that upon which the vertical arc is fixed, is turned down to a cylindrical surface true with the pivots. A collar *A* which fits the cylindrical surface is slit up on one side to enable it to be clamped firmly to any position of the axis by a clamping screw *B*. The collar is connected in the same gun-metal casting with the radial arm *C*, which

* "Proc. Inst. C.E.," vol. XCII., part II., page 248, 1887-88.

terminates at T in a plane, which is made truly radial with the transverse axis of the telescope. This radial arm C has a long German-silver spring S at the opposite side to the radial plane, which keeps it up firmly in contact with the point of the micrometer screw. A screw is cut on the drum of the micrometer D; on the spiral the scale of distances is engraved; and readings are taken from a line on the index I which slides on the bar E. The scale being one of reciprocals the divisions are at unequal distances, so a vernier cannot be used; consequently at long ranges where the divisions are close, the subdivisions must be estimated. Where this is too rough a method resort must be had to calculation. The outer end of the drum D is divided into 200, and reads by vernier V carried by the arm E in 5 or thousandths of a revolution. The micrometer screw has twenty-five threads to an inch, and the radius of the arm C is 4 inches. One complete revolution of the screw is one-hundredth of the radius, and using a base of 10 the radius factor is $1000 \times 100 \times 10$ or 1,000,000; consequently Barlow's or any other table of reciprocals can be used, and the distances obtained by inspection with comparatively little labour. This additional part has not range sufficient for altitudes, being available for about two degrees only. The distance may be taken as a subtense or small tangential angle as a radius which, with the azimuthal angle taken by the vertical arc of the theodolite, will give altitude by its sine and horizontal distance by its cosine in the usual manner.

CHAPTER X.

INSTRUMENTS OF REFLECTION — OCTANT OR QUADRANT — REFLECTING CIRCLE—SEXTANT—PRINCIPLE—PARALLAX— CONSTRUCTION—EXAMINATION—ADJUSTMENT—ARTIFICIAL HORIZON—SOUNDING SEXTANT—BOX SEXTANT—SUPPLEMENTARY ARC — IMPROVEMENTS UPON THIS — OPTICAL SQUARE—OPTICAL CROSS—APOMECOMETER—CYCLOSCOPE.

497.—**The Octant or Quadrant** measures angles within 90° by an arc of 45°. This instrument is generally termed an *octant* on the Continent, from the space of the divisions; a quadrant by English-speaking races, from the extent of angles it takes. The idea of bringing the reflection of an object from a mirror lineal with the direct sight line from another object, to measure the angle at the position of the observer subtended by the two objects, was originally proposed and worked out in a manner by Hooke,* and also by Newton.† Newton's invention was the more simple and important. This was communicated to Dr. Halley, then Astronomer Royal, but it was left unpublished until after his death when it was found in Newton's own handwriting among Dr. Halley's papers.

498.—Newton employed two mirrors to obtain the reflection of an object placed at any angle of less than 90° to the axis of the telescope or sight tube, to throw an image directly through the tube. One of these mirrors was placed at an angle of 45° to the axis of the telescope and covered half its field aperture, so that a direct image of an object could be received by

* "Posthumous Works," page 502; also "Animadversions to the *Machina Cœlestes* of Helvetius," page 49.
† "Phil. Trans.," vol. XLII., page 155.

the eye from the open, uncovered part of the telescope at the same time as the reflected image of another object from the mirror. The second mirror was placed so as to throw its reflection into the mirror on the end of the telescope without giving any obstruction to the open aperture. This side mirror was fixed with the centre of its plane over the axis of a movable arm which read upon an arc the amount of its angular displacement within 90°. The mirrors were so arranged that their faces should be parallel to each other when the movable arm was placed at the zero of the arc. The graduation of the arc was of double the closeness of the ordinary arc reading, so that the angular position of the two mirrors in relation to each other was indicated according to the following law.

That the angle between two reflections in the same plane is equal to twice the inclination of the reflecting surfaces to each other.

499.—**Hadley's Quadrant.**—In Newton's quadrant the arc was brought most inconveniently in front of the face. By Hadley's arrangement the telescope or sight line is brought in a direction about parallel with the chord of the arc, producing the very convenient form of instrument now in use. This instrument was exhibited at the Royal Society, 13th May, 1731.* It was tried experimentally by the Astronomer Royal, August 1732, in a yacht excursion, when readings were taken satisfactorily within a minute of arc.† It afterwards came into general use.

500.—The quadrant was at first held to be sufficient for measuring the sun's altitude for obtaining latitude, but Hadley as early as 1731 saw the advantage of extending the arc to be able to observe the opposite horizon if the direct one was obscured. It was also

* "Phil. Trans.," vol. XXXVII., page 147.
† "Phil. Trans.," vol. XXXVII., page 340.

found that measuring the moon's angular distance from a star beyond 90° was serviceable in determining longitude. He therefore proposed by a duplicate system of reflections to extend the arc by what is termed a *back sight* to 220°. The means he suggested, which were commonly carried out in instruments of the period, were found to be too complicated for practice.* In the meantime the construction of these instruments, originally framed of a combination of wood, ivory, and metal, was much improved by making the frame entirely of metal. There were also great improvements made in the optical parts, by which the arc of 90° was extended. In 1757 Captain Campbell had an instrument constructed of metal of 60° of arc which therefore read to 120°. This instrument with details of improvement, principally by Ramsden,† became the modern sextant.

501.—**Reflecting Circle.**—As soon as the success of the sextant was assured there appeared to be a general desire to complete the circle by reflections, many inventors thinking this would possess great advantages over the arc of 120°, and we find therefore no lack of inventions to this end, even by eminent men. *Reflecting circles*, as they are termed, that were of sufficient merit to come into limited use, were designed by Mayer, 1770; Borda, 1787; Mendoza, 1801; Hassler, 1824; Fayrer, 1830. Troughton's circle of about this period was no doubt the best instrument of the class.‡ We have also meritorious reflecting circles by Pistor and Martins, and by Amici.§ Although these instruments were used at sea to a limited extent, particularly in foreign ships, they were also used on land, where indeed they were more manageable. As no further reference to these reflecting

* See Nicholson's "Navigator's Assistant."

† Pearson's "Astronomy," page 537.

‡ Pearson's "Astronomy," page 577.

§ "*Gli Strumenti a Reflessione per Mesurare Angoli*," by G. B. Magnaghi, 1875.

circles will be given, anyone interested in the matter may refer to the books mentioned in the notes, where very full particulars of their structure are given. It was felt necessary to mention the subject here, as the same ideas are constantly cropping up as assumed advantages where previous experience is forgotten. Reflecting instruments at sea are tedious to use when the angle to be taken exceeds that taken in by the eye without movement of the whole body. On land when the angle exceeds 120° a theodolite is better; but supplementary angles may be taken with the sextant conveniently on land, where the portability of the instrument is of great consideration. This will be again brought forward in discussing box sextants with supplementary arc.

502.—**The Sextant**, of the invention of which some particulars have just been given, is only used as a surveying instrument for the exploration of new countries, for which employment—it may be used with or without a tripod or stand—it is found to be a most convenient, light, and portable instrument for the traveller for ascertaining longitude, latitude, and time with the aid only of an artificial horizon. Triangulation may also be taken with it of terrestrial objects, even for the complete circle, by repetitions from station to station in angles within 120°. The same principles which are followed in the construction of the nautical sextant are followed also in the manufacture of two modified forms of this sextant which are used for surveying only, the *sounding sextant* and the *box sextant*. As the nautical sextant is most open to observation of its parts it will be most convenient to discuss the construction and general arrangements of this instrument first.

503.—*Optical Arrangements of the Sextant.*—Newton in the description of his instrument placed the mirrors parallel to each other, that is, to zero of the arc, in his illustration for demonstration of the principle. In this position he showed the direction of the reflected ray coincident with a direct ray entering the eye from the same object or star. This scheme the author has generally found the clearest for illustrating the principle to persons not well acquainted with optics, there being a little difficulty in making out the law just given art. 498 from a more complicated scheme.

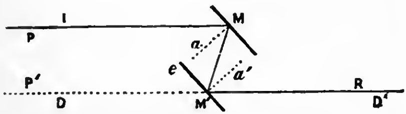


FIG. 200.—*Reflection in direct line from two plain mirrors.*

504.—*If two mirrors be placed with their faces parallel to each other in such a manner that a ray of light may continue after two reflections from them, the ray will continue its path parallel in its direction to its incidence upon the first mirror.*

Let $M M'$ Fig. 200 be two mirrors placed with their faces opposite and parallel to each other. Let the incident ray $I M$ fall on the mirror M whose normal is a. Then, as the angles of incidence and reflection are equal art. 49, it will be reflected at equal and opposite angles to the normal to M'. Let the normal of M' be a'. Then again, the incident line $M M'$ will be reflected at equal angles to the normal to D', that is, as shown by the scheme, it will continue parallel with the incident ray and in such a position that an object at P would appear to the eye, placed at D', as though it were at P' in the direct line of sight.

505.—*Parallax.*—It will be seen by the figure that the point P does not appear to the eye at D' in its true position but at P'; therefore with the mirrors $M M'$ quite parallel, the points P and P' appear coincident, and would read as one point with the index of the sextant set at zero, that is, at the position when the mirrors are parallel to each other; whereas the points

P and P' really subtend a small angle if direct lines be drawn from them to D'. It is therefore clear that the angle read by coincident reflection and direct or, as it is sometimes called, *visual* image is less than the true angle at about the position shown. This difference is called the *error of parallax*. When the object is distant this error is immeasurably small. The parallax error varies proportionally to the distance of the mirrors apart and with their angular position. If the mirrors are in such an angular position that the rays proceeding from an object impinging upon the centre of the first mirror would, if continued, reach the eye, there would be no error of parallax. This occurs in the nautical sextant at about 60°, and the parallax error increases on either side of this point.

In the practice of surveying this small error is neglected. When the box sextant is used the mirrors are placed at very small distance apart, and the parallax error therefore is extremely small even for near objects. Where two objects are to be triangulated, the one near and the other distant, the parallax error is much decreased or eliminated by taking the near object by direct vision, and the distant object by reflection. In this case, if the near object is towards the right hand, the sextant must be used in an inverted position. If the two objects are both near, a distant object may be sighted in the direction of one of them for the reflected image.

506.—It is readily seen that if the parallelism of the glasses shown in the figure is disturbed, say by a change in the relative angular position of M' so that the planes M and M' continued to subtend an angle to each other, then the normal of M' must also be changed in direction equal to this; but the ray $M M'$ remaining constant, as there is no movement of M, this ray will therefore be displaced in its reflection from M' an amount equal to the angle of incidence on M' from its normal, plus the angle of reflection from the opposite side of the normal, that is, to double the amount of angular change of the position of the mirror or of its normal, which is the same thing. The sextant therefore reads, by change of position of one of its mirrors, half the angle of reflection upon its arc; and to make it read to the angular value of its reflection the divisions on the arc are made doubly as close, that is, half degrees are made to read as degrees. This will be better explained by the following scheme:—

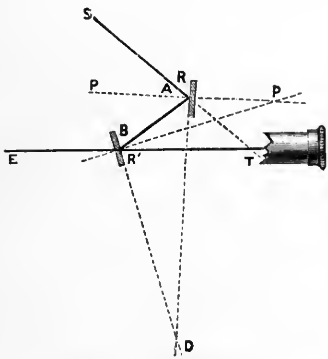


Fig. 201.—*Principles of reflection of the sextant.*

507.—The above scheme Fig. 201 is taken from Captain Magnaghi's admirable work before mentioned, which gives very clear geometrical demonstration of the value of angular positions in compound reflection. A ray of light SR directed to a plane mirror R is reflected therefrom to a plane mirror R', following a plane of reflection perpendicular to the intersection of the two mirrors. The direction $R'T$ of the ray reflected by the second mirror falls into the same plane of reflection and makes with the direction SA of the incident ray an angle double to that which is comprised between the two mirrors.

The two planes of reflection $S\,A\,B$ and $A\,B\,T$ unite in one because they both contain the line $A\,B$ and the normal $B\,P$ to the mirror R'.

In prolonging the normals of the mirrors to their point of intersection P we find that—

$$B\,T\,S = B\,A\,S - A\,B\,T;$$

but as $\quad \frac{1}{2}\,B\,A\,S - \frac{1}{2}\,A\,B\,T = B\,P\,A = B\,D\,A,$

therefore $\quad B\,T\,S = 2\,B\,D\,A.$

508.—The mirrors being placed in the position shown in the figure, if we look through a telescope whose visual axis is placed in the line $E\,T$, with its objective to the mirror R', we see in the centre of the field of view the image of the object S reflected consecutively by the mirrors R and R'. We also see in the telescope if the mirror R' is only a certain height above the plane of reflection, so as to permit half the object-glass to receive the rays coming from the point E situated in the prolongation of the line $T\,B$, also the image of E which is necessarily coincident with that of S, because the rays by which each image is formed enter the telescope in the same direction $B\,T$. Therefore when the images of the two objects E and S appear superimposed or coincident in the middle of the field of view, we have an index given that the mirrors form an angle to each other which is half that which falls on the point T from the same objects, and when one is known the other is known also.

509.—**Nautical Sextant**.—The ordinary construction of this instrument Fig. 202 consists of a cast gun-metal frame, forming approximately in outline a segment of a circular disc $A\,A'A''$ including within its extreme radii about $155°$.

The Limb $G\,G'$, which is made only about $\frac{1}{12}$ inch in thickness, has generally a face about $\frac{3}{4}$ inch in width, which is inlaid with silver or platinum as Fig. 108 to take the graduation to about $140°$. The limb is stiffened by a deep, thin rib about $\frac{1}{2}$ inch wide, supported by a corner hollow. The exterior radial arms and interspace framing Fig. 202 *M M M'*, which vary very much in design according to the taste of the maker, is made generally of about $\frac{1}{14}$ inch in width upon the face of the bars, with a depth of $\frac{3}{8}$ inch. This arrangement of the bars placed edgewise gives great stiffness to the surface of the arc with little weight. A handle *L*, made generally of ebony, is supported on two standards or

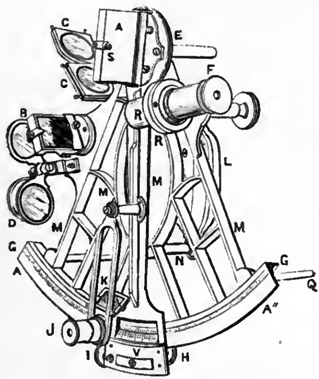


FIG. 202.—*Nautical or astronomical sextant.*

brace-pieces N which are carried off to about 2 inches from the back of the frame to hold the handle parallel with the face. The handle has sometimes a hole, bushed through it with metal, to support the sextant upon a corresponding pin forming part of a stand or a tripod when the instrument is used for taking observations on land. Three feet are placed at the corners of the frame of the sextant, one shown at *Q*, to support it conveniently on a table to take the reading of an observation just made.

At the centre of the arc a female axis of about $1\frac{1}{2}$ inches in depth *E* is attached by three screws to the frame perpendicular to the plane of graduation. This carries the male axis, which centres the vernier on the vernier arm *M*. The axis is covered by a protecting tube which forms one of the three feet upon which the instrument rests when laid down. The vernier arm is made of gun-metal of about $\frac{1}{16}$ inch in thickness and from 1 inch diminishing to $\frac{3}{4}$ inch in width. This is stiffened by a light rib on its upper side.

The Vernier V reads upon an 8-inch sextant, that is, one of 8 inches radius, to 10″, the graduations being to 20′ and the vernier taking 120 divisions. Description of the vernier reading was given art. 262. The vernier falls upon the arc on the plan shown Fig. 108. It is clamped near to position by the milled-headed screw *H*, and is adjusted by the tangent *I*. A magnifier *J* is placed on a jointed sling-piece *K* which traverses the vernier. This is sometimes provided with a ground glass shade to dull the silver for reading. The sling-piece moves the magnifier opposite to any division of the vernier.

Over the axis of the vernier arm a large, oblong mirror, termed the *index glass*, *A* is fixed with its face in a plane cutting the centre of the axis. *The index glass* is placed with its longest sides approximately lineal with the vernier arm. This mirror is placed in a metal tray and is sometimes made adjustable by three screws; but it is better fixed by the maker by screwing the flange-piece, which forms one end of the tray, hard down. The index glass moves with the index arm and gives the first reflection of sun, moon, or star which falls thence upon the *horizon glass B*.

The Horizon Glass B is placed upon a spur-piece which is formed in the same casting as the frame. This glass, which is worked perfectly parallel, has the lower half of its surface next the frame silvered. The silver is cut to a sharp line against the plain part. The horizon glass placed in its metal tray has adjustments given to it by means of capstan-headed screws in a manner that will be presently described.

The Telescope screws into a ring fitting at *R* which stands upon a bar erect from near the edge of the frame. The female screw by which the telescope is held is formed of two rings which adjust for the amount and direction of separation, so that the telescope may be directed coincident with the horizon glass. The bar or standard which supports the ring fitting is made of either square or triangular section, fitted accurately in a deep socket fitting, in which it slides to raise or lower the ring by means of a milled-headed screw placed on the end of the bar. This permits sufficient adjustment only to bring the axis of the telescope opposite the line of division between the plain and silvered parts of the horizon glass.

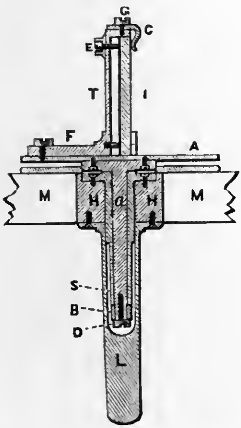
Four Circular Shades, carried in square frames fitted with dark bluish-gray glasses, are jointed to the frame at *C*. These have nib-pieces at the upper corners *C'*, so that one or more of the shades may be turned up at a time by the finger-nail to intercept any surplus amount of light from a luminous body reflected from the index glass; or the whole of the shades may be turned up when observation is made of the mid-day sun. Three other similar shades, but placed in circular frames, are fixed at *D*, which hinge over and back, to be thrown in or out of interception, and are used to subdue the light from the horizon if required.

510.—*The Telescopes* used as a part of the sextant are generally two in number. One for *direct vision* is a short tube of about 3 inches in length, focussing at about 4 inches. The optical arrangement is the same as that of an opera glass, consisting of an achromatic object-glass of about 4 inches focus and a concave eye-glass of about 2 inches negative focus Fig. 12. The second telescope is of about 7 inches to 8 inches in length. This has two Huygenian eye-pieces, which have each a wired diaphragm at the mutual focus of the eye-piece and the object-glass. One of these has two fine wires placed parallel for use in adjusting the telescope, and the other has two pairs of crossed wires to indicate the centre of the field of view. There is also a plain pin-hole sight provided for open vision.

511.—*The Case* in which the instrument is packed is generally made of well-seasoned mahogany, dovetailed together at its corners. The fittings are made to put the instrument back in its case as it was last used within a wide range. A tommy pin for adjustments and a hand magnifier are supplied with the instrument. The case is generally French polished inside as well as out to prevent absorption of moisture from sea air.

512. — *Manufacture and Examination of the Nautical Sextant.*—Besides the general good work that this instrument demands, the important points to be observed are, that the glasses should be of hard crown glass worked perfectly parallel from face to face; they should also be well polished. These observations apply to both the reflecting glasses and the shades. The silvering of the mirror should be protected with a good coating of copal varnish. The mirrors should be held by three points only and be quite free from strain. The upper of the three points should detach, so as to be able to remove the glass at any time for re-silvering. The axis should be fitted with all the care necessary for a theodolite and be placed truly central to the arc. The extremity of the vernier arm when free of its clamp should traverse the arc at equal distance from its face and move with very light friction. The extreme lines of the vernier should cut equal divisions all along the arc 0° to 140°, observations being taken particularly at both ends and in the centre of the arc. The vernier should lie flat

on the limb from end to end of the arc. The standard or stem-piece for elevating the telescope should move upwards and downwards stiffly but equally by the motion of its milled-headed screw. The division lines of the limb and vernier should be cut fine but very deep: they should be cut on the dividing engine from the axis of the sextant to ensure true centring of the arc, and not as in the usual plan of having the axis adjusted to the divisions.



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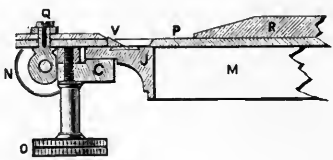

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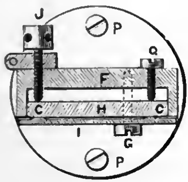
FIG. 203.—*Section of axis and index glass of sextant.*
FIG. 204.—*Section of limb and clamp and tangent.*

513.—*Axis.*—This is a most important part of the instrument and requires the greatest care in construction. Fig. 203 represents this to a scale half size. *a* the axis, made of hard gun-metal, has a collar by which it is attached to the index arm. The axis is ground and burnished carefully into *S* the socket-piece, which is fitted into the frame and held down by three screws. At the end of the socket there is a collar-piece *B* attached upon an angular or tight conical fitting by the screw *D*, which prevents the axis rising out of its socket. The axis is covered by a cap L which protects it from injury, and this at the same time forms a leg to the instrument as before mentioned. The index glass I is mounted in a tray T shown in section. There are two points of contact at the lower part of the back of this glass, formed by pins, and one point of adjustment pressing against the clip G by a spring C in front, acting *contra* to a screw at the back E, which adjusts only a small distance to bring the index glass to perpendicularity. The flange-piece F is adjusted in the manufacture so as to leave very small separate adjusting to the index glass necessary.

514.—*Section of the Limb and Clamp and Tangent.*—The general arrangement is shown in Fig. 204. M arms of the frame; J section of the limb; C clamp attached to the tangent N for clamp and tangent motion, described art. 283; O milled head to clamp; N milled head to tangent. The vernier is shown at V, reading through an opening on the face of the index arm P. Rib to stiffen this arm is shown at R.

515.—*The Adjustment Arrangement of the Horizon Glass.*—This most important adjustment is constructed in various ways. The plan now generally thought to be the best is for the maker to fix the horizon glass frame firmly in its true position and perfectly perpendicular to the surface of the frame, and to allow a small amount of adjustment to the glass only. A convenient plan of doing this is shown in vertical section full size in Fig. 205. The frame $F F$ is made in one casting which has its base collar fixed firmly to the frame of the sextant. Fig. 205A is a cross section A to B. H the horizon glass is held upon its face by three points, one of which is shown at L, which is placed in the centre of the top. The lower front points are the exterior corners of a plate which is cut away between. This plate is held by the screw G. The screw G forms a kind of hinge which, together with the springiness of the plate, gives a slight pressure directing the glass hard upon the points of the screws *J* and *Q*. The screw *J* resists this pressure lightly and permits adjustment of the horizon glass *H* to angular position, in relation to the plane of the index glass to a small extent, by means of a pin placed in the capstan head *J*. The perpendicular position of the horizon glass Fig. 205 *H* is secured by



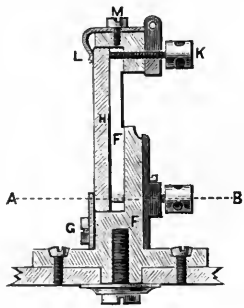


FIG. 205 A.—*Plan of section A to B.* FIG. 205.—*Vertical section of horizon glass.*

slight adjustment of the capstan head *K*, which moves against a spring *L* in the vertical centre of the top of *H*. This piece, with screw and spring, is attached to the horizon glass frame *F F'* by the screw *M*, so that it may be easily removed to replace or resilver the glass. The silver on the glass is cut to a sharp line at about the point *H* with a razor.

516.—*Testing the Parallelism of the Surfaces of the Glasses.* The best method is to firmly fix a telescope provided with webbed or pointed index diaphragm so that the webs or points cut a distant, sharply defined object, or its edge only, quite clearly. If the glass to be tested be now placed in four directions agreeing with its four sides in front of the object-glass of the telescope, then if the glass is worked perfectly parallel and is free from striæ, the distant object will not appear to be displaced by its presence in the slightest degree at any position. If the glass is not mounted and is quite square, if there should be any very small error, the thickest or thinnest edge should be placed towards the frame; but in this case only very small error is permissible. The coloured glasses require the same test as the white ones. Where the parallel glass to be tested is small, the object-glass of the telescope may be covered by a paper cap, with a small hole only left through its centre, sufficient to take the glass.

The glasses, when fixed in the sextant, may be examined for parallelism very approximately by setting them end up singly to the sun, with the sextant set at an angle that the direct and reflected images of the sun's limb appear just to touch, the eye-piece of the telescope being constantly covered by the sun-glass. If there is want of parallelism the image will be disturbed. One reason that the telescopic plan first proposed is better to be followed in the construction of the instrument, is that the telescope is fixed and that there is no indistinctness from unavoidable motion of the body, which occurs when the sextant is held in the hand.

517.—*The Quality of the Surfaces of the Glasses* may be examined, both for flatness and brightness and for equality of density, by holding them so that the reflected image of a straight body, as for instance a stretched thin string placed at a distance, may be observed by reflection in glancing over the surfaces with the eye nearly parallel with its plane. If the glass is imperfect the image that reaches the eye will appear to be wavy. If the reflection appears misty, this is generally due to want of parallelism of the glass; but this mode of observation is altogether a little technical and difficult to attain without skill.

518.—**To Silver the Index or Horizon Glass.**—Clean the glass thoroughly by boiling it in water containing an alkali (potash or soda), and then polish it off with whiting and water with a clean piece of old linen or quite clean wash-leather. Do not touch the surface with the fingers. Take a piece of clean tin-foil freshly opened from the roll and cut out a piece slightly larger than the glass to be silvered. Lay this upon a smooth pad—an old leather book-cover answers. Place a single drop of clean mercury about the size of an ordinary shot upon the tin-foil and rub this gently over the surface until it is entirely silvered. Now pour very gently sufficient mercury upon the foil till the surface appears to be flooded. Take a sharply cut straight-edge formed of stiff writing-paper, and draw this over the surface of the mercury to clear it. Take a slip of clean, smooth writing-paper very little wider than the foil and of about once-and-a-half its length: spring the paper to a slight curve and place one part of it over the silvered foil so that when it springs open it will cover it and exclude the air from the surface. Now give the glass a final polish and lay it upon the paper over the foil. Hold the glass down with slight pressure with the left hand, and slowly and steadily draw out the slip of paper in the lineal direction of the surface of the glass with the right hand. This will take out the air between the foil and the glass, so as to bring the mercury in contact and leave a perfect mirror. It must be now set aside with the glass turned face downwards in an inclined position, so that the surplus mercury may drain off from the foil. Small slips of foil should be put at its lower edge, which by their attraction for the mercury will accelerate the draining. The mirror should not be touched after setting it up to drain for twelve hours at least, after which the surplus foil may be trimmed off. After another thirty hours or more it may have any varnish or other protection applied to the back of the silver.

Where instruments are taken abroad the silver may become spotted, so that a small store of mercury and tin-foil should be taken out with the sextant for re-silvering. But it should be particularly observed that the mercury should never be placed in the same case with the instrument, as the smallest particle, if it touches the frame, will eat into the brass and destroy its strength. Sealing wax dissolved in spirit answers for a varnish at the back of the foil fairly well after re-silvering if proper varnish is not at hand. It is advisable before attempting to silver a sextant mirror to try a few slips of ordinary glass to get into the way of it.

519.—*Adjustment of the Index Glass.*—Hold the sextant clamped to about 60° in a horizontal position with the index glass near the eye. Look nearly along the plane of the glass in such a manner as to be able to see one part of the plane of the arc by direct vision, and another part by reflection of it at the same time. If the direct view and the reflected join in one line, and the arc appears as the continuity of a single plane, the index glass is perpendicular to the plane of the sextant. If it is not so it can be adjusted by turning the set screw placed at the back of its upper centre, Fig. 202 *S*, very gently.

520.—*Adjustment of the Horizon Glass to Perpendicularity.* Place the vernier at zero. Hold the plane of the sextant parallel to the horizon and observe if the image of the horizon seen by reflection at the edge of the silver line coincides exactly with the image received directly through the plain part of the glass. If it does so the horizon glass is perpendicular to the plane of the instrument, that is, assuming the index glass is also perpendicular. In this adjustment it is well to rock the plane of the instrument say 20°, to see that the horizon is cut as a clear line about its horizontal position for this amount of angle. If the mirror is not perpendicular adjust gently by the single screw at the top of the horizon glass frame. If the horizon is not water, the sharp outline of any distinct distant object will answer, or a piece of fine string stretched straight placed at a distance.

521.—*Adjustment for Index.*—This is the adjustment for parallelism of the two mirrors at the zero of arc. The sextant is clamped at zero as before: the arc of the instrument is turned in a vertical position and the horizon again observed. If this appears to cut a clear line through the plane glass and the mirror there is no index error and the planes of the glasses are truly parallel to each other in this position. If the line is not continuous adjust gently by the lower screw Fig. 205 at *G*.

522.—*Adjustment of the Horizon Glass by the Sun.*—This is a better adjustment than that given above, except that it introduces any error that may be due to the imperfection of the shades; and it is more difficult particularly for the first approximate adjustment. Arrange the telescope and shades so that a clear outline of the sun's limb may be observed without distressing the eye. Place the vernier at zero. Observe the sun, which will be most comfortable at about 40° elevation, first with the plane of the frame vertical, and then horizontally perpendicular to this. If the sun presents a round disc in both these positions the sextant is in adjustment. If in the vertical position there appears to be a small notch at top and bottom of the sun's limb, the glass is not perpendicular to the plane of the instrument, and this requires adjustment by the screw at Fig. 205 *K*. If notches appear when it is held horizontally at the sides of the limb there is index error, which may be adjusted at *G* if it is small.

523.—*Index Error after Adjustment Allowance.*—The limb of the sextant is graduated 5° beyond the zero position when the glasses are parallel to each other. This is called the *arc of excess.* The vernier is also divided three lines beyond its zero position, which is marked by an arrow. These extra divisions are placed on the instrument for correcting the index error by measurement of the angle subtended by the diameter of the sun's disc alternately on one side and the other of the zero line, in which observations, if the two readings agree, the sextant must be in perfect adjustment; when they do not agree half the error may be adjusted by the horizon glass. The same observations may be also made with a bright star by setting the index alternately on one and the other side of zero. When the sun is used the reflected and direct images are brought together, so that the two suns that appear in the instrument just touch limb to limb, first upon direct reading and then upon the arc of excess. When the division is adjusted very nearly, any small error, plus or minus, may be allowed as a constant for all readings. In observations of the sun care should be taken that the eye is protected, both by the sun-glass cover to the telescope and by sufficient use of the shades.

524.—*Adjustment of the Telescope to Set its Axis Parallel to the Plane of the Sextant.*—In fixing up the instrument after manufacture, the ring standard which carries the telescope is set at a measured distance from the plane of the frame, so that the centre of the ring coincides with the height of the silver line cut on the horizon glass. This is necessarily a primary adjustment. For final adjustment the long, inverting telescope is screwed home in the ring, and the eye-piece placed in it, which has two parallel wires across its diaphragm. The telescope is brought to focus on any distant object, the eye-piece being turned at the same time to bring the wires parallel with the face of the instrument. Two objects are taken subtending an angle of 90° or over—as the sun and moon or the moon and a bright star—and the index is moved so as to bring the object, say the limbs of sun and moon, in contact with the wire nearest to the sextant, and fixed there. Then by changing the position of the instrument a little, the images are made to appear upon the wire furthest from the sextant. If the limbs of the sun and moon still remain in exact contact as they appeared before, the axis of the telescope is truly adjusted. If the limbs of the two objects appear to separate at the wire furthest from the sextant, the ring-adjusting screw furthest must be loosened a very little and the screw nearest the sextant tightened the same amount. If the reverse, and the images appear to overlap, adjust in the reverse direction. By repeating this operation a few times the contact will appear to be the same at both wires, and the axis of the telescope will be in collimation, that is, parallel with the plane of the instrument. After the telescope is truly adjusted it may be raised or lowered a little to make the reflected and direct images appear equally clear without sensible instrumental disturbance.

525.—*Final Examination of the Sextant.*—It will be readily seen that an instrument, although correct in theory but depending upon perfection of workmanship in centring, division, surface and parallelism of glasses, and also in its adjustments, can scarcely be brought to perfection. The errors generally increase from the zero point, where adjustments are possible, and are greatest at 140°. In the ordinary commercial sextant of the dealers the errors of centring alone are commonly 3 minutes to 5 minutes, with like errors in other parts. It is therefore better, where the sextant has to be absolutely relied upon, to subject it to actual trial. The zero point can be readily fixed by rules already given; besides this the meridian altitude of several bright stars subtending angles of about 30°, 60°, 90°, and 120° should be measured either from a clear horizon or from a mercury artificial horizon, to be described presently, for angles under 60°, and the errors plus or minus tabulated. The data for the meridian altitudes of certain stars upon any night may be taken from the *Nautical Almanac*, which will require correction for the latitude and longitude of the observer. This subject is too complicated to be entered upon in detail here. At the present time the observatory at Kew undertakes the examination of sextants for a moderate fee. This is effected by means of fixed collimators art. 194. For angles distributed over the arc the parallax error is eliminated by placing the collimators in pairs. The Kew certificate may now be had with good instruments when purchased. It may be noted that an originally well-made instrument retains its qualities for all time, the wear of such instruments being inappreciable.

526. — *To Use the Sextant* the right foot should be placed nearly 2 feet in advance of the left and directed at right angles to it. In this position the body is firm. The instrument is supported by the right hand, the elbow being brought down firmly upon the body. The clamp screw first and then the tangent screw are moved by the thumb and finger of the left hand. Some practice is required to make a steady observation. To bring two objects into apparent juxtaposition methods of observation for terrestrial objects will be reconsidered in discussing the box sextant further on. As regards celestial observations reference should be made to works on practical astronomy, as the subject would take too much space to be entered upon here. The whole subject is ably discussed in Chauvenet's "Spherical and Practical Astronomy," with many refinements of correction of parallax, etc., which fall beyond the limits of practical surveying with the sextant.

527.—**Artificial Horizon**.—For ascertaining the latitude of a place from the observation of a celestial body by means of the sextant, it is necessary to have some means of estimating the position of the horizon. A method of doing this, originally proposed by the elder George Adams, optician, 1748,* was to float a parallel disc of glass upon a basin of mercury, and to receive the reflected image of a star from the mercury by the sextant simultaneously with its direct image. The angle then given by the reading of the arc is double the angle at which the true horizon is placed relatively at the same time. This idea, carried out in a practical form in an instrument thenceforth called the *artificial horizon*,† is due to Wm. Jones, a well-known optician at the end of the last and beginning of the present centuries, who arranged convenient means of making the instrument portable, and to keep the mercury from disturbance of the air by covering it with a glass roof. The form of artificial horizon that he devised has been in common use ever since. He also devised another simpler form, which was that of taking the reflection from a piece of silvered, or of black, glass. The performance of the artificial horizon depends in any case entirely upon means of obtaining a reflection from a perfectly horizontal surface.

528.—*Theory of Artificial Horizon.*—A small luminous body Fig. 206 M' placed at a distance will have its image reflected from a level reflecting surface $S S'$ at an angle equal and opposite to the incident ray, the angles $M' A S$ and $E A S'$ being equal. Let E be the place of the eye or the sextant: this will receive an image from the distant body M, sensibly parallel with $M' A$ in $M E$. The angle $M E A$ will therefore be double the angle of incidence $M' A S$, and the half of

* "Description of a New Quadrant," by George Adams, 1748.
† Adams' "Geometrical Essays," edited by William Jones, 1803.

this angle will therefore produce the horizontal line EH at the height of the observer's eye if the plane of reflection SS' is level. Therefore if we take half this angle MEA as it appears in the sextant, it will give an angular position of the object in relation to the

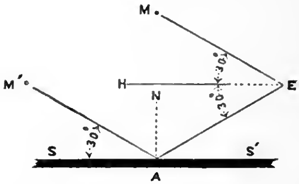


FIG. 206.—*Diagram of artificial horizon.*

horizon at the height of the eye, or be tangent to the surface of the earth. If $M'AS$ be 30°, the angle AEM will be 60°, showing the elevation of object half this or 30°. The sextant takes 120° with certainty; therefore 60° will be the limit of meridian altitude the artificial horizon will measure.

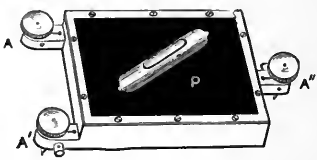
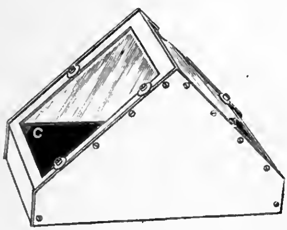


FIG. 207.—*Artificial horizon of black glass.*

529.—**Artificial Horizon in Black Glass.**—This instrument is the most portable, packing in a close pocket case. It is made of both circular and square form in plan. Fig. 207 is the Admiralty pattern. The black glass should have a truly plane surface. It is fixed over a brass tray by being floated on plaster-of-Paris to avoid strain. A light rim of brass is screwed down over the glass to keep it in position. There are three adjusting screws $A\ A'\ A''$. It is adjusted to level by a loose level tube ground on its under face P. The level tube, shown in detail Fig. 51, is placed on the surface lineal with the two screws Fig. 207 A A', and afterwards at a right angle to its first position with one end of the tube towards A''. It is finally tested by traversing at the position shown in Fig. 207, and at right angles to this direction, as shown in the figure. There is great risk of getting a strain on the glass in fixing it. The author therefore prefers the circular form and leaves the glass quite free except at its fixings at three equidistant points only. In this kind of artificial horizon there is only one surface of glass to be got true; therefore there is perhaps less risk of error on this account than in other forms. On the other hand the mercury presents a more perfectly level plane. The circular artificial horizons are commonly made $3\frac{1}{4}$ inches diameter; weight, $\frac{3}{4}$ lb.: the oblong, 4 inches by 3 inches; weight, 2 lbs.



208

FIG. 208.—*Artificial horizon, mercury.*

208 A

FIG. 208 A.—*Mercury bottle to the same.*

530.—**Artificial Horizon of Mercury** Fig. 208. This instrument consists of an oblong tray of about 6 inches by 3 inches by $\frac{3}{4}$ inch in depth made of wrought iron. It is covered by a roof with two sloping sides at about 45° to the plane. The sides of the roof are glazed with worked parallel glass fixed by screws at three points. The mercury when out of use is contained in an iron, screw-stoppered bottle Fig. 208 A. It is poured out in the open tray for use, and the tray is afterwards covered by the roof to prevent currents of air disturbing the level of the surface. After use the mercury is poured back into the bottle from the corner of the tray. It should be particularly observed that it is perfectly drained, as any free particles in the case in which all parts of the instrument are packed would be certain to attack the roof, which is made of brass and simply varnished. The instrument is packed in a mahogany case, size $7\frac{1}{2}$ inches by 6 inches by 5 inches; weight, with 1 lb. of mercury, about $4\frac{3}{4}$ lbs.

531.—*The Bottle* is made of cast iron. It has a screwed plug stopper with a leather collar and a covering cap with a small hole through its apex. To pour out the mercury the cap and stopper are unscrewed, the plug is taken away, and the cover is screwed on again. The mercury then issues from the small hole in the cap. To return the mercury the cap is reversed and screwed upon the bottle. It then forms a funnel. The tray has a covered corner at which there is a small hole. This permits the mercury to be poured into the funnel without splash. Both plug and cap are then screwed down and the bottle is placed firmly in a secure fitting in the case.

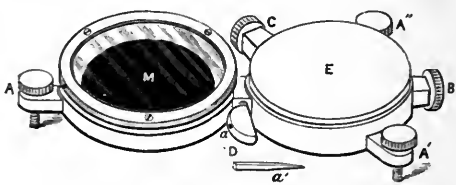


FIG. 209.—*Captain George's artificial horizon.*

532.—**Captain George's Artificial Horizon*** Fig. 209. This is a great improvement on that last described. The instrument being made entirely of iron there is no risk of getting it injured by escape of the mercury. It is also much more portable and

* Prov. patent No. 2624; Christopher George, 1868.

convenient. Two chambers *E* and *M* are connected together by a tube through a stem-piece in which there is a strong iron cock at *a*. The chamber *E* is cored out and forms a bottle into which about 1 lb. of mercury is introduced by removing a screwed stopper at *B*. The chamber *M* is an open tray with a cover formed of a piece of parallel glass placed in an iron rim which screws down upon it. A milled-headed screw at *C* forms an air plug. The cock moves very stiffly by the leverage given by a tommy-pin, shown *a'*, which is inserted in the hole at *a*. The chamber *E* is slightly elevated to cause the mercury to flow from it to *M*, the cock being turned on at the same time and the air screw *C* released a little. By the same arrangement, *M* being raised, the mercury flows back into the bottle for storage.

533.—*For Using this Artificial Horizon*, when the mercury is out in the tray *M* it is levelled by the three screws *A A' A''* so that it covers the bottom of the tray and presents a clear, level surface. A separate disc of parallel glass, which fits the tray *M* very loosely, is provided with the instrument. This floats on the surface of the mercury and keeps it quite still, even when the covering glass is removed. This arrangement is useful also in case of an accident to either of the glass covers. The disc is kept when out of use in a soft leather bag which fits in the tray *M*. This artificial horizon is generally carried in a solid leather case with sling to go over the shoulder. Its weight complete is about 4½ lbs.; size, 9½ inches by 4 inches by 1½ inches. The surface of mercury is a circle of 3 inches diameter.

534.—*In Using the Artificial Horizon with the Sextant* it is generally placed on the ground at such a distance in front of the observer as he can conveniently see the required reflection of the star or sun, the observer moving about until the reflection is obtained. This is a tedious process and requires some practice. It is much more easily effected if the sextant is mounted on a tripod or other stand. Where a stand is used it has generally a universal joint, so as to be able to take surface angles also from the fixed position. When the altitude of objects on the earth is taken, the observation requires reduction for refraction, which becomes an important factor, although this is variable with atmospheric conditions; but upon the whole it always tends to make the object appear higher than it is. Commonly one-seventh of curvature is used as an approximate for such correction. For solar and stellar refraction works on astronomy may be consulted.

535.—The index error of the sextant is corrected before refraction when the natural horizon is employed. When the artificial horizon is used double the index error is allowed before taking its half as a single measure. The artificial horizon is used also with the theodolite. It forms the most perfect means of adjusting the transverse axis by taking observation of the pole star with the telescope, first directly and then by its reflection from the artificial horizon. If the images cut the centre of the webs in the two positions by the movement of the transverse axis only from the one to the other, this axis is proved perfectly level.

536.—Various schemes for obtaining the horizon by some system of levelling apparatus attached to the sextant have been devised, none of which are very practical, as they all depend upon a pendulum or a gravitation surface of a liquid, and are all unstable as hand instruments. There have been numerous patents taken out with this object, from that of Winter (1760) downwards, which anyone interested in the subject may consult.*

*See British patents—Winter, 1760, No. 752; Ould, 1791, No. 1842; Nugent, 1794, No. 1980; Wright, 1796, No. 2081; Cook, 1796, No. 2087; Roxby, 1822, No. 4695; Glover, 1839, No. 8256; Lane, 1857, No. 1669; Rahill, 1860, No. 1845, etc.

The matter is mentioned here as the recurrence of the idea appears to be constant.

537.—**Sounding Sextant.**—This instrument is used for coast surveys. Angles are taken with it of objects, buoys, etc., from the land, as also from a boat on the water for such objects or for others upon land. It is constructed upon the same principles as the ordinary nautical sextant; but as it is to be used as an all-day working instrument, and not for a few diurnal observations only, it is made much more solid and its optical parts take a more extended field of view. The graduation

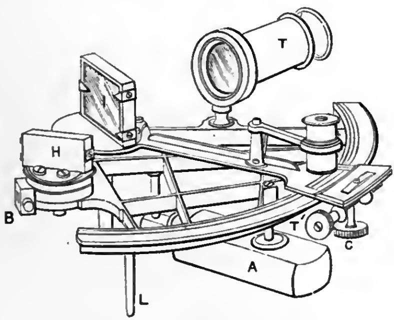


FIG. 210.—*Sounding sextant.*

is also stronger, such precision of reading only being required as may be afterwards plotted on a chart. This instrument is shown in perspective Fig. 210. The index glass *I* is large—about $2\frac{1}{4}$ inches by $1\frac{1}{4}$ inches. This is secured on all sides by a firm rim to the tray in which the glass is held at three points. The adjustment of the index glass is left under control, as it may occasionally be necessary to remove it from effects of spray upon and about it. The horizon glass *H* is made about $1\frac{1}{2}$ inches in width and $\frac{3}{4}$ inch in depth. This is entirely enclosed in a tray, the whole surface being a mirror without any plain part to the glass as with the ordinary sextant, so that it is entirely protected by the metal. By this arrangement the eye receives the direct ray from the object immediately before it, and the reflected ray from an object whose angular position it is desired to take with it; but these images do not come exactly in contact, as the narrow width of the frame interposes. It is however sufficiently near for terrestrial observations. The adjustment of the horizon glass to the perpendicular of the plane of the arc is the same as that shown in detail for the box sextant further on. The adjustment of the horizon glass to the index is by a stiff arm extended from the sole-plate projected into a loose opening, where it is held firmly by two opposing capstan-headed screws. This adjustment is shown at *B*. The arc of the sextant is of 6 inches radius, graduated upon silver to 20′, and reading by the vernier to single minutes only by the microscope. The clamp *C* and tangent *T′* are the same as those described for the nautical sextant. The frame is straight braced. The telescope has a wide field, with achromatic object-glass of $4\frac{1}{2}$ inches focus, the clear aperture being $1\frac{1}{8}$ inches. The supporting ring of the telescope has no rising stem or collimating adjustment, but is solidly fixed in its true position by the maker. The ring carries a plain disc, pin-hole sight, which takes the place of the telescope for near observations. The instrument in use is held in the hand by a firm, oblong handle *A*. The instrument rests, if required for reading, upon three legs as the ordinary sextant. The weight of the instrument is about $2\frac{3}{4}$ lbs.; when packed in its case, 5 lbs. Its examination and adjustment are of the same kind as those just described for the nautical sextant.

538.—**Box Sextant.**—This very neat and portable instrument was invented by the late William Jones* at about the same time as the artificial horizon just

* Adams' "Geometrical Essays," page 264, 1803.

described. It is used for taking angles within 130° upon the surface of the land to within a single minute of arc. It has become deservedly universal with British surveyors as a land surveying instrument, and is equally popular as a military one. It is the same in principle as the nautical sextant already described, but it possesses the great merit—as a surveying instrument constantly in hand—that all its glasses and delicate parts are securely protected from accidental injury by being covered; whereas the nautical sextant, made for one or two diurnal observations only, has all these parts exposed. And it is not only that all parts are protected when

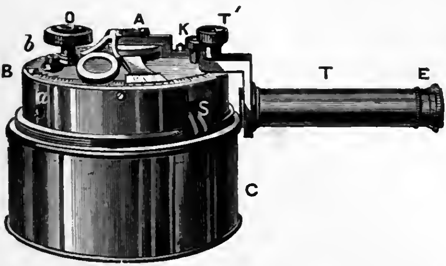


FIG. 211.—*Perspective view of the box sextant ready for use.*

the instrument is in use, but they are doubly protected by the covering box when carried about out of use; so that it is found that a well-made box sextant set originally in perfect adjustment will retain this adjustment in average use for very many years. The author has seen an instrument twenty years in use still in perfect adjustment. The box which covers the instrument out of use forms also a most convenient handle or support for it when in use by attaching it in a reversed position underneath, as it appears in Fig. 211. This attachment is made either by a screw cut entirely round the body of the instrument, or, what is much better, by a bayonet fitting, for the reason that large screws of this description are liable to *cross thread.* The general description of the outer parts is as follows.

539.—*C* covering box which inverts from the position shown in the figure and covers the instrument. This has a diameter of 3 inches and a depth of 1½ inches. *B* box containing the optical and motive parts of the sextant. *A* axis of index glass. This axis also carries a toothed segment fixed close under the front of the box, by which both the index glass and index are moved by means of a pinion to be described. *I* index which carries a vernier divided into 30, which reads into the arc to single minutes; the arc is divided to half degrees on silver. *M* magnifier. This is centred by a swivel hinge joint over the axis, so as to permit it to be brought to focus upon the arc at any position. This magnifier is held down on the front of the box when out of use by a nib catch at a position of about 80° of the arc. *D* a milled head, the axis of which carries a pinion which works into the segment above described under the index glass. The pinion is about 1 to 9 of the segment, so that the index traverses the arc of 60° (reading 120°) by one-and-a-half turns. This gives a conveniently slow motion to the index glass, and enables this sextant to be set rapidly with great precision, if it is well made. *S* two nibs, part of two levers for putting the shades in or out of action.

In the closed form of sextant the shades block the reflecting position between the index and the horizon glass. For surface surveying they have therefore to be opened out, through an opening closed by a slide shutter which moves by a stud in a slot on the under side. The shades are formed of one green and one dense red glass which must be worked parallel, as before described with the nautical sextant. These are used for taking altitudes of the sun for adjustments only.

The Key K is a milled head which screws out, and carries a watch-key pipe at the end of its stem by which adjustments may be made from three square-headed screws which fit its pipe, two of which are close to *b*, which is the axis of the horizon glass. These adjust perpendicularly to the plane of the arc. One screw at *a* adjusts the parallelism of the index and horizon glasses when the index is at zero.

The Telescope is achromatic, with drawer tube for focussing. It magnifies about 2½ diameters. It has concave eye-glass, and therefore gives an erect image Fig. 14. A sun-glass *E* screws over the eye-glass when it is required for sun observations. The telescope is attached to the sextant by means of a crank-piece upon the telescope that is fixed by the milled-headed screw T' and two steady pins. The crank-piece screws in a reverse position upon the telescope for portability before putting it by in its case.

By some makers the telescope is made to slide into the body of the sextant and thus become quite portable. This plan is a very neat one, but it requires care to see that the shades do not interfere before it is put by. The weight of the entire sextant with its solid leather case is about 18 ozs. only. For close work the telescope is not generally used. A sliding shutter pierced with a small hole covers the telescope opening into the sextant, which is used as a sight hole.

540.—*The Interior or Optical and Mechanical Part of the Sextant* is shown Fig. 212. *I* index glass, fixed over the toothed segment on the same axis. The pinion is shown working into the segment moved by the milled head *O* of Fig. 211 on the face of the sextant. Fig. 212: *C* horizon glass, cut by *ED*, adjusts to the vertical by screws $C\,C'$ which have square fittings on the face of the instrument, shown Fig. 213 full size. The differential adjustment between horizon and index glasses is made by a screw with square fitting at P. This adjustment acts by screwing against a helical spring, shown at Q. The reflected rays enter by a wide window in the side of the box Fig. 212 d to d', the direct rays by a small window ff'. The path of the ray is shown by fine lines from R to E, for the position in which the index and horizon glasses are placed. The place of the eye through the pin-hole is shown white. S shades with their axes are shown cut off, to prevent confusion of other parts. They are simply round discs of parallel glass on arms which rise from the back of the face by pressure of the nibs at S.

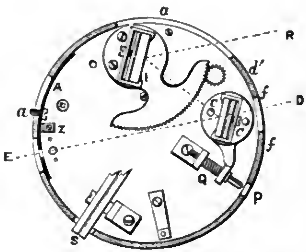


FIG. 212.—*Box sextant under the face.*

541.—*The Construction of the Box Sextant* may be fairly inferred from inspection of the engravings. The face-plate is made of a casting in brass $\frac{1}{8}$ inch thick, which should be well hammered to harden and stiffen it. The axis, which has a wide collar, is fitted into a hole in the plate, first by turning it as exactly as possible, and then by burnishing it in by friction, the hole being broached slightly conical with a D-broach. The careful fitting of the axis is an important part. The horizon glass frame Fig 214 is held down by a central screw which fits tightly both in its fore hole and thread. The flange of the tray F is cut to an angle on its under side to permit adjusting to verticality by rocking over this angle, by tightening and loosening the adjusting screws $c\,c'$ which protrude in square heads to the face of the instrument. The horizon glass H, which is half silvered, is fixed in a tray-piece which has two narrow fillets turned to the face of the glass, and a spring-piece at the back brought up by a screw a. This glass is entirely open at its unsilvered part. The toothed segment should be cut upon its own axis, and although fitted to the pinion without any looseness, it should not press the index axis. The silver is inlaid in the arc on the plan shown Fig. 108. The vernier is soldered closely on the index and should read down to a fine, clean edge.

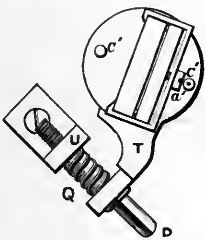


FIG. 213.—*Plan of horizon glass.*

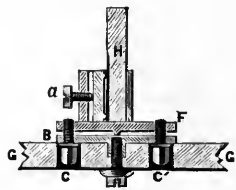


FIG. 214.—*Section of the same.*

542.—*Examination of the Box Sextant.*—The glasses should be cleanly silvered, with a sharp, clear cut between the silver to the clear glass of the horizon glass. The pinion should move softly and equally in causing the index arm to traverse the arc. If the pinion is moved in little jerks backwards and forwards there should be no shake, but the index should follow every slight motion. The magnifier rising joint should move rather stiffer than the traversing joint, so that the focus is not changed by traversing across the arc. The magnifier should have about 1 inch or under focus, and should stand square to the plane of the sextant when in focus. The graduation should be deep and fine, and the vernier should read $30 = 29$ at the two ends and the centre of the arc. If there is a small excess or defect of vernier to arc, this should be noted and allowed for, either at the time of reading or as an index error. The sliding fittings of the pin-hole sight, shades, and under shutter should move firmly but not stiffly. The telescope should fit without shake. The covering box should fit well in both positions of cover or hand-hold.

543.—*Adjustment.*—The box sextant is best adjusted by the sun upon the plan described art. 522. The adjusting screws, as already stated, are moved by the key, which unscrews from the face of the sextant Fig. 211 *K*. The adjustment is made permanently by the maker, except only that of the horizon glass, which is at the command of the user. The adjustment to perpendicularity of face is made by the two screws upon the face near *b*; adjustment to zero of arc by the screw at the side *a*. In defect of appearance of the sun, the sextant may be adjusted to any clear, sharp line, as that of a stretched piece of twine, for perpendicularity of plane, and to any object of clear outline sufficiently distant, say at half-a-mile, to avoid error of parallax for index zero, art. 505.

544.—*Use of the Sextant.*—The sextant has its under shutter opened by pressing the stud attached over in its slot. The nibs of the shade levers Fig. 211 *S* are then raised and the shades protruded. The cover is then screwed, or slid on if it fixes with bayonet notches, upon the under side of the sextant to form the hand-hold. The pin-hole sight is pressed over for use if not already in its position, unless it is intended to use the telescope. The box sextant is held in the left hand, with the right-hand thumb and forefinger constantly holding the milled head, and turning this so as to bring the any two objects, of which it is desired to obtain the angular position to the observer, exactly in apparent juxtaposition the one over the other. In turning the milled head it is better to let all the other fingers of the right hand clutch and steady the instrument. To take angles objects should be observed that cut sharp, erect outlines, as buildings, posts, trees, etc., if possible. In open country it is necessary to use pickets, to be described further on. With pickets the reflected image of the upper half of one picket should form continuous outlines with the direct image of the lower half of the other picket in the eye, so that the pair of pickets appear as one. Where an angle greater than 120° is required an intermediate picket is set up, and angles taken to the right and left of this are added together.

545.—It must always be remembered that the sextant takes angular positions *actually*, whereas plans are made in *azimuthal* angles. There are some not very satisfactory means of approximate correction for this, for which books on surveying may be consulted; but altogether the sextant is not very useful for taking angles for plans on other than fairly level ground, wherein it is proved a most valuable and sufficiently exact instrument. Where ground is undulatory fairly good work may be done with it by taking stations for exterior triangles at equal heights on the hill-sides, as ascertained by a hand level or clinometer to be described, or sometimes from hill-top to hill-top where these are of fairly equal heights. For sketch plans of very hilly or mountainous districts the prismatic compass art. 126 is better, as this gives, although with less precision than the sextant, its angles in azimuth.

546.—**Box Sextant with Supplementary Arc.**—This sextant is preferred by many for its more extended use. It is complete as an ordinary sextant for angles up to 130°; but it is thought desirable to extend the angle to 220°—by a single observation this may be done. The ordinary arrangement of the box sextant just described is left intact and forms the upper part of the instrument. This arrangement, as in the box sextant, is attached entirely to the face or arc plate, the only difference being that the index glass is made of less depth. For the supplementary arc arrangement a mirror is fixed upon the lower or *sole plate* exactly under the position of the index glass. This mirror is termed the *supplementary index glass.* The position of the face of this glass is at right angles to the face of the ordinary index glass when the index is at zero. The arrangement of glasses is shown Fig. 215: $M M'$ index glasses. The supplementary angle is read through a separate pin-hole sight which is placed at about 90° from the pin-hole sight of the proper sextant and a little lower down on the rim. The arc of this sextant reads in the ordinary

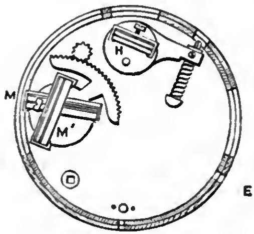
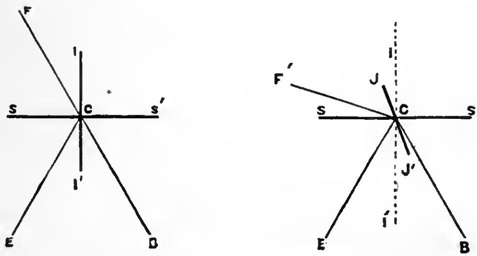


FIG. 215.—*Interior construction of box sextant with supplementary arc.*

manner, left to right, to an inner circle of figures for angles from 0° to 130°. The supplementary arc reads by the same vernier and is figured in the same manner at the tens; but it reads into an outer circle of figures which progress in the *reverse direction*, that is, right to left. The readings of the supplementary arc are from 90° to 220°, so that for a certain range, that is, for angles from 90° to 130°, these may be taken either by direct arc or by supplementary arc. The supplementary angle is taken by means of the coincident images of *two reflections*, one from the index glass and one from the supplementary horizon glass, and not by one direct and one reflected image as in the sextant proper.

547.—*Theory of Supplementary Angles to the Sextant.*— For the measurement of these angles we have to consider direct reflections only of two reflecting planes placed one above the other nearly in contact, so that the images projected from either plane may reach the eye superimposed. Let Fig. 216 $I\,I'$ be the surface of a mirror *(index glass)* which is movable to any angle in relation to the face of the mirror $S\,S'$ *(supplementary horizon).* For demonstration of the principle these mirrors are shown in this diagram at 90° to each other; therefore coincident reflections will be at $90°+90°=180°$. Let the lines $F\,C$ and $B\,C$ form a right line (180°): F fore sight and B back sight. An object at F would be reflected from



FIGS. 216, 217.—*Diagram of supplementary arc sextant.*

the mirror $I\,I'$ to the eye at E, the angles $F\,C\,I$ and $E\,C\,I'$ being equal. Another object at B reflected from the face of the mirror $S\,S'$ would also reach the eye at E, the angles $B\,C\,S'$ and $E\,C\,S$ being equal. And as the angles $F\,C\,I$ and $B\,C\,I'$ are equal in crossing a right line, the line $F\,C\,B$ must be also a right line (180°) which is indicated by the angle of coincidence of the two reflections to E. The positions of the reflections are shown as angular measurements upon the graduated arc.

In Fig. 217 let $S\,S'$ remain as before, and the angle $B\,C\,E$ will remain as shown in both figures. Move the index glass from the position *I I'* of Fig. 216 to the position *J J'* of Fig. 217, so that after this movement the eye at *E* would receive the image of an object at a new position *F'* as reflected from the mirror *J J'*, *F' C J* and *E C J'* being equal. In this process, as the reflector *J J'* in the angle *I C J* would have moved half the angle *J C F*, the record of this movement upon the index, which moves with *J J'*, is at the same time double the true angular difference as with the sextant proper fully described, the graduations being in both cases the same *pro ratâ*. The increase of angle is taken supplementary to the angle given by the first reflection, by addition to this angle in a direction right to left from the right line of the former sight *E C;* consequently this increase is read backward on the sextant, that is, right to left, and is indicated by the outer line of numerals.

548. — *Manufacture.* — The general structure of this instrument is nearly the same as the ordinary box sextant, except the parts just referred to. The supplementary horizon glass is an ordinary mirror similar to the index glass but of only $\frac{1}{4}$ inch in depth: it is mounted in the same way. Its adjustments are similar to the horizon glass in kind, but there are no exterior screws, this glass being permanently fixed by the maker. Opposite the supplementary horizon glass a wide window is cut through the rim of the case near the sole plate to take sight of the object at angles exceeding 120°, so that in this sextant two large windows are cut out opposite to each other. The diameter of this sextant is 3 inches; the exterior depth, about $1\frac{5}{8}$ inches, that is, $\frac{1}{8}$ inch deeper than the ordinary box sextant. It weighs about 20 ozs. It is carried in a solid leather case with strap to pass over the shoulder.

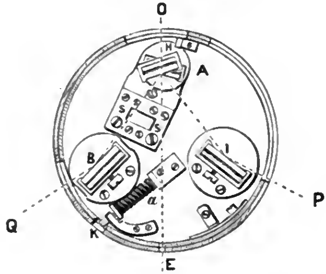
549. — *Examination and Adjustment.* — Examination will be nearly the same as for the common box sextant.

The most important point is that the readings taken within both arcs should be alike, assuming, which is necessary, that the part comprising the sextant proper is perfectly adjusted. Thus there is a 90° on both direct and reverse arcs. The 90° may be measured by any pair of objects on the direct arc, and afterwards compared by shifting the index to the 90° on the supplementary arc. If no object is found at 90°, 95° 30′ or any other quantity may be compared. It is also well to compare readings at or about 140° on both arcs. The 90° and 140° fall over each other in the reading, and this checks the duplicate error. If the adjustment is not fairly perfect, the instrument should be returned to the maker. Indeed, this instrument would be better without any external means of adjustment, leaving these to be made by the optician in such a permanent form as they will not be liable to change. This instrument is, as the plain box sextant, exceptionally protected from accident.

550.—*In Using this Instrument* the arc up to 120° is taken exactly as with the plain box sextant. Beyond 120° the sextant is shifted to take sight through the supplementary pin-hole, it being particular to observe that the pinion is now turned the *reverse way to increase the angle*, and that the vernier reads for the supplementary arc right to left. It is in this reversing, if not carefully observed, that a little difficulty occurs in using this instrument.

551.—**Box Sextant, with Continuous Arc to 240°.** This instrument is an improvement by the author upon an instrument originally designed by Mr. W. Franklin. The reading is taken continuously from the same sight-hole and by the same arc, and in a direct manner without any reversal for part of the arc. This sextant reads with certainty to 240°.

In the construction of this sextant there are two horizon glasses superimposed one above the other and crossing each other, with faces which are adjustable for perpendicularity at an angle of 120°. The horizon glass is severed top and bottom with a clear band cut through it, as in the old form of back-sight nautical sextants. One of the wide glasses reflects into the upper mirror and the other into the lower mirror of the horizon glass. The pin-hole sight or the telescope is placed in the same position as in the plain box sextant described. The horizon glass is fixed and both the index mirrors adjust to angular positions, or one index glass only and the horizon glass adjust. This arrangement is indifferent. The arc is graduated as the plain box sextant, but it



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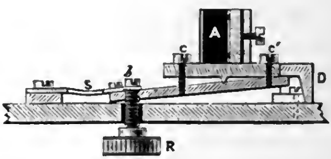

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FIG. 218.—*Stanley's continuous arc box sextant.*
FIG. 219.—*Section supplementary horizon arrangement.*

reads with two circles of figures from 0° to 120°, and from 120° to 240°, the 0° of the under line being under 120° of the upper. When the arc is set to zero the index glasses are in such a position that the direct vision and the reflection as seen in the upper mirror of the horizon glass are coincident for direct images, as at the zero of the plain sextant, but at this point the lower mirror of the horizon glass reflects to the eye an object at 120°. When the index is moved forward the angles continue onward, reflected from both glasses, so that the upper reads on 10°, 20°, 30°, etc., whereas the lower reads 130°, 140°, 150°, etc.; so that if the objects desired to be triangulated are under 120° the coincidence is seen in the upper mirror, and if over this in the lower, the great distance of 120° apart of the angles preventing the risk of accidentally taking the one for the other. In the compact form of a box sextant this instrument embraces the uses of the ordinary reflecting circle of double the diameter, due to the entire circle graduation; and the range is sufficient, as beyond 240° the head materially interferes with observation. The size and weight of the instrument are but little over, and may be the same as, the plain box sextant. The adjustments are made permanently by the maker. The use of this instrument is fully inferred from the description given. The construction is shown in Fig. 218. *E* place of the eye with direct ray through the horizon glass *H* to *O*. The index glass *I* is that of the ordinary sextant, shown by dotted lines, throwing the image of an object at *P* to the upper horizon glass and thence to the eye at *E*. *B* is the fixed supplementary glass with its surface at 60° to the lower horizon glass at *A*. The sight lines from an object at *Q* are reflected from *B* to *A* and thence to *E*. A spring arrangement shown *S S* with a milled head underneath permits the lower glass *A* to be drawn down to convert the instrument into a simple box sextant.

552.—*Details of Spring Arrangement* to the supplementary horizon glass are shown in Fig. 219 full size in section. The springs *S S* in Fig. 218 and *S* Fig. 219 form two points of support to the horizon glass, the silvered face of which is shown at *A*. A third point of contact is near *D*, placed in the centre of the end of the supporting plate for the horizon glass. When the screw *R*, which is placed in a loose fitting, is released, the springs bring the supporting plate up tight to *D* and hold the horizon glass firmly in an elevated position. When the screw *R* is tightened it brings this glass down.

The horizon glass is adjusted over a rocking centre by the screws $C C'$. A screw and collar b prevent loss of the screw R. By this arrangement the horizon glass is brought in or out of the field of view, for using it for the supplementary arc or leaving it the plain sextant.

553.—**Open Surveying Sextants**, similar to nautical sextants but generally smaller and of stronger construction, preceded the box sextant, and are still used to a limited extent upon the Continent, particularly with some form of supplementary arc, or arrangement to produce a large part of reflecting circle. These forms are also occasionally revived by the opticians of our own country. The reason for this is easily seen. To the optician who lives in a town, moves on a level surface, and has comfortably warm hands, even in the winter, to hold and move the separate parts of an instrument, the open sextant appears the most perfect, as he can get at every part easily to clean and adjust. The surveyor takes another view of the subject. He is exposed in the open country to all weathers and all difficulties of movement over the land; therefore that form of instrument which is best protected and least liable to injury by a fall will be sure to be popular with him, particularly if the instrument is of portable form. It is upon these conditions the box sextant of some form alone is generally preferred.

554.—**Optical Square.**—This extremely handy little instrument is invaluable for taking offsets in chaining for any irregularity or obliquity to the right line in the boundaries of fields, hedgerows, fences, streams, etc., giving as it does instantly at sight a right angle to any object that may be sighted on either hand. The instrument is constructed optically exactly the same as a box sextant; but the glasses are fixed with their faces permanently at the angle of 45° to each other, by which the reflection of 90° is truly given on principles fully discussed at the commencement of this chapter. This instrument being made very small, that is, 2 inches or less in diameter, it is found most convenient for manipulation to place the adjustments to the larger glass, that is, the index glass. The horizon glass Fig. 220 *h* is therefore fixed firmly as the index glass of the box sextant by two screws to the sole plate. The index glass *i* is held and adjusted in exactly the same manner as the horizon glass of the box sextant, as shown in detail Figs. 213, 214, the only difference being that the frame that holds the glass is made of the entire height. The rim of the case of the optical square is formed of

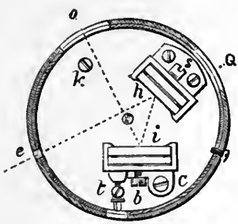


FIG. 220.—*Optical square.*

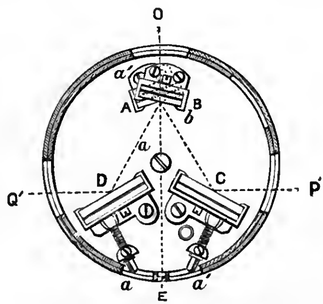


FIG. 221.—*Double optical square.*

a short length, $\frac{3}{8}$ inch to $\frac{5}{8}$ inch, of a pair of telescope tubes which slide easily together. One of these is attached to the sole plate and the other to the cover, so that at first they close together as a box and lid. All the openings required for sight, as Fig. 220 at *Q* for horizon sight, *o* for index sight, and *e* for pin-hole or eye sight, are cut through the two tubes.

The inner case is cut in the plane of some part of the circumference of the instrument from a pin-hole into a bayonet notch, with sufficient horizontal slot for the two cases to revolve upon each other upon a fixed pin sufficiently to close and open the sight holes. This plan secures the instrument from any intrusion of dust when it is closed and out of use. An adjusting key is placed in the case, held by a tube or stud at the position *k*. The weight of the entire instrument is about 4 ozs. if of ordinary make; but smaller ones are made in German-silver or silver, 1¼ inches diameter, ⅜ inch thick, weighing under 2 ozs. These latter are very convenient for the waistcoat pocket and are equally exact to the larger instrument. From *e*, the eye, the reflected sight lines are shown dotted to *h i* and the object *o*.

555.—*Examination and Adjustment of the Optical Square.*—Place two pickets in an open space at a distance apart, the further the better. Range an intermediate short picket in right line with these or *t* the top of a stake the height of the eye, or what is better still if at hand, the top of a tripod stand. Place the optical square over the intermediate station or tripod. Place another picket, which we will distinguish as the 90° *picket*, at a distance, and make this appear in the optical square coincident by reflection with the direct sight of one of the pickets in the right line from our station. Turn the optical square right over on its place, and in looking the opposite direction take a sight at the other right line picket and observe the 90° picket. If this still appears coincident with the direct line in reflection the optical square is in perfect adjustment. If it does not appear so, half the difference must be adjusted by means of the key taken from the interior of the case and placed on the square at *k*, and this observation repeated until the 90° is correct.

556.—*In Using the Optical Square* it is customary to walk along the chain line at about the desired position for taking an offset, looking by direct vision through the plane part of the horizon glass *h* at a fore sight object until the required object, which may be the corner of a field or a tree or other, is sighted by reflection at right angles to this, where it appears by coincidence of image with the fore sight. The heel of the forward foot in stepping indicates fairly the vertical position of the optical square; but some surveyors prefer the use of a drop arrow to fix the point. The offset is then chained in the line.

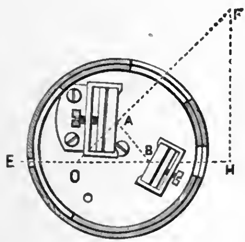
557.—**Double Optical Square.**—This instrument is exactly what its title indicates, that is, two optical squares, the one placed exactly over the other, the one reflecting to the right hand and the other to the left. A simpler name however would be an *optical cross.* This arrangement of reflectors greatly extends its use. First, as regards the 90°, this need not depend in any way upon the position of the observer, as two objects may be observed, one to the right and one to the left, to appear to cut the direct forward line of sight, and therefore to cut the base line at the exact position of the instrument at right angles to it. Secondly, an intermediate station can be found in direct line between any two points, as the $90^\circ + 90^\circ$ forms this line.

558. — The arrangement of the optical part of the instrument is shown Fig. 221. The two index glasses $C\ D$ are fixed at equal angles to the direct line of sight $E\ O$. The two horizon glasses $A\ B$ are superimposed with the interval of a small space, $\frac{1}{16}$ inch, between them. The horizon glasses are each separately adjusted so that their reflecting planes are respectively 45° to the index glass from which they receive the reflections. The diameter of the instrument as usually made is about $2\frac{1}{4}$ inches; its depth, $\frac{7}{8}$ inch. The weight is about 9 ozs. It is generally carried in a light, solid leather, sling case. Total weight with instrument, 12 ozs.

559.—*Examination and Adjustment of the Double Optical Square.*—1. Place the instrument, as already described for the optical square, at a station intermediate between two pickets. Examine the right angles, first looking towards one picket and then towards the other from the same position, as with the optical square, turning it over for this examination. 2. Turn the instrument half round and examine it this way also by turning it over again in like manner. Adjust either horizon glass if required. 3. Now take the position for the eye of the former 90° and see if the extreme pickets appear in true position by the exact coincidence of their images at 180°. 4. Do this again, facing the opposite way and turning the instrument half round. If the extreme pickets still range in line from the central station the adjustment is perfect. If they do not do so half the error must be corrected by returning to the first and second adjustments to find out between which pair of mirrors it exists. For this adjustment the instrument is much better to be placed upon the top of a tripod, as the position of the axis should remain after turning it over or changing the direction of the instrument. It is only from severe accident that the maker's adjustment will be disturbed.

560.—**Apomecometer.**—This little instrument, the invention of Mr. R. C. Millar, is intended to measure the height of buildings, trees, etc., by measuring the distance from the vertical upon the surface of the ground. It performs one of the functions of the box sextant in the same manner as the optical square, that is, to measure a single angle by reflection. The angle measured is 45°, consequently by measuring a space upon level ground up to a vertical, the vertical will be known, this being equal to the horizontal. Of course this will always be approximate, as the ground will seldom be truly level; but by taking a position, even on an incline, as nearly as possible level with the object, a very fair estimate may be made. Horizontal distances may be measured in the same manner from a perpendicular to any line.

561.—The instrument is constructed in exactly the same manner as the optical square just described as regards its mirrors and its adjustments, but the faces of the mirrors are fixed at the angle of 22° 30′, so as to give reflection of 45°, upon principles fully discussed. In Fig. 222 *A* is the index glass, *B* the horizon glass, *E* the pin-hole sight. There is a window opposite the index glass and one behind the horizon glass, each sufficient to take in a wide field of view at about 45° and in the direct line respectively *E* to *H*. These



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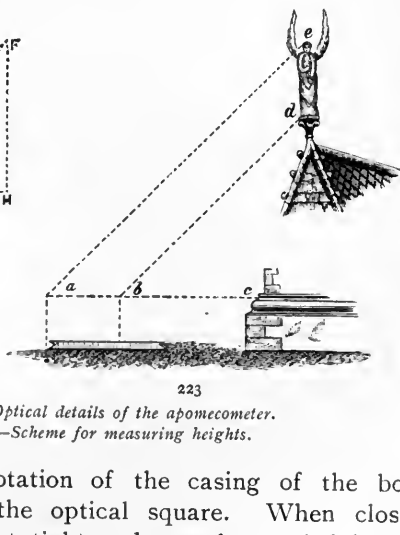

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FIG. 222.—*Optical details of the apomecometer.*
FIG. 223.—*Scheme for measuring heights.*

windows close by rotation of the casing of the box, which is made as the optical square. When closed the instrument is dust-tight and may be carried in the waistcoat pocket loose or in a light, snap, leather case. The size of the instrument is $1\frac{1}{4}$ inches diameter, $\frac{3}{8}$ inch in thickness, weight 2 ozs. in German silver.

562.—*The Use of the Apomecometer.*—To measure the altitude of a building the open side nearest level is selected, and a station for observation is taken which is at a distance thought to be approximate to the height.

The instrument is held edgewise with the pin-hole sight to the eye, and the reflection of a point of the building about level with the eye is observed by direct vision through the instrument. At the same time there will appear a reflection of the summit of the building. If we now walk backwards or forwards as the case demands, keeping sight of a level object, as for instance in Fig. 223 the plinth of a building, then at a certain point the summit of the building will appear by coincident reflection. The distance from the object is the same as the height of the point of sight to the summit, assuming that this is vertical to it. This distance may be measured on the ground, or if a rough estimate is required it may be stepped, the principle of which is shown by Fig. 222 in the line OH, being equal to FH. If a part of an object is required to be measured such part may be taken on the horizontal plane, as for instance the height of the figure in Fig. 223, by *a b* being = *e d*, as the base *a b* can easily be measured. An approximate may be found by dropping a small pebble at *a* and at *b* and then measuring the distance apart of these pebbles.

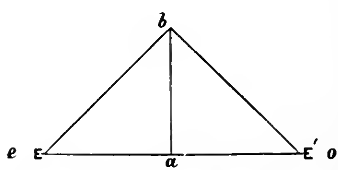


FIG. 224.—*Scheme for measuring distances.*

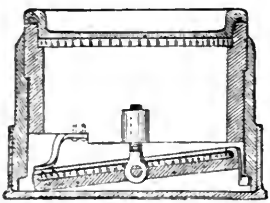
563.—The distance of an inaccessible object may be measured, as for instance a buoy at sea, by measuring in any straight line double the distance and taking equal angles thereto by the apomecometer on any direct line. A very approximate idea may be formed by walking over measuring points. As for instance, *b* being a buoy at sea, walk from *e*, which may be a walking-stick set up towards an object *o*. At *E* the buoy and object *o* will appear to be coincident. Then drop a stone or make a mark directly under the instrument. Walk on till beyond *E'* and turn to face *e*. Now in returning, the buoy and the object *e* will appear coincident at *E'*. The distance *E E'* is double that of the intermediate *a* to *b*.

564.—**Humphreys' Cycloscope.***—This instrument is designed to set out railway curves. It is constructed in the form of a short cylinder of about $2\frac{1}{4}$ inches in length and diameter. A plane mirror of parallel glass is placed at each end of the cylinder. One mirror is fixed permanently perpendicular to the cylindrical axis and is silvered over its entire surface. The other mirror is silvered over an equal half of its surface only, and is arranged to move angularly on an axis perpendicular to the cylindrical axis. Mechanical arrangements are made whereby the angle subtended between the fixed and movable mirrors may be adjusted to any angular magnitude required. By this means a series of reflections looked at through a small hole in the fixed mirror will appear at the edge of the half mirror ranged at regular intervals, and will fall upon the circumference of a true circle.

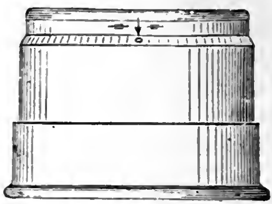
565.—The principle of this instrument is that when two mirrors are placed nearly parallel, with their reflecting surfaces facing each other, a series of images of an object are produced, and the angles subtended at the mirror between each successive pair of images are equal, and each of these angles is equal to that between the mirrors. Now when from a point in a circular arc a series of lines are drawn making equal angles, their directions cut the circumference at points equally distant from each other. This angle is given in minutes by the formula

* Patent No. 723, H. T. Humphreys, March 1866.

$1718{\cdot}873 \frac{a}{r}$, where a is the length of the part of the arc cut by the lines and r is the radius of the circular arc. If then the mirrors are set to this angle, the successive images of an object will fall in the direction of points in the circumference of a circle of radius r, and any distance a apart, as measured along the arc, the distance of the instrument from the object being first set out at a. Thus by chaining from point to point a distance a, and fixing poles to correspond with the direction of successive images of the first pole, a series of points in the circumference of a circle of radius r will be obtained. The first pole is fixed on the tangent through the point from which the arc commences. When $\frac{a}{r}$ is not greater than $\frac{1}{20}$, the chord may be taken for the arc.



225.—*Section.*



226.—*Side view.*

FIGS. 225, 226.—*Humphreys' cycloscope for setting out railway curves.*

566.—The engravings Figs. 225, 226 represent the instrument as originally constructed, in which the adjustment is made by screwing the case. It was found afterwards to be better to put a clamp and tangent screw and to read the arc by vernier to minutes. A confusion of images is caused by the simultaneous reflection of the hole through the entire mirror, with the reflection of the pickets used to set out the curves. Some improvement is made in this by making the sight hole mentioned a clean line cut through the silver of the entire mirror perpendicular to the silvered edge of the half mirror. This line reflects only very narrow black images. If the pickets used are made red and white the differences of the reflected images of the line and the pickets are distinguishable with less confusion. The instrument has not proved very satisfactory in use.

CHAPTER XI.

ALTITUDE MEASURING INSTRUMENTS OF A PORTABLE KIND—SIGHTED POCKET LEVEL—TELESCOPIC LEVEL—ABNEY'S CLINOMETER—TROUGHTON'S CLINOMETER—BUREL'S REFLECTING LEVEL—CLINOMETERS: DE LISLE'S REFLECTING — STANLEY'S REFLECTING — STANLEY'S PRISMATIC — BARKER'S — CONTINENTAL FORMS — WATKIN'S CONCAVE REFLECTING—STANLEY'S DIRECT-READING—GEOLOGICAL — COMBINED COMPASS AND RULE FORMS — MECHANICS' LEVELS AND CLINOMETERS — BONING RODS — WATER LEVELS — FOOTNER'S RAILWAY GAUGE LEVEL AND CLINOMETER.

567.—Where small portable instruments of the box sextant or prismatic compass class are used for surface triangulation, or a level for levelling only, it is customary to carry some form of clinometer to give surface inclinations for correction of chain measurement on the surface and for cross inclinations of a section. The clinometer which is used for these purposes forms also a pocket level. It is found therefore convenient to group pocket levels and clinometers together in this chapter, as the one is very frequently a modification of the other.

568.—**Sighted Pocket Level.**—This consists of a tube which is generally drawn of square section. A pin-hole sight is made in the closed end of the tube Fig. 227 at E. The field end of the tube F is half closed, or a circular window is made eccentric as shown at F'. The sight is taken by looking through the centre of the pin-hole across the hair in the window F'. A level with a small bubble is placed or inserted in the top of the tube at B. The metal casing of this is cut away on the upper and under sides to render the bubble visible from the interior of the tube by means of a reflector *R* which occupies one half vertical section of the interior of the tube, as shown at *R′*. This is placed at 45° to the axis, shown by dotted lines to *R*. The reflector is placed upon an inner tube so that it may be withdrawn to be cleaned. When the level is set

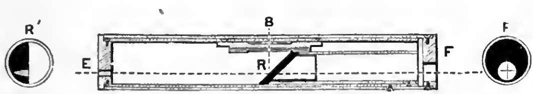


FIG. 227.—*Sighted reflecting pocket level.*

horizontally, a distant object in the direct sight line is seen through half the tube; and simultaneously the reflection of the bubble in the other half appears, as shown at *R′*, to be bisected by the edge of the screen: the distant object and the eye are then level. The instrument is about 4 inches long and weighs about 8 ozs. in its case.

569.—**Pocket Telescopic Level.**—In the above-described pocket level, where it is made short, the average middle-aged man will not have sufficient accommodation of vision to be able to see the bubble and the screen sharply defined simultaneously with the distant object

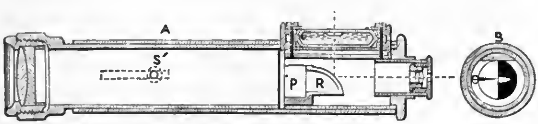


FIG. 228.—*Pocket telescopic level.*

to which the level is to be taken. In Captain Barrie's* level these objections are avoided by making the reflector and bubble form part of a telescope Fig. 228. An achromatic of short focus is used, and the eye-piece is of long focus so as to bring the bubble in focus in the

* Patent No. 69, Wm. Barrie, 1856.

centre of the mirror, which is made of curved form to decrease the apparent size of the bubble. The image of the bubble does not give by bisection a very definite index. The author has found this level may be much improved by placing a point in the telescope at the mutual focus of the object-glass, eye-piece, and the bubble. The appearance of the mirror and point is shown at *B*. The point is shown by a dot at *P*. The curved mirror *R*. The dotted line shows the path of reflection from the bubble. This level will work with very fair accuracy as a hand instrument. Size, about $4\frac{1}{2}$ inches by $\frac{3}{4}$ inch. Weight in case, about 8 ozs.

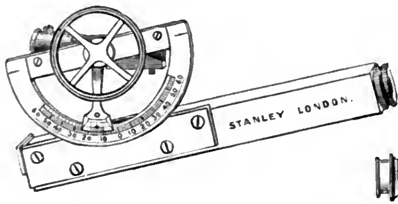


FIG. 229.—*Abney's clinometer.*

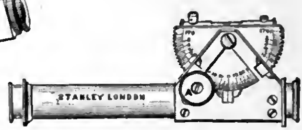


FIG. 230.—*Troughton's clinometer.*

570.—**Abney's Clinometer.**—This very popular little instrument, the invention of Captain Abney, Fig. 229, embraces the same form of sighted level with reflector as that shown in section Fig. 227, but the level instead of being fixed lineal with the tube is placed above it upon an axis which forms the centre of a divided arc. The axis with the bubble is turned to any angle by means of a light, milled-edged wheel placed in front of the arc. The axis carries an index which reads on the arc the angular position of the level to the axis of the instrument. There is also a scale placed upon the arc which gives a percentage allowance to be made in the chain in measuring inclination. As the bubble of the level in its course passes the centre of the axis its reflection is made to become coincident with the axis of the sight through the tube only when it is quite level. Therefore whatever the inclination of the tube the bubble may be brought level by turning the milled head until it appears centrally in the sight axis of the tube, and the angle at which this occurs can be clearly read afterwards upon the arc. The size of the instrument in its case is 5 by $2\frac{1}{2}$ by $1\frac{1}{2}$ inches; weight, 8 ozs.

571.—**Troughton's Improved Abney's Clinometer.** There is a little difficulty in Abney's clinometer in bringing the bubble to the centre of its run directly by movement of the fingers when the instrument is held to the eye. In Troughton & Simms' improved instrument Fig. 230 the arc is toothed, and it is moved by a pinion similar to the movement of the box sextant, so that the bubble moves slowly in relation to the motion of the fingers in adjustment. This enables it to be set with greater facility and accuracy.

The difficulty of sight accommodation is found in the clinometers just described, for persons of weak sight, just as before mentioned for the simple hand level; but this instrument admits of the telescope principle as well as the other, but it necessarily enlarges the instrument and increases its weight.

572.—**Reflecting Level.**—This simple level Fig. 231, the invention of Colonel Burel, is one of the most portable. When it is used with a fair amount of care it will give very approximate results. It consists of a piece of parallel glass which has half the surface silvered to form a reflector. It is suspended in such a manner that the glass hangs vertically by gravitation. The position of the mirror to the plain glass may be that shown in the engraving, or perhaps preferably the edge of the mirror may be placed vertically, as shown at *R* Fig. 232. The mirror Fig. 231 is inserted in a solid metal frame which is suspended from a gimbal which permits it to hang perfectly free to the action of gravitation. The centres of suspension are made with slightly rounded knife-edges. A ring at the upper part of the instrument is placed over the thumb or finger to support the instrument in use. A stout pin passes through a prolongation of the lower part of the frame, screwed or otherwise, which permits adjustment by filing to bring the mirror when it is suspended exactly into a vertical plane. The instrument, fitted into a neat case, weighs from 5 ozs. to 9 ozs.

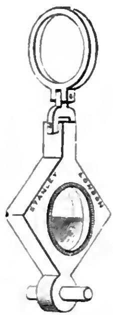


FIG. 231.—*Reflecting level.*

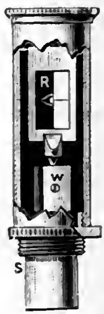
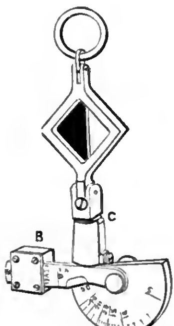


FIG. 232.—*The same construction in protecting case.*

573.—*In Using the Reflecting Level* it is held upon the thumb at about arm's length, and adjusted by raising or lowering the arm until the reflection of the pupil of the eye seen in the mirror is exactly bisected by the line cut by the mirror against the clear glass. The distant object seen in front that cuts this sight line, and the image of the pupil of the eye, will then be in true level position with the eye of the observer, provided the air is still, so that the mirror is not deflected from verticality. From the natural unsteadiness of the hand there is some little difficulty of getting this level quite free from oscillation. This may be obviated, or nearly so, by clutching a picket or staff by the hand and suspending the level from the thumb projected out for the purpose, or by resting the hand against a tree or other firm support.

574.—**Reflecting Level in Case.**—In the presence of wind much greater exactness may be secured by placing the pendulous level, just described, in a tubular case Fig. 232. The case is made of double tubes, so that the aperture cut on one side may by a half turn of the outer tube close and protect the instrument when out of use. The transparent side of the inner case is sometimes closed by thin glass tube of its own internal diameter. It is much better if made with two vertical sides glazed with parallel glass. When this form of instrument is used, it may be, if required, made to fit on the top of a light staff. The eye is then brought with much greater certainty to the point of bisection on the edge of the mirror, and much greater accuracy is attained in levelling with it.

575.—**De Lisle's Reflecting Clinometer.**—There have been several arrangements made for converting the Burel level into a clinometer: that devised by General A. De Lisle, R.E., with modifications by Colonel Bell and Mr. Alfred Cooke, as represented in Fig. 233, is the most popular. In this a heavy arc is constructed upon the lower part of the instrument. This is jointed upon a vertical axis at *C* so that it may be revolved to bring the mass of the arc either forward or backward, to take inclines upwards or downwards, or to rest at an intermediate position to make the instrument flat and portable in its case in the position shown in the figure. The arc has a stiff centre axis with a radial bar, the edge of which forms the index. A sliding weight is placed on the radial bar, which is of sufficient weight when slid out to its greatest extension to exactly counterbalance the weight of the arc in a horizontal position and to make the mirror quite vertical. In this position it forms a simple Burel level. A set of gradations are made upon the arc, which are numbered 1 to 50 to 1 to 1. The radial bar index set to one of these gives the amount of inclination that will result from the coincidence of the reflection of the centre of the pupil of the eye cutting the object to be observed. The length of this instrument is about 6 inches. Its weight about 10 ozs.



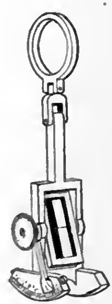


FIG. 233.—*De Lisle's reflecting clinometer.* FIG. 234.—*Stanley's reflecting clinometer.*

576.—**Stanley's Reflecting Clinometer.**—This conversion of Burel's level into a clinometer was designed by the author as an improvement on De Lisle's in making it a lighter instrument and with a wider range. In this form the framework remains constantly vertical and the mirror only moves to varying angles of altitude. The axis of the mirror carries an index which reads upon an arc upon the side of the instrument 1 to 150, 100, 80, 60, 50, 40, 30, 20, 15, 10, 8, 6, 4, and 2. Upon the opposite side azimuthal angles may be read directly. Size, 4 inches; weight, about $3\frac{1}{2}$ ozs.

577.—**Prismatic Clinometer.**—This instrument was originally devised by the author about 1860. The form of the instrument is that of a prismatic compass art. 132. A similar card and talc dial is used to that of the prismatic, but this is centred upon a transverse axis which is pointed at the ends to fit into hollow centres. The card is weighted on one side, so that when the sights are in a truly horizontal position the prism will show the zero of the card cutting the sight line. If the instrument is inclined upwards or downwards, the degrees of elevation or depression will be indicated by the card retaining its pendular position. This is a very convenient instrument for use with the box sextant, and as it is only of about half-an-inch in thickness and of the same diameter, it will pack conveniently in the case with that instrument—weight, 8 ozs.

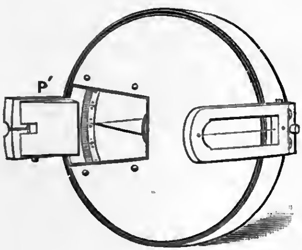


FIG. 235.—*Stanley's prismatic clinometer.*

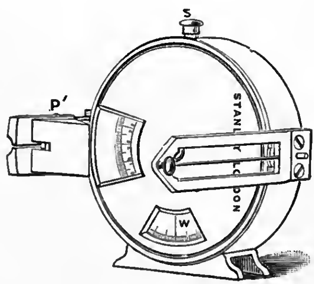


FIG. 236.—*Barker's clinometer.*

578.—*In Using this Form of Clinometer* the prism is raised or lowered in its sliding fitting until the divisions of the card are sharply defined. Then in looking over the edge of the prism through the slot above it, the hair in the window of the back sight will appear to cut the divisions of the card; and the object seen in the distance, in front of the hair to which the instrument is directed, will appear coincident with the number of degrees of inclination indicated by the card.

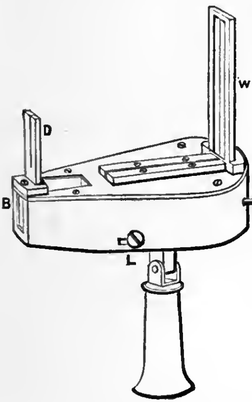
This clinometer is sometimes fitted upon a prismatic compass, so that inclines may be read by the same prism and sight arrangement. This is however done more neatly by the arrangement next described, if the instrument is intended to be used with the prismatic compass only, and is not wanted separately for use with the chain.

579.—**Barker's Combined Prismatic Compass and Clinometer.***—The prismatic compass of this arrangement is of Hutchinson's form art. 132. The clinometer is of the same kind as that just described, but this, instead of being a separate part of the instrument capable of detachment, remains permanent. To effect this arrangement the clinometer card is mounted over the compass card on a pin axis instead of centres. A part of the clinometer card is cut away so as to permit the compass card to be read beneath. This cut-away part is held by a stop to a position out of the field of the prism when the instrument is to be used as a prismatic compass. When the stop is released and the instrument is held with its face vertical, the pendulous clinometer card comes in view, and cuts by its reading through the prism the sight line, as before described for the prismatic clinometer. The prism is focussed to the upper or lower card by a long, sliding fitting. It is used as the instrument last described.

580.—*Continental Form of Clinometer.*—Hand clinometers on the Continent are generally made on Captain Burnier's plan Fig. 237, which was explained for the prismatic compass art. 133. Indeed this instrument is more generally combined with the prismatic compass. The graduation is set up on a plated ring vertical to the plane of the swing of a pendulum, shown in section Fig. 238 *A*. The reading index is a hair which is read on the graduation by means of a cylindrical lens *B*, when this is brought coincident with the sights *D′ W′* as described for Burnier's compass. When the clinometer and compass are combined the vertical rims stand

* Francis Barker's patent, No. 1926, 1881.

opposite to each other *A C*. Lifts, Fig. 237 *L*, are provided to take the working parts out of bearing, and a stop *S′* to prevent oscillation. The illustrations show the combined instrument: *B* cylindrical lens reading the drums; *A* clinometer; *C* compass; *D D′* fore sight; *W W′* windows, both of which fold down on the top of the instrument.



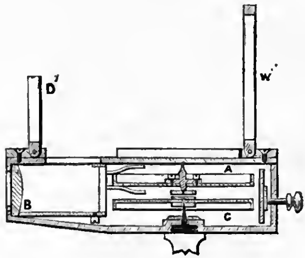


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FIG. 237.—*Continental form of clinometer (Burnier).*
FIG. 238.—*Section of the same.*

581.—**Major Watkins' Clinometer.***—The vertical plane of division is adopted as in that of Captain Burnier, but the reading, instead of being taken on the exterior of the ring by a magnifier, which entails a projection, is placed on the interior of the ring. This reading is magnified by a concave reflector, shown Fig. 239 at *R*, which reads to a line on a slip of ivory placed just beside the eye hole *E* shown in the engraving. The pendulum is stopped by a pin, upon which it springs when the box is rotated vertically to prevent wear when out of use. There is much less work in making this instrument than Burnier's, and the round form is more

* British patent No. 217, 1884.

portable. The only point on which it does not bear comparison is in that the concave mirror represents a uniform distance sight which makes the reading indistinct to persons of weak sight, whereas Burnier's admits of adjustment by placing the instrument nearer or further from the eye, the cylindrical lens being made large to admit of this form of adjustment. This instrument could be improved by the mirror being made adjustable. Weight, 6 ozs.

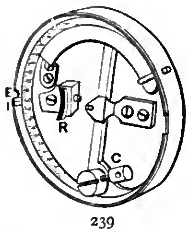

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FIG. 239.—*Major Watkins' clinometer.*

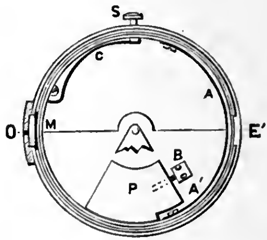

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FIG. 240.—*Stanley's direct vision clinometer.*

582.—**Stanley's Clinometer.**—About twenty years ago the author made a few clinometers with the circle reading vertically Fig. 240 *A A'* at the back of the instrument. These were unsatisfactory from the nearness of scale presenting difficulty of reading to other than young men with great accommodation of vision. Quite recently an improvement made in this instrument appears to make it satisfactory. Instead of an open aperture for reading the scale, half of a convex or cylindrical lens of the focus of the distance of the scale is placed in an aperture of nearly the diameter of the thickness of the instrument, as shown at *M*. Opposite the centre of the cut edge of the lens is a narrow slot: this cuts the edge of the graduation on a scale similar to that shown in Fig. 239—at *A A'* Fig. 240. This plan admits of the same form of accommodation to vision as Burnier's plan.

The scale *A A'* reads to a point in the window opposite the eye part *M*. The pendulum *P* is adjusted by a screw at *B*. Its oscillation is stopped by a spring *C* when the milled head *S* is touched. The spring *C* also forms a latch to the pendulum when it is inverted before putting it by. To use the instrument with the eye at *E'* it is only necessary to look through the window near *M* with the instrument held vertically at the object to which inclination is required: the point will then cut the degrees of inclination as shown on the scale. Weight, 6 ozs.

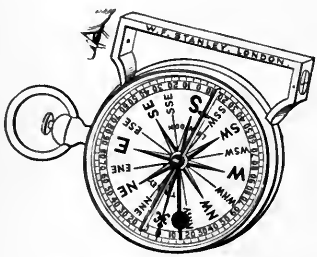


FIG. 241.—*Compass with clinometer sight.*

583.—**Clinometer Sights.**—A clinometer sight is often attached to a light pocket compass, as shown Fig. 241 at the upper part of the engraving, consisting of a pin-hole and hair cross. This, used in the manner shown by the position of the eye in the engraving, can only be made to take sight inclines by another person reading the pendulum index, which marks the inclination in the degrees to which the compass is divided. This portable pocket instrument is however useful in other ways. Standing face to the instrument it will measure inclines directly very fairly by looking over the top edge and bringing this to the visual rate of inclination at which the pendulum index can be read in front view. Geologists commonly use it in this way to take the dip of strata. It can also be used by putting it on or against any inclined surface. The instrument is generally put in a gilt or nickel-plated case. It is made of about 2 inches diameter, and weighs about 3 ozs.

584.—**Rule Form Clinometer.**—This is made in the form of a stout, 12-inch, one-fold, boxwood rule. It is much used by civil engineers as a working tool. It is intended to be applied directly to an inclined surface, either placed on a straight-edge or otherwise, generally to take the inclination of earth work. It may be placed upon a picket laid upon the ground to take natural slope. When used in this manner the lower surface is placed on the straight-edge or picket, and the rule is slowly opened until the bubble in the level in the upper

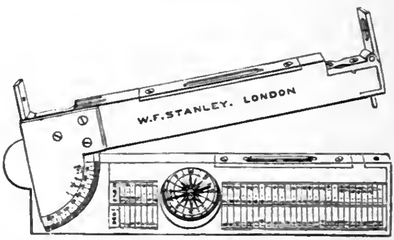
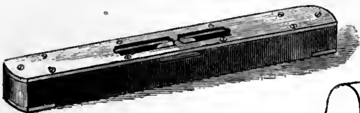


FIG. 242.—*Rule form clinometer.*

limb becomes central. The arc of the head joint will then indicate the inclination. It may be used in another way: the lower limb may be set level on the dumpy level compass or on any flat plane, and the inclination may be sighted through the pin-hole and cross-hair sights shown at the ends of the upper part of the instrument. The size of the instrument is $6\frac{3}{4}$ by $1\frac{3}{4}$ by $\frac{1}{2}$ inches; weight, 9 ozs. There are several varieties of this instrument. A sketching protractor with clinometer will be referred to with sketching instruments in the next chapter.

585.—**Mechanics' Levels.**—In crowded Eastern cities, in levelling through close passages, in many cases the surveyor has to resort to mechanical levelling to carry his levels through. Mechanics' levels are too well known to need much description. The ordinary good kinds are made from 6 inches to 18 inches long, generally of rosewood, as this wood is very hard and



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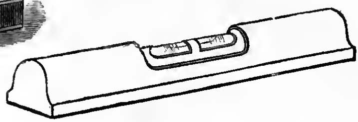

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FIGS. 243, 244.—*Mechanics' levels.*

stands well. They have a brass plate at the top, and tips of the same metal at the base. The illustration Fig. 243 is of a 12-inch level. The level tube, which is of blown glass, is fixed in plaster-of-Paris and the upper plate screwed down over it.

The Author's Hand Level is shown Fig. 244—12-inch. This is made of a casting either of iron or brass. The level tube is ground to curvature and is somewhat superior to the ordinary run of this class of work. The level tube is placed in stiff spring fittings which are adjustable, so that the tube may be easily replaced if broken.

These levels are generally used upon a stout fir straight-edge of about 5 feet to 10 feet in length, the level being taken by blockings upon the ground. Corrections of error, both in level and straight-edge, may be made for any considerable distance by reversing the forward and backward position of the level with its straight-edge alternately.

586.—**Square Level—Circular Level.**—Fig. 245 represents a very useful class of level for setting up some instrument stands, plane tables, etc., in which a pair of level tubes are placed at right angles to each other, generally made very small—$1\frac{1}{2}$ inches square only. A circular level was lately very popular and is still used to a small extent, the upper surface of which is formed of a worked concave glass. As the spirit cannot be hermetically sealed in, it evaporates and this level soon fails.

FIG. 245.—*Square level.*

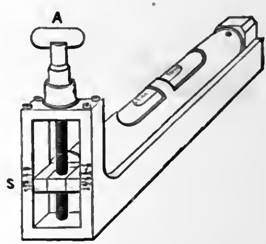


FIG. 246.—*Surface level and clinometer.*

587.—**Incline Level.**—For laying railway rails and drainage works the bubble is frequently made adjustable by the tube in which it is contained being hinged at one end and fitted in slides to rise with a screw at the other end, as shown Fig. 246. A scale of percentage of inclination *S* is commonly divided upon the adjustable end. The tube is raised or lowered by the thumb-screw *A*.

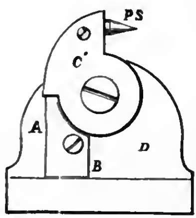
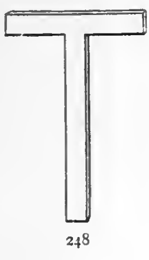


FIG. 247.—*Stanley's sight for mechanics' levels.*

588.—**Sighted Levels.**—A mechanic's level is commonly made with a hole longitudinally through it of about $\frac{1}{2}$ inch diameter, closed at one end, except a small hole of $\frac{1}{30}$ inch or so, and a cross upon a piece of glass at the other end. This plan permits a sight to be taken through it which gives an approximate level. Occasionally the same form of sight as that described is hinged on the top surface at each end of the level. The author has found a better plan of sighting to be given by a pair of sights placed on a centre upon the ends of the level to turn up when required for use, as shown Fig. 247, *PS* one of the pair of points. This when turned up shoulders on the stop-piece *A B*. The stop-piece is made of sufficient thickness to admit the point in a hole near *B* for protection when it is folded away out of use. The section of the level, as shown by the end view *D*, is the same as that of the level Fig. 244. Very fair accuracy may be obtained by making these sights appear coincident upon a distant staff or rod.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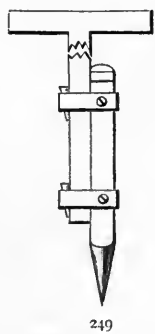
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Fig. 248.—*Boning rod.*

Fig. 249.—*Boning rod with standard.*

589.—**Boning Rods** Fig. 248. These are very commonly employed with mechanics' levels. They are made somewhat like a stout T-square of 3 feet to 4 feet in length, about 3 inches in width, and $\frac{3}{4}$ inch in thickness both of the stem and head. They are at first placed at a distance apart 9 or 10 feet, and a straight-edge of this length is laid from one to the other, upon which the level is placed, the boning rod being tapped down in the ground till the bubble is in the centre of its run. A third boning rod is then placed at the same distance as the first pair, and the straight-edge with the level upon it is reversed end for end. This, if the work is fairly done, leaves the two outer boning rods level, however imperfect the straight-edge and level may be, if the run of the bubble is taken correctly. By removing the central boning rod from the outer pair of rods, levels may be continued by sighting over them, or *boning forward* as it is termed. Boning rods are commonly fixed on the Continent by driving a separate standard into the ground, which has a pair of brass slings by its side to hold the rod Fig. 249. This is a much neater plan than that in common use of blocking the rod up with stones.

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FIG. 250.—*Tubular water level with open phials.*
FIG. 251.—*Browne's standard water level.*

590.—**Water Levels.**—The antique form of level composed of two phials fixed on the ends of a tube and partly filled with water, by which a level is sighted in looking over the surface of the water, is still used to a limited extent in rural districts on the Continent; but the spirit level in some simple form is fast superseding it. The same principle of level but with long tube has been found convenient for the surveyor in measuring through close buildings Fig. 250.

591.—**Browne's Water Level*** is found to be a convenient level for levelling in close towns. This level consists of a pair of glass tubes of about 2 feet in length, placed in a casing tube for protection. The casing tube is divided into inches and parts, or the scale is a detached piece of painted wood, or any rod or rule. A cock at the bottom admits the water to flow to level in the pair of tubes, one of which is shown Fig. 251. There is a handle at the top which unscrews to fill the level, and a small air cock. It is easily seen that the water finds its level, and the difference of reading of the two level standards is the difference of level of the surface upon which they are stood up. By closing the cocks the level is made portable. In this position it does not matter how high the centre of the pipe is placed—for instance, in crossing over a wall—as the water will still find its level when the cocks are released by syphoning the water from the one side or the other. It is a very convenient and exact level for laying drain pipes in open weather—of course it will not stand frost.

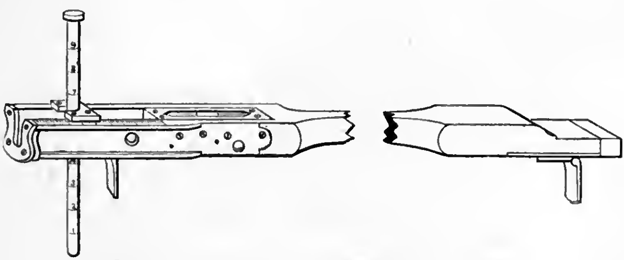


FIG. 252.—*Footner's railway gauge and clinometer.*

592.—**Railway Gauge**, combining level and clinometer. This high-class gauge is the invention of Mr. H. Footner, C.E., of the North-Western Railway,

* Patent No. 6742, John Browne, June 1834.

and is formed of a bar of Spanish mahogany neatly shaped and polished. The end fittings are of steel. The gauge is formed of two turn-up steel flap-pieces with back stops. A spirit level is sunk in the end fitting, shown in Fig. 252, towards the left hand. The clinometer is formed by a boxwood pin of ½ inch in diameter; 9 inches long. This slides perpendicularly in a spring fitting sufficiently stiff to support the gauge, and is made to fall on the centre of the rail. The pin is divided into inches and eighths. When it is out of use it slides up the end of the gauge and leaves the whole instrument smooth and portable to carry open or go into a leather case. Its use is implied.

CHAPTER XII.

GRAPHIC SURVEYING INSTRUMENTS AND APPLIANCES CONNECTED THEREWITH — PLANE TABLES — ALIDADES — TELESCOPIC ARRANGEMENTS—SUBTENSE MEASUREMENTS — VARIOUS DEVICES FOR HOLDING THE PAPER — CONTINUOUS PAPERS — ADJUSTMENT OF TRIPOD HEADS — METHOD OF USING — EDGEWORTH'S STADIOMETER — TACHEOGRAPHOMETER — DOUGLAS'S REFLECTING CLINOMETER — SKETCHING PROTRACTOR — SKETCHING CASE — CAMERA LUCIDA, ETC.

593.—**Plane Tables.**—These instruments have been used for filling in the greater number of topographical surveys in all countries. They possess the merit that any intelligent, untrained person can be readily brought to comprehend their manipulation in the work to be performed, as angles of position of objects are taken directly by drawing lines pointing to them from a point upon a sheet of paper stretched upon a table. In new countries natural objects without very marked outline are conveniently defined for position. The objection to this method, from the point of view of the practical surveyor, is that the work which can be done with equal facility in a comfortable office from the field-book is with this instrument performed in the open air, with risk of rain, dust, and other atmospheric discomforts affecting both the person and the material on which he works. Comparisons are commonly made between the rapidity of theodolite and plane table work, but this is scarcely fair. It is doubtful whether any plane table work on details is superior to work with the prismatic compass and clinometer, which is quite as rapid, including the plotting of the work afterwards in the office. The prismatic and clinometer weigh only 2 lbs. or 3 lbs., whereas the plane table apparatus weighs from 20 lbs. to 50 lbs. The subject of plane tables will in these pages be considered only in its general aspect, with the examples of a few good instruments, referring the reader who will care to follow the subject further to an excellent paper by Mr. J. Pierce, Jun., read before the Institution of Civil Engineers, February 1888.*

594.—*The Plane Table* in its simplest form consists of a small drawing-board mounted upon a firm tripod stand. A rule termed an *alidade*, with sights placed at its ends, gives the direction of any object from a given point on the sheet of paper stretched upon the table, to which a fine line is drawn by an HHH pencil to point the direction. The alidade generally carries a trough compass fixed upon it, or this may be a separate instrument which is placed against its *fiducial* or ruling edge to give a north to south line, to which all other lines are assumed to take angular direction. A loose spirit level is also provided, by means of which the board may be set level by shifting the legs of the tripod.

595.—**Plane Table with Telescope.**—Where greater refinement of observation is required than is possible with sights, a telescope is mounted on the alidade, which moves in the vertical plane upon an axis, so that it may be directed in a lineal direction with the fiducial edge of the rule to any point in azimuth. The telescope sometimes carries a level, so that the table may be set level by means of the alidade.

A class of plane table which meets all necessary refinement for ordinary filling in of field work is shown in the illustration Fig. 253. This nearly resembles those made by the author for filling in details of the great

* "Proc. Inst. Civil Engineers," vol. XCIII., part III., paper No. 2308. See also "Military Surveying in the Field," by Major The Hon. M. G. Talbot, Prof.; "Papers Royal Engineers," vol. XIV., page 25.

trigonometrical survey of India. The drawing surface of this table consists of a loose panel which stretches the sheet of paper by pressing it into its frame, where it is afterwards held by a pair of ledges which fit at their ends into long slots. The panel of the board, shown in detail Fig. 255, is mounted upon a firmly

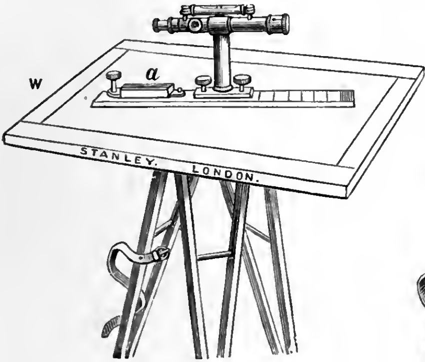


FIG. 253.—*Plane table.*

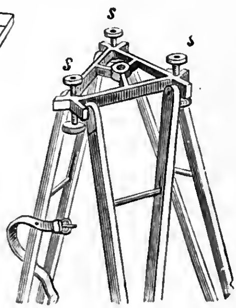


FIG. 254.—*Tripod stand.*

braced tripod stand. The head of the tripod stand, shown Fig. 254, is secured to the board with a central screw (not shown) which permits the board to be set in any direction, it being the rule that the edge *W* should

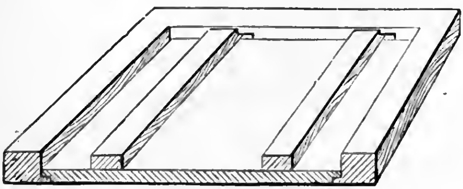


FIG. 255.—*Panel board of plane table.*

always take a north to south direction. Three screws *s s s* at the corner of the triangular head can be raised or lowered by milled heads from the under side. These screws permit about 15° of adjustment to the table without any unsteadiness, as the centre screw clamps the table finally hard down upon them when all adjustments are made. A small trough form of magnetic compass *a* is placed upon the rule to strike the magnetic north to south line, to which all angles are referred in transposing the work of the plane table. The diaphragm of the telescope is provided with a platino-iridium point fixed vertically at the mutual focus of the object-glass and the eye-piece. A pair of points to subtend an angle to measure a staff for distance Fig. 257 is a convenient addition.

596.—*The Telescopic Arrangement* of the alidade is varied in different countries. In some countries it is placed near to one end, which is perhaps better than in the centre of the rule, as it is more easily read. In the modern French military alidade a prismatic eye-piece is used, so that observation is made by looking directly down upon the eye-piece of the telescope. In the Prussian alidade adjustment is made to the standard of the telescope so as to bring the horizontal axis upon which it moves level, that the telescope may move in azimuth, however irregular or uneven the surface of the paper on the board may be. This is necessary for any great degree of refinement in the plane table, as the surface of a piece of wood upon which the paper is stretched will be almost certain to warp if exposed to all weathers, and this, with the small width of the alidade, can scarcely retain the axis in exact horizontality, placed as it is high above the surface of the table. Some plane tables made by the author for General Robinson for Indian service were of papier-maché to remedy the defect of warping, but even this material warps upon exposure. Plane tables have been made in Germany of metal and of glass, but in this case the weight is a great objection. The author has found surfaced slate very good, but it has the same objection of too much weight for a portable instrument.

597.—*Lateral Adjustment to the Alidade.*—The author's plan of obtaining this is to increase the practical width of the rule by giving it an extended point of support on one side so as to set the telescope in azimuth. For this construction the telescope is mounted upon a plate

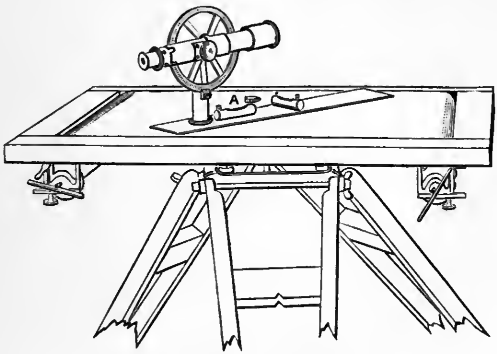


FIG. 256.—*Stanley's plane table.*

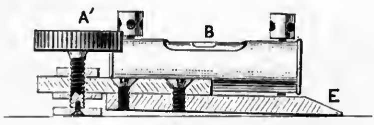


FIG. 256 A.—*Alidade to plane table.*

with an arm extending outwards upon the back of the rule. This has a milled-headed screw placed at the near extremity of the arm. The screw is inserted in a deep bush for wear, shown in perspective in Fig. 256 and in section Fig. 256 A. The adjusting screw *A′* has a collar fixed upon its point which is centred upon a tight screw tapped up the milled head. This collar, as it does not turn with the milled head, does not abrade the surface of the paper by contact with it. A small cross level *B* is put upon the arm between the milled head and the standard of the telescope. The under side of the rule is cut away or placed obliquely to the surface, so that it bears on the outer ruling edge only. The milled-headed screw being at its normal position and the table level, less than half a turn one way or the other will bring the small cross bubble to its centre in a few seconds for any average irregularity of the surface of the table, and by this means cause the telescope to move correctly in azimuth.

598.—*The Telescope Arranged for Subtense Measurements.*—Where a stadia art. 456 is to be used for estimating distances from station to station, where an ordinary telescope is used, the author places two platino-iridium points vertically from top and bottom of the diaphragm,

FIG. 257.—*Subtense points.*

and adjusts these by a screw until a subtense angle upon the stadia of 1 foot cuts the points at a distance of 100 links or feet, whichever the measurements of the land are taken to. In this case it is necessary to have an altitude arc to the telescope, as shown upon the alidade in Fig. 256. This has a degree scale reading by vernier to about 3 minutes, and also a percentage scale of differences of hypotenuse and base.

599.—*Various Devices for Fixing the Paper on the Surface of the Table* have been made. Many prefer simply pinning it with drawing pins on a quite plain pinewood surface. In this case the table is better slightly sunk round the edges with a rabbet of the depth of the thickness of the head of the pin, so that the alidade may rest firmly even over the pin heads. The French plane tables have very generally rollers at each end of the table, upon which a long slip of paper is rolled, sufficient for twelve or more stations. The rollers for small tables are made of brass tube about $\frac{5}{8}$ inch in diameter. They commonly move with a turn-key which is inserted in a square fitting in the end of the roller. The rollers keep the paper tight by means of ratchet wheels and spring pawls at each of their ends. This plan is very convenient for topographical work, as for instance a river

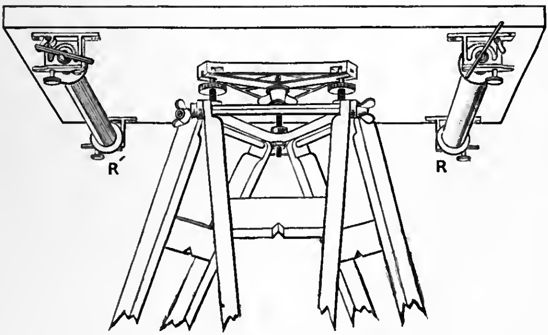


FIG. 258.—*Plane table with rollers.*

may be followed from station to station right down its course and appear on a single slip, its bearing being indicated by the compass north line. Fig. 258 shows the manner in which the author has made this plane table.

600.—*Adjustment of the Plane Table.*—There are a great many devices for this. Mr. Pierce, in the admirable paper already mentioned, gives illustration of the different plans. Some of these have all the complication of the adjustment of the stage of a theodolite, and one has superadded to this a slide-rest motion. These things of course are necessary if the field work is made to take the place of finished office work. One general feature of plane table tripods is some means of adjustment of the table to uneven ground, where the tripod cannot be brought to place the head nearly level. Gurley's plane table adjustment is perhaps the simplest of any of these devices, and appears to the author to be as good as any. Fig. 259 *D* the table top; *A* a ball fitting turned inside and out, and attached firmly to the table top; *C* a socket fixed firmly in the head of the tripod; *B* a bolt with globular head fitting the interior of *A*, and carried through the head to a winged nut which clamps it

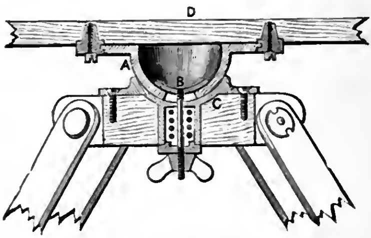


FIG. 259.—*Gurley's plane table adjustment.*

firmly. A spring is placed to act against the winged nut, so that when this is slightly loosened the ball fitting *A* may move between *B* and *C* with moderate firmness when the table is being set to an angle. To meet the conditions of mountainous districts the author in using his tripod head, shown Fig. 254, uses an adjustable stand in which one or two of the legs are shortened from the normal. In Figs. 165, 166 the methods are equivalent, except that in the last case we have a screw adjustment, which is nicer.

601.—*Method of Using the Plane Table.*—The table is first set and levelled up at a commanding position to observe the extent of country it is intended to plot from observation from a single station. Let Fig. 260 1 be the first station for plotting the enclosure *a b c d e f*. Draw lines by the alidade pointing to these angles represented by these letters from a point near 1. Set up a picket or stadia at the station 2 where it is intended that the plane table shall next be set up, and draw the line 1 2 distinctly on the paper. Measure the line 1 2 either by its subtense on the stadia or by direct chain measurement, and plot this from station 1 on the paper according to the scale to be worked to in making the plan. On removing the table set up a picket or distinct land mark vertical with the position of station 1 on the paper. Move the table to station 2 at the measured

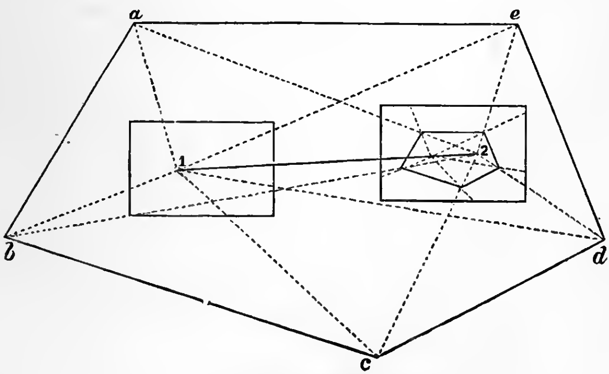


FIG. 260.—*Diagram of plane table work.*

distance and set the direction of the board by means of the alidade so that the line 2 1 cuts the picket left at station 1. Now draw lines from station 2 from all the points *a b c d e f*, cutting the former lines as represented by dotted lines in the figure, and the intersections of these lines will give the true positions of *a b c d e f* according to the scale selected for the base 1 2, and these may be tied up to represent the boundaries, as shown on the plane table 2. It will be readily seen that the line 1 2 represents a bearing in azimuth; so that if the edge of the table be set, say truly N. to S., in both positions the line on the paper 1 2 will agree in both these positions of the table; but the check by the alidade of this line is valuable to save risk of error.

Where an extent of land is to be surveyed by the plane table, longitudinal bands are taken of a mile or so in width. Where the roller plane table with continuous paper Fig. 258 is used, the forward points of observation are lined in and the backward ones simply tied up, being certain by observations written in pencil upon the paper that identical objects are tied up from the positions of both stations. Where an object cannot be seen from both stations its position may be indicated by the stadia from a single bearing, or it may possibly be tied up from a further advanced station.

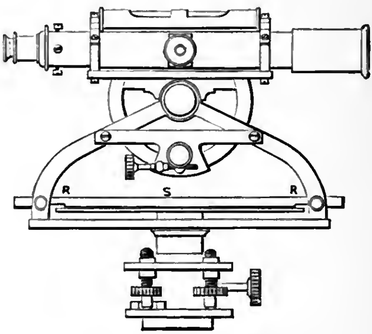


FIG. 261.—*Edgeworth's stadiometer.*

602.—**Edgeworth's Stadiometer.***—This instrument has not fallen under the author's observation among the numerous instruments that have passed through his hands, although a description of it appears generally in text-books on surveying. A good description of it is given in the inventor's specification of patent, from which the engraving Fig. 261 is taken. The vernier plate of an ordinary theodolite is extended to a plate

* Patent No. 1202, D. R. Edgeworth, April 1866.

of about 10 inches in diameter. This is adjusted to level by means of parallel plate screws. The plate or plane table is divided on its edge to $\frac{1}{4}°$. The part representing the limb of a theodolite is carried out from its axis by two arms only: upon these the standards $R\,R$ of the telescope are mounted. These standards leave a striding space near the plate, into which any scale S of equal parts with a zero centre is introduced, which is intended to be used for the plotting, the striding space being so arranged that the fiducial edge of the scale shall pass exactly over the axis of the instrument. The standards unite in the same casting to form the horizontal axis bearing of the telescope. This axis permits the telescope to move in azimuth. The telescope carries a vertical arc divided to degrees, also a scale of centesimal differences of hypotenuse and base, with the ordinary clamp and tangent adjustment of a theodolite. It is also fitted with a level above it which is used in setting up the instrument. Stadia webs are placed in the diaphragm and are made adjustable to subtend upon the stadia a percentage of arc agreeing with the unit to which the land is measured. The inventor does not appear to have known the optical error of the system proposed for measuring distance art. 459. Neither does this appear to have been recognized by others writing upon the instrument who have generally followed the late J. F. Heather's description.*

603.—*To Use Edgeworth's Stadiometer.*—After it is set up a circular disc of paper of an inch or so less diameter than the table is held down upon it by four spring clips. The telescope is directed consecutively from object to object, the position of which it is desired to take. It is clamped by the screw below the plate during the observation. The stadia is placed against the object and the distance taken by the subtense of the webs in

* Heather's "Surveying Instruments," 1870, page 85.

the diaphragm, which may be exact if a constant is added after proper adjustment art. 460. If the stadia is above or below the horizontal plane it is inclined by means of a sight-hole through it, as originally proposed by Green, so that the subtense is equal under all conditions. The horizontal distance is taken by the difference of hypotenuse and base, as shown on the vertical arc, so that the record of a complete observation appears for calculation as—

stadia reading + constant – altitude correction.

This distance is at once set off from the centre of the instrument by the scale by a line drawn upon the disc of paper, and observations are written against the line. In making a number of observations from one station two or more discs of paper may be employed to save confusion of lines and interference of descriptions. These papers are separately used in plotting as protractors by pricking holes through the stations defined in the field from the centre of the disc which represents the station of observation.

604.—**Tacheographometer (Wagner-Fennel).**—In this instrument the tacheometer Fig. 193 is combined with a plane table, the whole being supported on complete theodolite adjustment. The support of the upper part of the tacheometer, including all parts directly connected with altazimuth arrangements, and the peculiar system of scales and slides Fig. 193, is mounted upon a plate which represents the alidade of an ordinary plane table. To facilitate the movement of the heavy, complex alidade, it is mounted on three rollers. These rollers are fixed in such a manner as to turn in a circumference concentric with the zero of the alidade, or they may be lifted so that the alidade comes in direct contact with the paper. By protrusion of one or other of the rollers the telescopic arrangement may be levelled without changing the adjustment to the table. Brakes are also placed upon the rollers that they may not shift when the lines are ruled by the alidade. The numerous refinements permit finished drawing to be made in the field in the graphic manner of the plane table. The instrument is said to weigh about 70 lbs. The subject is too complicated to follow without copious illustration, which our space will not permit,* particularly as the system appears to the author as retrograde from good ordinary theodolite and office work combined, under the most favourable conditions.

A number of instruments have been devised to be used with a plane table in the open field, some of which are intended to supersede the use of the alidade. A few instruments only of this class will be considered.

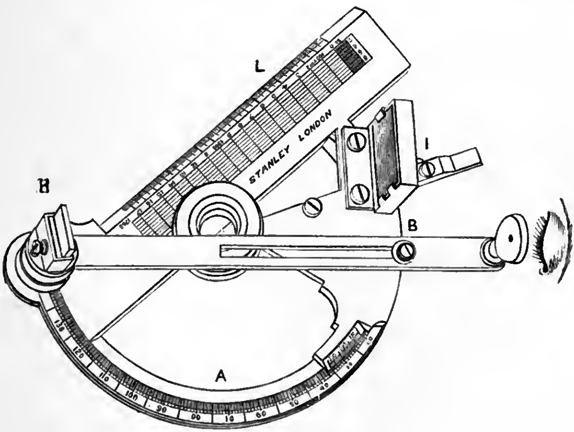


FIG. 262.—*Douglas's reflecting protractor.*

605. — **Douglas's Reflecting Protractor.** — This instrument is proposed by its author† to combine the measuring principle of a semicircular protractor in

* See "*Les Tachéomètres Wagner-Fennel*," Luckhardt & Alten, Cassel, 1886.

† Sir Howard Douglas's patent, No. 3461, 1811.

such a manner that in measuring any angle the index or limb should pass over the whole of the measured angle, so that an angle taken in the field may be at once protracted in actual magnitude without the trouble of reading it off. The instrument is intended for military surveying. A vernier is applied to read off the angle with more accuracy if it is desired to record it. The semicircle is divided to 180° instead of double this number as with the sextant. The same length of arc is therefore obtained for the graduation as with a sextant of double the radius.

The instrument is shown in Fig. 262, and is described by the inventor as follows:—"To the radius or limb of the semicircular protractor *A* the index glass *I* is fixed. The horizon glass *H* is fixed to a bar *B* which has a motion on a centre directly under the horizon glass. This bar slides on a pin under *B* attached to the limb or radius carrying the index glass. This pin is adjusted so that there may be no apparent index error, and moves exactly in the radius from the axis under the horizon glass. The sliding bar moves over half the real angle, and the principal limb then protracts the true angle."

606.—**The Sandhurst Protractor** is a military protractor adapted especially for topographical delineation, which is commonly used with the plane table. It is different from many instruments of its kind in having useful matter only upon it. It is made of boxwood, upon which the protractor is cut, and has also one scale at the lower edge of 6 inches to a mile in yards, the tens of which are carried across to make parallels of 90° in the manner of an ordinary military protractor. Over the back of the protractor is a scale which gives a standard for shading slopes of land upon topographical maps from 2° to 35°, also lines for contour shades. A small plummet is supplied with the instrument, the cord of which is passed through a hole in the centre, from which the degrees are protracted. When the protractor is held up, degrees downwards, the cord of the plummet will pass over the degrees and indicate the angle at which

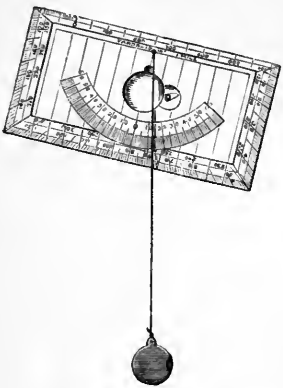


FIG. 263.—*Sketching clinometer protractor.*

it is held. By looking over the edge in this manner the angle of inclination of the land may be taken as with a clinometer, or by looking along the edge—a second person reading the plummet—angles of altitude may be taken.

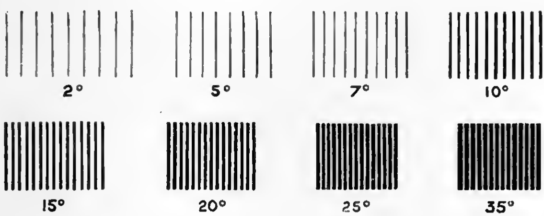


FIG. 264.—*Example of scale of shades for slopes.*

607.—**Military Sketching Case.**—For exploration of new countries with the prismatic compass, clinometer, and passometer this case will be found very convenient, as forward sketches may be made of the country ahead which may point out deviations from the course selected for roads or railways, which further progress in the same direction may, by the conditions found in the country when approached, render necessary. The sketching case shown in the illustration Fig. 265 is made of firm mill-board covered with leather, so that when it is closed it forms a waterproof portfolio, with strap to go over the shoulder to carry it under the arm. The hanging part

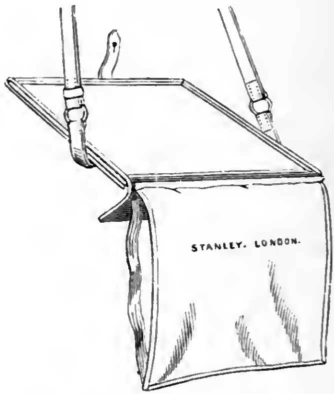


FIG. 265.—*Military sketching case*

shown in the engraving is a bag to hold paper and sketches. A tab with a button-hole keeps one edge of the drawing plane fairly steady in use by attaching it to a button of the coat or waistcoat. The strap when the table is used goes over the back to support the apparatus generally.

A light tin frame fixes the sheet of paper on the table, which permits the paper to be easily changed when desired.

608.—**Cavalry Sketching Case.**—This forms a very convenient exploring sketching board, permitting sketches to be made on horseback while continuing *en route*. The pattern shown in Fig. 266 is that of Captain W. Verner, made by Messrs. Elliott Bros., to whom the author is indebted for the loan of the engraving. It consists of a small board $9\frac{1}{4}$ inches by $7\frac{1}{2}$ inches, at two sides of which there are small rollers to hold paper 7 inches wide and from 3 feet to 6 feet in length, according to its thickness.

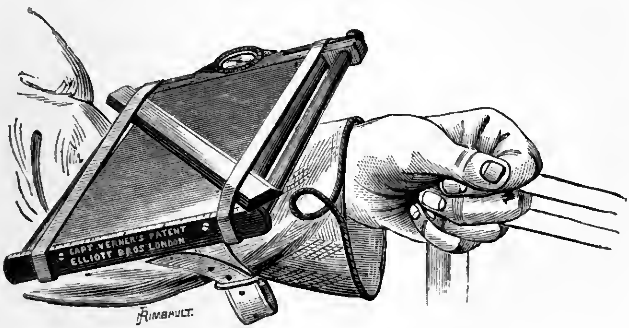


FIG. 266.—*Cavalry sketching case.*

Two stout India-rubber bands are passed over the board, which hold a small straight-edge to scale to any position on the paper with sufficient firmness to be able to draw a line against it. A small compass on one side of the board indicates direction. After one sketch is made, a new part of the paper is rolled forward.

609.—**Camera Lucida—Optical Compass.**—In new countries where land-marks are not clear a sketch of the general aspect of the country will make the points of triangulation more clear. Where the plane table is not used these sketches may be made with accuracy as to positions by the use of the camera lucida, or points of observation may be taken in correct bearing by the optical compasses. These instruments are described in the author's "Treatise on Drawing Instruments," sixth edition, pages 142-7.

CHAPTER XIII.

INSTRUMENTS FOR MEASURING LAND AND CIVIL WORKS DIRECTLY—CHAINS—VARIOUS TELLERS—STANDARD CHAINS—ARROWS—DROP ARROW—VICE FOR ADJUSTING CHAIN—CAINK'S RULE FOR INCLINES—STEEL BANDS—WIRE LAND MEASURES—LINEN TAPES—OFFSET RODS—PINE STANDARD RODS—RODS WITH IRON CORE—BEAM COMPASS RODS—COINCIDENCE MEASUREMENTS—COMPENSATED RODS—COLBY SYSTEM—PERAMBULATOR—PEDOMETER—PASSOMETER—SOUNDING CHAINS—SOUNDING LINES—TELEMETERS—HAND RODS—RULES.

Instruments Generally Employed for Measuring Land are chains, steel bands, and tapes. Where roads are roughly measured, pedometers are commonly used. Where very exact measurements are required, rods have been used. Rough approximate measurements are obtained by stepping, with the use of the passometer to count the steps.

610.—**Land Chains.**—Although these are made in many qualities the forms vary very little. They are too well known to need much description. In the British Isles and some colonies the chain of 100 links, equal to 66 feet, the invention of Edmund Gunter about 1620, is generally used, 10 square chains (100,000 square links) giving the statute acre, presenting a decimal system of measurement much in advance of our system of measurement of any other quantities at the present time. The best land chains are made of steel, which is afterwards hardened and tempered to spring temper, in the process of which the surface is burnt off with asphalt varnish to produce a covering to resist the rusting effects of moisture. Steel chains are made *light* and *strong*. The light chain, of No. 12 Birmingham wire gauge, weighs under 5 lbs. The strong chain, of No. 8 B.W.G., weighs about 12 lbs. A light chain of 50 links, of weight under 3 lbs., is sometimes used with the complete chain of 100 links for taking offsets.

All the best chains, whether of steel or iron, are made with long links formed by turning up the ends of a length of wire. Three small oval links are placed between each pair of long links. These three interval links are found to cause the chain to *kink* less than when only two are used. Each oval link is sawn through at the meeting line, which is brought up on one flat side of the oval in bending it from the wire.

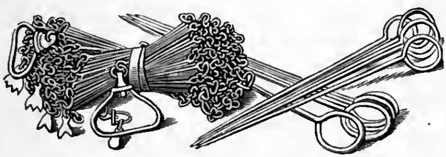


FIG. 267.—*Land chain and arrows.*

The saw-cut forms the point of adjustment. The small link is afterwards re-sawn and closed to shorten it, or forced open to lengthen it. There are generally four *swivels* in the length of the chain, two of which are at the handles: these prevent the chain from becoming twisted in turning the handles over in use. A swivel is shown Fig. 268 at *S*. Iron chains are sometimes galvanized to prevent rust. This process however makes the chain much more brittle, and cannot be recommended.

611.—**Tellers** are small pieces of brass suspended to the chain by a spare link placed at every ten links. They divide the chain decimally from either end equally. Proceeding from one end of the chain the tellers read

10, 20, 30, 40, 50, and the other end they read by subtraction from the complete chain: $100-10=90$, $100-20=80$, $100-30=70$, and $100-40=60$. Fig. 268 shows detached pieces of chain with value of the tellers figured under. *S* inserted swivel. The 50 teller shows

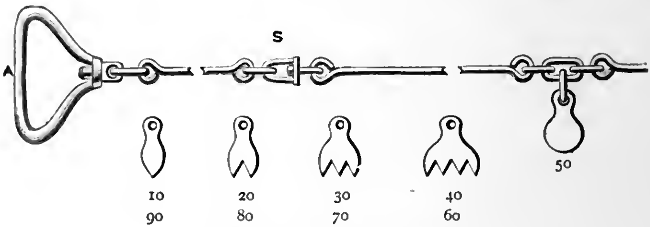


FIG. 268.—*Gunter's land chain.*

the link attachment. *A* shows the position at which the arrow or other mark is placed to commence or finish the chain measurement, the handle being included in the first link. These tellers are liable to catch and get dragged off in chaining. When this chain is used abroad, or far from home, it is well to have an extra set of tellers to repair losses.

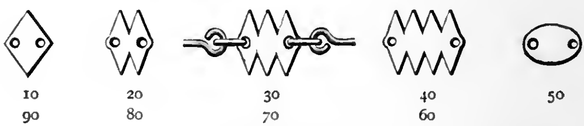


FIG. 269.—*Inserted tellers.*

612.—*Inserted Tellers.*—This form of teller is preferred by many Fig. 269. It is much less liable to get dragged off, but it is not considered quite so distinct, and it is a little liable to get clogged with grass and weeds.

The author's design for inserted tellers is shown Fig. 270. These are perhaps quite as distinct as the last. The holes in wet weather fill up with mud and the surfaces keep bright, so that they remain very readable. There is much less drag, and the chain therefore wears longer.

FIG. 270.—*Stanley's inserted tellers.*

613.—**Feet Chains** are usually made 50 feet, more rarely 100 feet. They are generally made in foot lengths, but sometimes for flexibility are preferred in 6-inch lengths. They are commonly made of No. 8 B.W.G. steel or iron. The weight of 50 feet is 6 lbs.; 100 feet, 12 lbs. If made of light steel, No. 11 B.W.G., the 50 feet weighs $6\frac{1}{2}$ lbs.

614.—**Mining Chains** used in mineral districts are made generally 10 fathoms, or 60 feet, in 6-inch links counted off by tellers in fathoms. Where used with the dial they are made either entirely of brass, or with one fathom at one end in brass and the other part in steel. The weight is about the same in brass or steel—No. 8 B.W.G., 9 lbs. Occasionally they are made extra strong, No. 7 B.W.G.; weight, 12 lbs. In coal mines Gunter's chains are generally used.

615.—**Metre Chains** are made 20 or 25 metres long. They are marked with tellers at every two metres with a plain ring at the metre. The tellers are generally of the inserted kind Fig. 269. In taking measurements the sign of the teller is doubled: thus the ordinary 1 or 10 is counted 2 metres; the 2, 4, and so on. 20-metre chains in light steel, No. 12 B.W.G., weigh $4\frac{1}{2}$ lbs.; strong, in No. 8 B.W.G., 9 lbs. 25-metre, light, 6 lbs.; strong, 11 lbs.

A land chain is generally secured for carrying by a leather strap with a buckle. Occasionally it is carried in a sail-cloth bag with a strap over the shoulder.

616.—**Standard Chains**.—These are of the same form as the ordinary steel chain, but all the links are hard soldered after being adjusted link by link. They are not intended to be used for ordinary chaining, except it be for laying down base lines. Their ordinary employment is to test chains, or to set out with two pegs on a straight piece of ground a standard length or station where the ordinary chains in use may be tested daily. A standard chain is commonly enclosed in a box with a lock to prevent its accidental use for an ordinary chain.

617.—**Arrows.**—These are sometimes called *pins.* Ten form a set. They are shown with the chain in Fig. 267. They are commonly made of the same wire as the chain—No. 8 B.W.G. They are much better made one gauge stouter (equal to about $\frac{1}{7}$ inch), and always much better of hardened steel than of iron. The common length is 1 foot in the pin. Where heath, stubble, or woodlands prevail, 18-inch are much better for use, and in some exceptional cases even 2-feet are very convenient. Surveyors going to new countries are recommended to take the longer arrows as well as those supplied with the chain. It is common either to tie a short length of scarlet webbing upon each ring of the arrow or to sew a piece of red flannel or bunting upon it to find it easily in long grass. Arrows are sometimes carried in a quiver with a strap over the shoulder Fig. 272, which leaves the hands of the fore chainman free to remove obstructions where they occur.

618.—**Drop Arrow** Fig. 271. Where ground is very hilly it is common to roughly level the chain by holding the lower position shoulder high, either by guess-work or by using any kind of rough hand level or clinometer to ascertain this. The arrow is then dropped and the point, holding at first lightly in the ground, is pressed hard down or another arrow supplanted for it. The chain in this case is used in odd multiples of links as they occur, of which record is taken separately at each station. In going downhill a drop arrow answers very well. In going uphill a plummet to the last arrow is better. Some use the drop arrow as a plummet, carrying for this purpose a piece of fine whip-cord, with a bent hook tied to one end, in the pocket, to be used when required.

271

FIG. 271.—*Drop arrow.*

272

FIG. 272.—*Quiver with arrows.*

619.—*Examination and Adjustment of Chains.*—Respectable makers send out chains tested to within half of one of the small links of standard, that is, within a quarter of an inch; but in use this error may increase either by the bending of the long links of the chain, by which it becomes shorter, or in the more general case of friction from wear and from strain, by which it becomes longer. In London, standards are fixed upon the pavement in Trafalgar Square and at the Guildhall. These standards are also fixed at many municipal town halls. Surveyors very commonly lay down a standard on the pavement, or by pegs on a level gravel path. Where a peg is used it should be driven home nearly to the surface. It should if possible be made of a piece of heart of oak 12 inches long and about 2½ inches square. The standard length, which may be set off by a standard chain or new steel tape, should be from a saw-cut across the centre of one peg to a similar cut on the other. It is well also to have the centre space (50 links) indicated by a smaller peg.

620.—*The Chain to be Adjusted* should be first examined and its long links set straight by means of a hammer on a flat, hard stone or anvil, after which the error will be, if it has been much used, that it is too long. It should be then laid in direct line on the standard just described, and stretched lightly with a pull of about 7 lbs., and then left to rest. Assuming it too long, the centre of the chain should be observed to ascertain which half is of the greater length, then short links should be taken out at distributed distances, if more than one is required, by twisting the link open in a vice, and opening and closing another link to restore the chain.

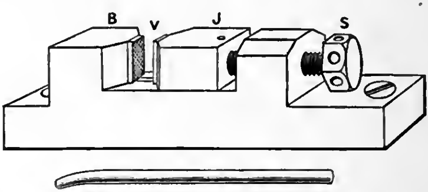


FIG. 273.—*Stanley's vice for adjusting and repairing land chains.*

621.—**Chain Vice.**—The links of steel chains can seldom be twisted open without breaking, and broken links cannot be restored by steel links. Iron links answer, but they are very stiff to twist open. Generally it will be found best for professional men to repair the chain with spare *brass links*. These wear very well. Where a smith is near with his vice and a light hammer the links are readily opened. It often occurs in open districts and abroad that no smith's shop is to be found. To meet these cases the author has constructed a special vice, as shown Fig. 273. This vice is let into a piece of hard wood—an old oak post answers admirably. In stone districts it is perhaps better to let it into a stone and fix it by pouring hot lead round it. The part *B* is used for an anvil for straightening the links. The vice *V* holds the link endwise very firmly by bringing up the slide *J* by the screw *S*. The link may then be knocked open by the pane end of a light hammer. The link is closed again in the same manner. If the vice is left out of doors the screw should be well greased and the whole covered with a leaden cover. The weight of the vice is about 6 lbs. It is made of cast iron with chilled face, or is faced with steel.

622.—*Opening and Closing the Chain for Use.*—The chain is most readily unfolded by taking the two handles in the hand and walking away from it as it lies on the ground. It is most convenient to place it about 45° and half a chain length from the first station, each chainman taking a handle and moving to his position. The only danger in undoing a chain is from the two chainmen taking one handle each and walking in an opposite direction, in which case if there happens to form a kink the opposite movement of the two men will probably stretch or break the chain. In closing the chain it is taken by the centre links and folded up two links at a time till the handles are reached. If the links are placed consecutively in position round the axis formed by the first links, it may be folded up very compactly in a twisted form ready for the strap to be passed round it by which it is carried.

623.—*Chaining* is performed by two chainmen, termed the *leader and follower*. The follower, having pressed a stake into the ground for a starting point, then places the centre of the outside of the handle of the chain against it. The leader takes ten arrows in his right hand and one handle of the chain in his left, and walks directly towards a point which is to be the termination of the measurement, stopping at nearly the length of the chain, examining the chain to see that it is straight. He then places an arrow lightly outside the centre of his handle. The follower looks over this arrow to the distant station to see if it is in direct line. If it is not so, he waves his right or left hand once, twice, or thrice for 1, 2, or 3 inches for movement to right or left. The follower picks up the arrows consecutively as left by the leader, and when he has the ten 10 chains have been measured, which is then recorded in the field-book, or earlier than the ten if a shorter distance or object completes the measurement. It is most important to observe that if an arrow is taken for the first station, *the follower having ten counts nine only for the first ten.* To prevent accident it is therefore safer to start from a stake or other landmark, *not one of the arrows.* Some surveyors advise eleven arrows. If eleven are used, one should be distinctly marked from the rest so as never to be counted. This may be done by omitting the red webbing tye, or using a green tye for the odd arrow. The French always make the drop arrow the eleventh arrow, which is never counted in direct chaining.

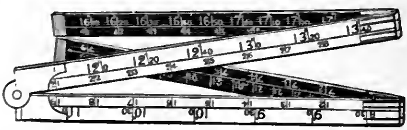


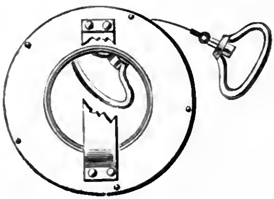
FIG. 274.—*Caink's rule for correcting inclines.*

624.—**Caink's Rule** for correcting inclines in chaining is the invention of Mr. Thos. Caink, C.E., of Malvern. It is made four-fold, each fold being one link. The link is divided decimally along the inside of the rule. On the outer edge of the rule there is a scale marked degrees, a part of which is subdivided where the scale is open to read closer to 20 or 30 minutes. These degree divisions, which read up to 16° on one side of the rule, indicate the space from the end of the rule to be allowed in addition for the same degrees of inclination of the land up to 4 links of measurement. On the opposite side of the rule the inclination scale is carried from 16° to 22° 10′. For these higher numbers the length of the rule is first set off, and then plus such part of the rule as is indicated by the position marked upon it of the required number of degrees.

625.—*To Use Caink's Rule.*—The follower has a clinometer of one of the kinds shown Figs. 235-240. He notes at starting the position upon the face or body of the leader that corresponds with the height of his own eye. He takes the inclination of the land to this point of the leader's body while he is standing upright at one end of the chain and the leader standing at the other, noting the number of degrees shown by the clinometer. He then places the rule in the direction of the chain, with the number of degrees indicated, in front of the arrow, and moves the handle of the chain to this position. For the sake of verification, if he has a second arrow he may place it in the new position, which gives the true allowance. In either case the leader moves the chain forward the amount required and places his arrow ready to continue the work. By this method it is seen that there is no after calculation or separate records necessary for undulating land, but the true horizontal position is given correctly at each chain. The same form of rule is made for feet and metres.

In mountainous countries eight links is insufficient allowance for ordinary inclinations. Such countries are measured much more accurately by some system of subtense measurement, for which see chapter XII.; but where a small piece of sudden steep inclination occurs half a chain may be taken, and the number of degrees indicated upon the rule be doubled, so that the full rule, instead of taking 22° only, will take 44°.

626.—**Steel Bands** for measuring, termed *steel band chains*, are made in various forms in this country by Messrs. Chesterman & Co., and sold by nearly all opticians. They are much lighter than chains of equal strength, and are made to standard length. They are also lighter to use, being smooth and without any projection. On the other hand the reading is less distinct



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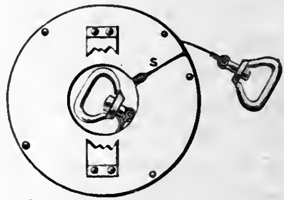

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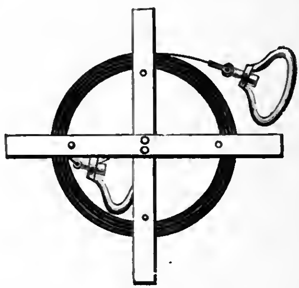


277

Figs. 275, 276, 277.—*Chesterman's steel bands and tapes.*

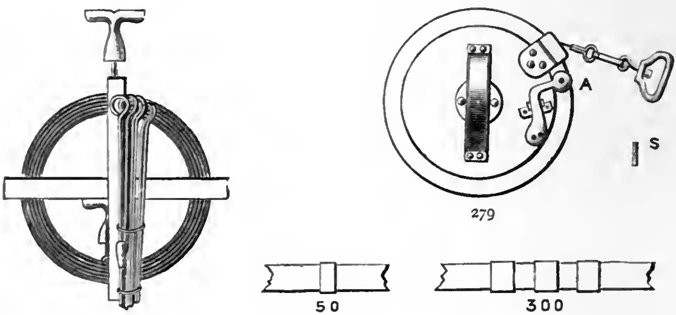
Fig. 277 a.—*One link of steel band.*

than the chain, and they need more careful usage in chaining. They also require oiling before being put by. From the thinness of the metal they are altogether more delicate and less durable than the chains for hard wear; but it is thought by many to be a compensation that they are always of true length while they last in repair.

The bands commonly used for land measuring are made $\frac{1}{2}$, $\frac{5}{8}$, and $\frac{3}{4}$ inch wide, of Nos. 26 and 24 B.W.G. in thickness, respectively. Joints are placed at three places in the chain, as it appears to the author, without any advantage to it. The chain is divided into links by a small stud rivetted through the centre of two small washers, a large stud being placed at the fives and an oval plate held by two rivets at the tens, which are numerically indicated in plain engraved figures, as shown in detail Fig. 277A *b*. These band chains are made in links, feet, metres, or to any foreign measure to order, and of any length corresponding with land chains. Weights, approximately—100 feet: $\frac{3}{4}$ inch, 7 lbs.; $\frac{5}{8}$ inch, $4\frac{3}{4}$ lbs.; $\frac{1}{2}$ inch, 4 lbs. 100 links: $\frac{3}{4}$ inch, $4\frac{3}{4}$ lbs.; $\frac{5}{8}$ inch, $2\frac{3}{4}$ lbs.; $\frac{1}{2}$ inch, $2\frac{1}{4}$ lbs. 20 metres: $\frac{3}{4}$ inch, 5 lbs.; $\frac{5}{8}$ inch, 4 lbs.

Steel band measures are also made with divisions throughout, etched upon them with acid in a manner that the divisions and figures stand in relief up to the original surface, whereas the new surface, which is etched back to form the ground, appears dull. The brightness of the figures and divisions on the dull ground makes them easily read. These bands are divided into links, feet and inches, metres and decimetres, or closer quantities either on one or both sides of the band. With the etched band there is perhaps a little risk of weak places from over-etching, although these bands are most carefully made; but perhaps the risk is not greater than in the inserted stud band, where weak places are necessarily made by the loss of width at the points where the holes are made for the studs, wherein moisture hides.

The steel bands have handles the same as a land chain. They are either wound upon a reel formed of two crosses of wood rivetted together with a block between, or the cross is made of steel Fig. 277. They are more commonly placed in a wind-up case similar to that of an ordinary measuring tape, but in steel; but provision is made that one of the pair of handles may be secured about the position of the axis of the tape for winding it up. In Fig. 275 the axis is made very large, so that the handle may be pressed in from an opening in one side of it. The newest idea is to cut a slit in one side of the plate up to the centre, as shown Fig. 276. In this case the handle and band are put in from the side, so that the axis is no larger than is necessary to take the handle. A strap is placed on the side of the case for holding it. This is shown cut off to admit sight of the handle.



278 279 279 A

FIG. 278.—*French band measure.* FIG. 279.—*Marchant's 500-feet band.* FIG. 279 A.—*Details of 279.*

The French make the handle generally T-shaped and hollow in the cross part, which makes it very light and perhaps less cramping to hold. The arrows are very commonly held by loops to the cross on which the band is wound. This general arrangement is very portable and convenient to carry: it is shown Fig. 279.

627.—*Wire Land Measures.*—Where long, open stretches of new country are to be measured up, it is common to employ a steel wire chain, of 5 chains or of 500 feet in length, fitted with a pair of strong, cross handles only. The wire may be of No. 8 B.W.G. Short links soldered are sometimes put at the even chains, or 100 feet, to divide the chain roughly. Where closer division is required, as in the case of coming up to rivers, etc., a light pocket tape is used from the nearest marked quantity of the chain. The wire is rolled in a large hoop form for carrying over the shoulder. One defect of wire is that there is always a tendency to kink. The author has recently made some chains for Mr. F. W. Marchant, of New Zealand, of 500 links Fig. 279, the section of which is shown at *S* full size. This *band*, as we may term it, is wound upon a reel in an iron case. A spring brake is placed at the position *A*, which holds the band from springing out into loose hoops when it is reeled up. The 50 and 100 links are indicated by short lengths of brass tube placed over the band—single at the 50 links, but numerically indicated by number of bands as 2, 3, and 4 chains. In Fig. 279A a 50 and 300 links are shown: weight, $3\frac{1}{2}$ lbs.

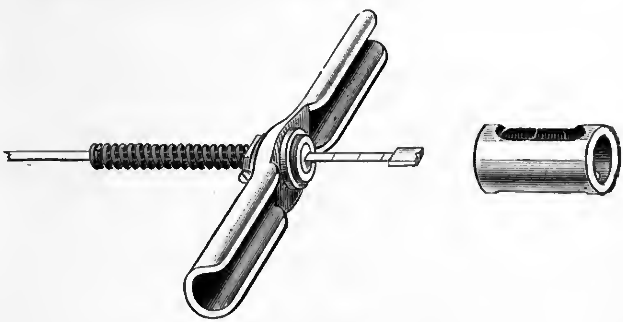


FIG. 280.—*Richmond's tension handle.*

628.—**Richmond's Tension Handle.**—Various devices have been employed for giving equal tension to chains and bands to ensure equality of measurements.

Salter's spring balance has been very commonly used attached to one handle of the chain to give a uniform pull, say of 15 lbs. This appears to answer very well. Mr. Richmond, surveyor, of Sydney, has devised a very simple plan for tension of light bands, which, being lighter and attached, is much more convenient than Salter's balance. This is shown Fig. 280. The band passes through a fitting in the centre of the handle, and a spiral spring is fixed to this and the band at a short distance along it. By pulling the handle a given tension can be put, which is shown by the mark it reaches towards the end of the band. The end of the band is adjusted to standard length. A small notch is placed in the centre of the end, from which a plummet may be suspended if necessary.* The engraving is of a slightly modified form by the author, in which a thin tubular cap covers the free end of the band to save this exposed part from accidents.

FIG. 281.—*Copper case thermometer for suspending to a band chain.*

629.—**Chain and Band Thermometer.**—Where very great accuracy of chain or band measurement is aimed at, temperature is taken to allow for expansion of the metal. A thin plain glass thermometer of the *clinical* form is the most sensitive of any. This is carried in a wooden pull-off case lined with India-rubber. When it is used it is placed upon the ground by the side of the chain. The delicacy of the clinical form of thermometer is often objected to by the practical surveyor, hence there are several other forms with boxwood and ivory scales. These are not very satisfactory, as the boxwood and ivory retain the heat of the body, from being

* "The Surveyor," vol. II., No. 5. Sydney, Nov. 1889.

carried in the pocket, for a long time after exposure. The author has enclosed the clinical form of thermometer in a copper case with open face Fig. 281. The copper being a good conductor of heat, this is very sensitive to the temperature of the air. Two turn-down hooks are placed at the ends of the tube to suspend it to the band. The thermometer stem has two India-rubber caps, so that it will bear dropping on grass. It is contained in the same form of pull-off case as the clinical.

The co-efficient of expansion for steel between 32° and 212° Fahr. is about ·000012, which is less than ·01 inch per degree per chain. Temperature corrections can therefore only be recognized upon very exact work, appreciable only when long bands are used of the Marchant type lately described, of from 5 chains to 10 chains in length.

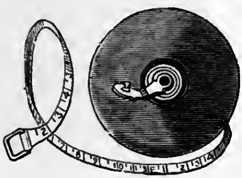

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FIG. 282.—*Linen tape.*

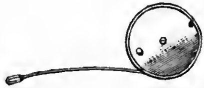
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FIG. 283.—*Small steel pocket tape.*

630.—**Linen Tapes.**—This most useful implement Fig. 282 is one of the most unsatisfactory measures the trader and user has to do with. It consists, as is well known, of a tape oiled, painted, and varnished, which is rolled up in a leather case when out of use. When the weather is moist it shrinks, and when dry it expands. If it is too heavily painted it becomes brittle and rotten; if it is lightly painted it remains more flexible, but is affected more by moisture. A good tape bears very well a stretching force of 7 lbs. to 14 lbs., but if strained over this it is permanently stretched. There is no plan known to the author by which these defects can be remedied. Numerous attempts have been made—often valueless or worse—some, although popular, mere claptraps, such as the insertion of wire. The best tapes for strength and permanency are made entirely of green, hand-made, unbleached flax. The tape is said to come from Holland to this country. These are at first oiled with a drying oil (boiled linseed oil), and when seasoned for a month or so, painted once or twice with white lead colour — not too thickly. The printing is more permanent if done in oil; but the tape is somewhat more flexible if the figures are stencilled in Indian ink and the whole afterwards thinly varnished over with copal varnish. The great secret for preserving the tape is to use it very carefully in fine weather only. In wet weather in taking offsets a light steel, 50-link chain is quite as convenient as the tape, and safer.

Tapes are divided into links, feet and inches, metres, and all measures. A decimal yard is commonly placed on tapes for measuring earth work. For use with the chain a 66-feet tape is usually employed, but many think a 33-feet better, using the chain for dimensions above this. For measuring buildings, 50-feet or 100-feet tapes are employed, subdivided to inches.

Pocket Steel Tapes, 6 feet to 12 feet Fig. 283, are used more generally by mechanical engineers. These are very light, are held open by a catch, and close by a spring.

FIG. 284.—*Jointed offset rod, top and centre.*

631.—**Offset Rods** are generally made 10 links long, either in one piece or jointed in the centre with a bayonet joint. They are generally about $1\frac{1}{8}$ inches in diameter, diminishing towards the top to $\frac{7}{8}$ inch, and made either of yellow pine or ash. A hook is commonly put at the top Fig. 284, which takes the handle of a chain to draw it through a hedge or other obstruction. The author's plan of making this is shown at *H*. The lower end of the offset is shod with a steel or wrought-iron socket point, so that it may be set up in the ground and used if required as a picket. Bands are painted alternately black and white at every link. Square or flat rods are occasionally used for the same purpose, but they are not generally so convenient.

The Offset is Used in the manner of an ordinary rule to take rectangular short measurements from the chain as it lies upon the ground, commonly to obtain the contour of irregular outlines.

632.—**Measurement by Rods** has become less necessary than formerly, from the sufficient accuracy of measurement of the total length of Chesterman's steel tapes, by which practically correct base lines may be laid down. For geodetic works requiring the greatest accuracy the bases have been laid with rods of various forms, and with perfectly jointed steel chains. These rods will be briefly described. It is only in the construction of iron bridges, roofs, etc., that rods are at present generally employed in the work of the civil engineer.

633.—**Pine Standard Rods**, made of straight-grained pinewood seasoned five or six years and then well soaked in linseed oil, make very fairly good standard rods. The ordinary length in use is 10 feet by $1\frac{3}{4}$ inches square. If the rod is used for butt measurement the ends are tipped with gun-metal in which a turned steel stud is hard-soldered. The stud is afterwards ground to true face in a lathe, and left of standard length at 60° Fahrenheit (15·5 centigrade) Fig. 285. A disc of brass 1 inch diameter is inlaid at every foot for 5 feet from one end of the rod, with a line at the true foot. These rods, after the work upon them is finished, are lightly French-polished to keep them clean and to prevent the effects of change of amount of moisture in the air upon them. The effect of temperature upon deal was found by Roy to be about the same as upon glass—·0000085, average of total length per degree centigrade, which is about three-fourths that of iron.

FIG. 285.—*One end of a pinewood butt rod.*

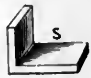


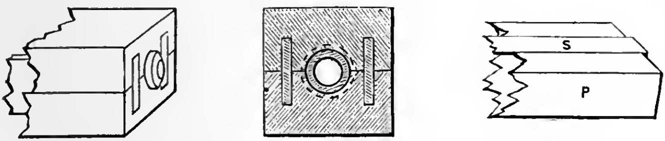
FIG. 285 S.—*Block square.*

Where butt rods are used for continuous measurement it is necessary that they be brought very carefully together. In base line measurement three or four are used, but for metal work or masonry two 10-feet only are generally employed. It is necessary that the rods should lie upon a straight surface or be supported in a straight line. In bringing them together, a piece of India-rubber $\frac{1}{8}$ inch or so in thickness will prevent any palpable disturbance of the percussion if the fixed rod is well weighted. One 5-feet butt rod is very commonly supplied with a pair of 10-feet rods for supplemental measurement.

634.—**Angle-piece.**—A solid angle-piece with two planes at right angles is very convenient for use with butt rods to give means of scribing the true length down to a surface Fig. 285 *S*.

635.—**Butt Rods with Iron Core.**—Where rods are to be used for preparing iron work it is better to have an iron core through the rod, which expands and contracts with the metal on which they are used. The rods the author has designed for this purpose are made out of a length of seasoned pine $2\frac{1}{4}$ inches square, sawn down and turned cut sides outwards to prevent warping. A 10-feet length of iron steam tube about $\frac{1}{2}$ inch diameter is painted several times and then bound round with paper soaked in paraffin. This is placed in a pair of meeting grooves, as shown in section Fig. 287. The two pine flitches are cross-tongued together and glued up with the inserted tube between them. The tube has a turned steel cap placed over each end Fig. 286, and this is ground in a lathe to true standard at the temperature of 60° Fahr. A steel pin is placed through the centre of the rod to indicate 5 feet. The finished size of the rods is 2 inches square.

The author has made these rods in sets, consisting of two 10-feet and one 5-feet rules packed together with an angle-piece Fig. 285 *S* in a deal case.



286 287 288

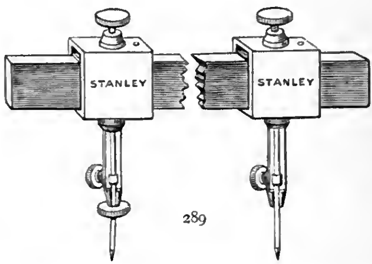
FIGS. 286, 287, 288.—*Butt rods with iron core.*

636.—*The 5-feet Rule* is of steel, $\frac{3}{4}$ inch by $\frac{1}{4}$ inch, inlaid in a piece of dry pine, altogether of only half the thickness of the rods, so that it stands the correct height for central butt measurement Fig. 288. The rule is divided into feet and inches, with one foot to eighths. A centigrade thermometer is placed in one of the rods to indicate prevailing temperature, and a small piece of scale showing amount to be allowed in 10 feet per degree centigrade for temperature above or below 15·5° centigrade is engraved upon the thermometer scale. The co-efficient for the expansion of wrought iron is given by Sir William Thomson as ·000019 mean per degree centigrade.

637.—Where a long length is laid down for a base line or other purpose, it is better to take the thermometer reading at each measurement and defer correction to the completion of the work; the temperature errors may then be added together as a total, and the space allowance may become a measurable quantity. For example, say ten 10-feet lengths give by these united centigrade degrees, plus and minus, shown at separate readings $+ 167^\circ$, and that the standard of the rods is true at $15{\cdot}5^\circ$. Then—

$$167-(10\times 15{\cdot}5)=+12^\circ \text{ per foot total allowance,}$$

that is, $12^\circ \times 10$ feet $\times \cdot000019 = \cdot0228$ feet or $\cdot2736$ inches to be added. In measuring iron of course no correction has to be made.



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290

FIG. 289.—*Beam compasses.* FIG. 290.—*Standard scale.*

638.—*Beam Compass Measurements* are occasionally preferred for iron work. In this case the beam is moved from centre punch mark to mark along a surface by the beam producing a scratch for the forward position in which to place the punch mark. Rods of pine are commonly employed. Figs. 289, 290 will sufficiently illustrate the instruments.

639.—**Method of Coincidence** in measurements by rods has often been applied to measurement of base lines. The plan consists in allowing one rod, or a lighter continuous part of it, to pass the other rod, so that a line cut to standard on one rod may be read into one on the other. The best plan to do this is to have a scale fixed along the face of one rod near its end, as shown Fig. 291, and to have an extension from the other end of the second rod to pass alongside this scale, so that two lines may be brought in coincidence. The rod *B* has a fixed scale *b* placed on top of it at one

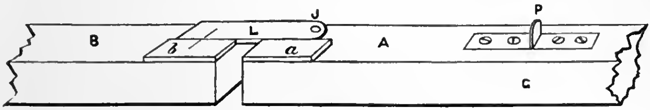


FIG. 291.—*Coincidence rods.*

end. The rod *A* has a scale protruding from it. This scale may be jointed with a good ground joint at *J* for portability. The rods are laid lightly together, and any final adjustment is given by light taps with a small hammer or mallet upon one or the other side of the stud *P* until exact coincidence of the lines shown at *b* is brought about. This tapping operation appears a rather rough process, but practically it is very exact.

640.—**Compensated Rods.**—The plan of Bessel for the measurement of a base upon the shores of the Baltic in 1836 is looked upon as a model of the most perfect work of its kind. The rods were composed of two bars of iron with accurately planed surfaces, with a similar bar of zinc placed between them. The bars were laid one on the other, but not in contact, the surfaces being kept apart by glass plates, upon which they could slide with little friction. The linear expansion of zinc per degree centigrade is about ·0000292 (Fizeau); that of iron much less than half this—about ·0000119 (Thomson). The bars are attached to each other in such a way as the expansion of the zinc may act in the opposite direction to the expansion of the iron. The form followed for the construction is shown in Fig. 292, where $I\ I'$ are the iron bars, Z zinc. The length of the zinc required for compensation between the junctions is found in the equation—

$$(S + Z)\ (0000119) - Z\ (0000292) = o,$$

S being the total length of the standard rod in feet, and Z the length of zinc in feet required for compensation. This plan is that adopted for the compensation of pendulums. For the verification of a rod it may also be made to form the rod of a pendulum, by which temperature expansion and contraction upon the system

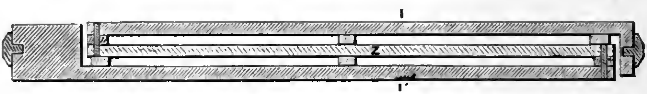


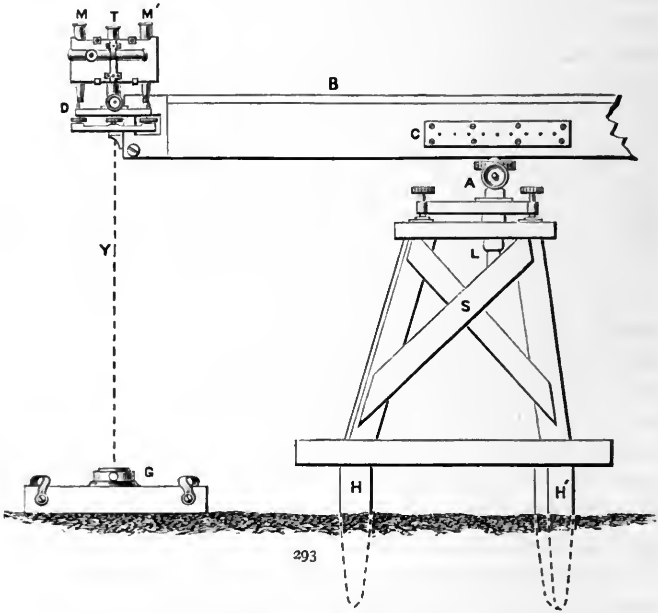
FIG. 292.—*Bessel compensated rod.*

will be clearly indicated by difference of time rate in the change of temperature during night and day. This test becomes important where great precision is aimed at, as expansion in metals varies according to their purity and state. The standard lines in rods made upon this model are placed upon small inserted discs of platinum placed near the ends, which are read by microscopes in coincidence upon a pair of rods.

641.—**Colby Compensated Rods**, the invention of Major-General T. F. Colby, who was for twenty-seven years superintendent of the Ordnance Survey, upon which these rods were used. Each rod is composed of one rod of iron and one of brass, which are so arranged in pairs that the difference of expansion of these metals shall act to diminish the amount of entire expansion at the points measured, a quantity equal to its increase by temperature, in a manner to be described.

The Rods are each made 10 feet 1·5 inches long, 5 inches broad, and 1·5 inches deep. Fig. 294 *i* is a side elevation of one rod, Fig. 296 *i b* plan of iron and brass rods, Fig. 297 *i b* perspective view. By this it will be seen that the rods are placed edgewise. The distance apart is 1·125 inches. They are supported in the middle upon rollers Fig. 294 *F*. They are firmly fixed together at their centres by transverse steel cylinders Fig. 295 *R R′* 1·5 inches diameter, each rod being left free to expand or contract from the neutral central point independently of the other. The neutral point is formed of a T-piece *E* fixed firmly on the bottom of the box *bx*. At the extremity, and at right angles to each of these bars, is a flat steel tongue, Figs. 296, 297 *A*, 6·2 inches long, 1·1 inches broad, and 0·25 inch thick, which projects 3·25 inches from the side of the iron bar *i*. The tongue *A* is jointed by double conical pivots at *f* and *f′*, which form axes perpendicular to the surface of the tongue, allowing it to be inclined to slightly different angles to the direction of the bars according to the expansion or contraction the system experiences by heat. The pivots are 0·5 inch diameter, and are placed at 2·3 inches from the end of the tongue next the brass bar. On the tongue at *P*, flush with its upper surface, a small stud of platinum is inserted, upon which a small dot is struck to form the point of standard measurement.

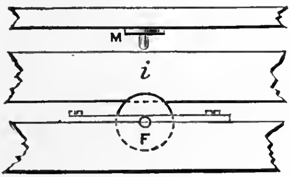
The bars are placed in strong wooden boxes, to the bottoms of which are fixed the plates that hold the brass rollers upon which the bars are supported Fig. 294 *F*, and the central stay *E* mentioned before, which prevents any displacement of the bars when the rods are held by the rollers *R R′*. To protect the tongue *A*, which projects beyond the boxes, there is a special covering nozzle which has a hole and cover over the dot. A level is placed on one of the bars, which is seen through a window in the lid of the box. At the ends of the box, plates are fixed for supporting the tripod of the double compensated microscope Fig. 293 *D*, which is employed to observe the standard points of one pair of rods brought by adjustment to true position *M M'*. A pair of sight vanes which shut down are placed on the ends of the box for placing the rods approximately in line.



Colby Compensated Measuring Rods.

FIG. 293.—*End of rod mounted with microscopes, trestles, and ground plate.*

Two Rigid Tripod Stands Fig. 293 *S* are used to each of the rods placed under the rollers Fig. 294 *F* upon which the bars are supported in the box. The tripods carry a universal slide-rest by which the rod may be adjusted to position both in horizontal and vertical planes Fig. 293 *A*. Six rods were used for the Ordnance Survey at one time, which were designated by the letters A B C D E F. The weight of each rod complete with microscopes in its case is 136 lbs.



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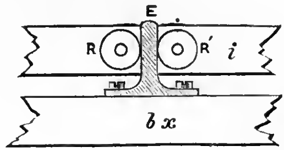

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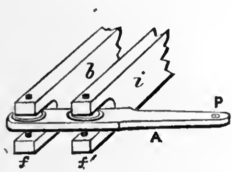

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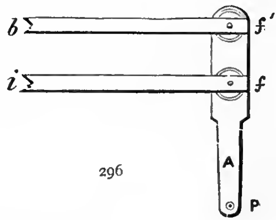

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Colby Compensated Measuring Rods.

FIG. 294.—*Side elevation of point of support of rod.*
FIG. 295.—*Side elevation of centre, with section of box bx.*
FIG. 296.—*Plan of rods and compensating arm.*
FIG. 297.—*Perspective view of the same.*

642.—*Compensated Microscopes.*—The compound microscopes Fig. 293 *M M′* used with the Colby apparatus form a complete separate instrument consisting of two microscopes placed parallel to each other and united together for reading the rods when they are brought with their standard points the distance that separates the axes of the two microscopes apart. In the intermediate space between the two microscopes, and parallel with them, a telescope *T* is fixed on the same piece of apparatus, with adjustment for reading a point on the ground *G* perpendicular to the measuring rod. The microscopes are held apart by two bars of brass and iron 7 inches long, 0·5 inch broad, and 0·375 inch thick, which are placed at 2·5 inches apart and secured with the telescope, which forms the fixed centre, by collars to the bodies of the microscopes. The difference of expansion of the iron and brass maintains the separation of the microscopes at their foci at one distance with every change of temperature of the air. The object-glasses are of 2 inches focus. The microscopes are brought to adjustment and bearing by levelling on a tribrach whose base is fixed firmly to one of the rod cases, and by lateral adjusting screws. Special microscopes are used with each of the six rods of the Colby apparatus, which are distinguished by the letters M N O P Q R S. The weight of each compound microscope is 5 lbs. Very full particulars of the Colby apparatus, with engravings of all parts, are given in "The Ordnance Survey Account of the Measurement of the Lough Foyle Base."

643.—In measuring a base line a piece of nearly level land is selected, and the rods are supported upon the trestles or tripod stands at about 3 feet from the ground. The heights of the upper surfaces of the tripods are ranged by a theodolite or level for all intermediate points between the two ends of the line. Generally twelve trestles are employed with these rods, which are fixed firmly to the ground at every station by legs well rammed in, Fig. 293 *H H′*. The cases containing the rods, or the rods themselves are made sufficiently strong to be supported upon two points only without serious deflection.

The Colby system of measurement of base lines varied in detail has been employed by nearly all the nations of Europe and in America.

644.—**Perambulator.**—A very ancient instrument, described by Vitruvius as among the effects of the

Emperor Commodus as being used by hand or attached to a carriage to measure distances. The instrument is at present used as formerly for measuring roads. Upon pavements and asphalt roads it measures accurately, where by reason of traffic it is sometimes a difficult or very slow process to use the chain. The plan of manufacture is varied considerably. The author makes the felloe of the wheel in segments of well-seasoned mahogany in two rings Fig. 298. These are rivetted together from side to side in a manner that the grain of the wood is crossed as much as possible to prevent

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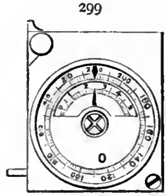

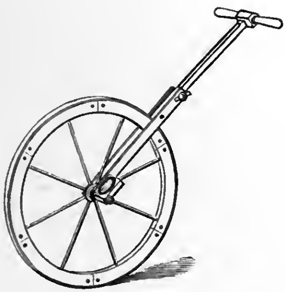

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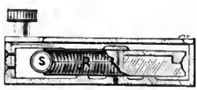


299 A

FIG. 298.—*Perambulator.* FIG. 299.—*Details of registering box.* FIG. 299 A.—*Section.*

lateral warping. The tire, which is 6 feet in circumference, is made of hard rolled brass 1 inch by $\frac{1}{4}$ inch thick. The spokes are light steel tubes, covered with brass tube, which are screwed into a brass nave. The axle of the wheel is placed in a steel fork which is formed by screwing, by means of a winged nut, two bars of about 18 by $1\frac{1}{2}$ by $\frac{3}{8}$ inches upon a boss formed at the end of the steel stem of the turned wood handle. Made in this manner the handle may be easily detached and placed flatwise upon the wheel, so that the whole may be packed in a square deal case of moderate dimensions for portability.

645.—*The Registering Part of the Instrument* Figs. 299, 299 A.—The axle is protruded through the fork described on the left-hand side, and thence through the registering box supporting one of its ends. The other end of the box is supported by a stud which fits into the side of the fork. The axle in the part contained within the box is cut into a screw Fig. 299 A *S* of about sixteen threads to the inch. The screw works in the edges of a pair of discs *R*, placed one upon the other upon the same axis, which are cut on their edges with teeth to form worm wheels in which the screw upon the axis of the wheel works. The upper disc has 110 teeth. This therefore moves one revolution by 110 turns of the wheel. It is divided into 110 divisions at its circumference, but is figured 20 yards to 220 yards or 1 furlong, so that each division represents 2 yards, corresponding with the circumference of the wheel, Fig. 299 *O*. The divisions are read by a point attached to the side of the box shown at the top of the figure. Single yards are shown by the intermediate position of the pointer between the divisions, but single feet may very well be estimated approximately. The lower disc *i* is cut with 111 teeth. The ratio 110 to 111 gives a differential displacement of one tooth only after 110 revolutions of the wheel, or of 220 yards traverse. The two discs take, therefore, by revolution over the surface $220 \times 110 = 24{,}200$ yards or 13·5 miles before they return to the same relative position as at starting. This is therefore the space this perambulator will traverse without re-setting. To enable the lower disc to be read the upper disc is cut away for half the interior circumference of its circle. A part of the upper disc is formed into a point, to read direct from the centre into divisions on the lower disc, in furlongs up to 13 miles.

The Measuring Box is covered with glass for protection. The box can be taken off by removal of the milled-headed screw at any time to set it back to zero, but in practice it is often found more convenient to spin the wheel round to zero or an even mile of the outer circle, and record differences of reading, if this can be done in the distance within the record of 13 miles of the lower disc. The screw and axis, which are of hard steel, should be occasionally oiled with watch oil to keep the perambulator in good working order.

FIG. 300.—*Construction of pedometer.*

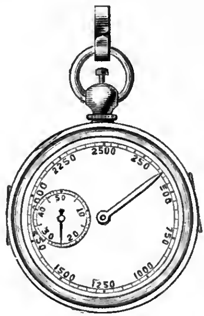


FIG. 301.—*Face of passometer.*

646.—**Pedometer**—used for roughly ascertaining distances passed over in walking. This ingenious instrument was the invention of William Payne in 1831 (patent No. 6078). It is of the size of an ordinary watch and has a similar face, but between the figures, which indicate miles 1 to 12, there are four divisions only, to indicate quarter miles. The pedometer is slung up by a loop Fig. 300 *H* fixed upon the handle, which in use is passed over the edge of the waistcoat pocket so as to keep the instrument in an approximately vertical position.

The Registering Apparatus consists of a pendulum *P* placed horizontally by being supported by a delicate spring *L* to its highest position, where it rests against a stud. The action of the pendulum is caused by its following the motion of the body in stepping, until stopped by the foot reaching the ground, where the momentum attained by the pendulum carries it from its upper position of rest where it is sprung against the stop to its lower free position, where it is stopped by a screwed adjustable stud S shown under it. The axis of the pendulum is free upon the axis of the ratchet wheel R. When the pendulum falls, a fine spring fixed to its upper surface, falls at its end into the teeth of the ratchet, moving over two or three teeth, which are held against retrograde motion by the spring pawl D. When the pendulum rises, the ratchet is moved forward the number of teeth that the spring at first slipped over. The ratchet is connected with a pair of geared wheels, not shown, the axis of the second of which forms the axis of the hand. In this manner each oscillation of the pendulum is communicated to the index hand. The ratchet is made with extremely fine teeth, so that by adjustment of the screw stud S a greater or less number of these teeth may be taken by one beat of the pendulum, and thus the mileage rate may be adjusted approximately to the step. This is done however very imperfectly, as the variation of the average steps of men is one or two inches, and the difference from the number of teeth taken will scarcely indicate less than 3 inches in the step.

647.—**Passometer.**—This instrument was originally invented by the author as an improvement upon the pedometer (1868). The instrument, Fig. 301, is not intended to indicate miles or any distance, it simply counts the number of steps taken. The action is just the same as the pedometer, but the ratchet teeth are larger and less liable to lose a tooth, as it is made to take one tooth only at a single step. The dial arrangement is entirely changed. The steps are numerically indicated by a separate hand which reads into the graduations up to 50 steps upon a small dial. Each revolution of the small hand reads through gearing one division of the central hand, which moves over the complete circumference of the dial, reading up to 25,000 steps. This is the extent of indication. It is necessary in continuation beyond 25,000 steps to take a record of progression per 25,000 where a greater distance is required to be measured.

The average step may be got perhaps within 1 or 2 per cent. by training in walking several miles steadily, counting the steps, always remembering that we take shorter steps uphill and when we are tired. But the mean step of the individual under all the different circumstances is the only rule that can be followed.

FIG. 302.—*Sounding chain.*

648.—**Sounding Chains** used for coast surveys are generally made of brass, but sometimes of iron. They are made generally of 10 fathoms entire length. The links are 1 inch, and the feet are indicated by tellers. The form of teller designed by the author is shown in Fig. 302 for the 3. A lead weight, similar to that shown Fig. 303, is used upon the end of the chain—of 28 lbs. for ordinary coast work, or heavier if there are strong currents. The chain is generally contained in a strong wooden box when out of use.

A very elaborate apparatus with steel wire line has been made for deep-sea sounding by Sir Wm. Thomson and others; but this subject is beyond the province of this work.

649.—**Sounding Lines** used for survey of shallow coasts and harbours are made of water-laid line of fine green hemp, about $\frac{3}{4}$ inch circumference. White tapes are inserted as tellers at every foot, and red tapes at every fathom. 3 to 6 fathoms are the ordinary lengths employed. If the water is shallow the fathoms are easily counted, but if thought necessary, knots may be

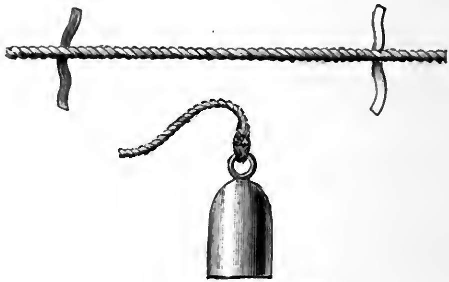


FIG. 303.—*Sounding line and weight.*

tied to indicate number of fathoms on the red tellers. The under side of the weight is commonly covered with tallow when it is desired to bring up a specimen of the bottom, if this is loose sand or mud.

650.—**Telemeters.**—These instruments scarcely enter within the practical limits of surveying instruments, but as several attempts have been made to introduce their use it is necessary to mention them. The general attempt has been to measure a great distance, 1000 feet or more, by means of the angles subtended from the ends of a short base to a distant point. This base in the telemeter of Piazzi Smyth is 60 inches; Colonel Clarke, 72 inches; Otto Struve, 73·5 inches; and Adie, 36 inches. The angles are generally taken upon the principle of the sextant by coincidence of image. The author, as far as his information reaches, is assured that no instrument of the class is satisfactory. Further, the subject is one to which he has devoted some study, and designed two telemeters.* One of these appeared to him for a time

* Patent No. 2142, May 1880.

satisfactory within certain limits. The base in this instrument was 50 feet, formed of a fine pianoforte wire stretched between two observing telescopes, the tension of the wire directing the one telescope to a right angle, and the other telescope to an arc which read either degrees and minutes or absolute distances in the eye-piece to the direction in which the telescope was pointed. In first trials this instrument was found fairly satisfactory; but in subsequent trials in windy weather the deflection of the wire rendered the action of the pair of instruments quite unreliable.

There are some instruments, as Colonel Gautier's telemeter, used in the French army which depend upon combined reflectors placed normally at 15° to 45°, as in the apomecometer art. 560, but with tangent screw to give a small motion of displacement to one mirror which reads on a scale of calculated distances to angle from a certain base measured between two stations of observation. A quite similar instrument, invented by Labez, has one reflector only at 45°.* These instruments may be useful for measuring approximate distances for range in the army, but can scarcely rank as surveying instruments, the box sextant art. 538 being in every way a superior telemeter for the purpose when a measured base can be fixed and well-known trigonometrical calculation be used.

651.—**Hand Rods**, although used more generally by building surveyors, are extremely useful also to the civil engineer and land surveyor for town work among buildings and in mines. They are made 5 feet in length, less generally 10 feet. The 5-feet are made of single blades of lancewood or are jointed to fold. The 10-feet are always jointed and made much stouter than the 5-feet. The 5-feet are generally sold in pairs.

* "Practical Surveying," George W. Usill, pages 65, 66, 1889.

652.—**Ordinary 5-feet Rods** are divided to every 3 inches, with feet only stamped with numbers, as shown Fig. 304. Where the rod is jointed the best form of folding joint is shown in the figure in section and plan. The spring *S* is sunk into the face of the rod at the joint on one side, and springs into a groove *(housing)* in the other side so as to lock the joint when it is either open or closed. The most useful dimension for the rod is

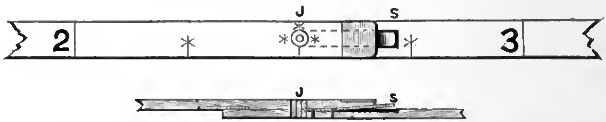


FIG. 304.—*Ordinary 5-feet jointed rods—plan and section of joint.*

1 inch by $\frac{1}{6}$ inch. Rods are nearly always made of lancewood, but they are preferred dyed black for neatness by many surveyors. A pair of rods are commonly carried in a cowhide case. They are also very commonly carried in the stem of a walking-stick hollowed out for the purpose. The rod or rods in this case are made much lighter, generally $\frac{1}{2}$ inch by $\frac{1}{8}$ inch for a pair of rods, or $\frac{7}{16}$ inch by $\frac{7}{32}$ inch for a single rod. The latter is to be preferred in this case for its extra strength.

305

306

FIGS. 305, 306.—*Stanley's surveyors' rods.*

653.—**Fully Divided Rods.**—The author has made rods for many years divided to single inches. These measure from both ends—one end direct as Fig. 305 and the other end inverted as Fig. 306. By this plan the rod gives direct measurement in feet, inches, and parts from either end, and the division is always placed outwards against the work, so that measures may be taken from either end by turning the rod over sideways, without turning it end for end.

654.—**Connecting Link for Rods**, which weighs only 1 oz. and may be carried loose in the pocket, is often found convenient for measuring heights, as it permits the ends of a pair of rods to be brought together Fig. 307. By this means the arm will raise the rods

FIG. 307.—*Connecting link for rods.*

about 7 feet, and with 10 feet, the height of the pair of 5-feet rods, this will make 17 feet of measurement. When the 10-feet is set against a wall, its height, if 20 or 30 feet, may be guessed very approximately by standing at a distance from it.

655.—**Slip Jointed Rod**.—This form is less general, but it is a very convenient form of rod. The jointing is effected by two loops which are fixed to the centre end of one part of the rod in a manner that the other part may slide through the loops. When the rod is extended to 5 feet there is a stop which prevents further extension, and a spring to keep it at this exact position, Fig. 308. The outside of the rod is divided into feet and inches.

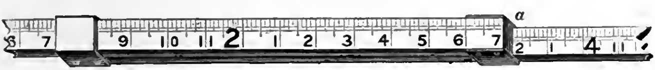


FIG. 308.—*Slip jointed rod.*

The inside is divided so that any addition to the half rod, produced by opening the rod a quantity, may give the measurement from end to end of the rod at this position, thus:—The half rod being 2 feet 7 inches closed, if the loose side be drawn out 19 inches the rod from end to end will be 4 feet 2 inches, which will be indicated by the division and figuring inside the rod.

This is very convenient for measuring openings such as doorways or passages.

656.—**Brace-piece.**—A 10-feet rod is sometimes made with a brace-piece which folds up inside the rod. This brace-piece is jointed to fix both half rods to 90° when it is desirable to use the rod as a square.

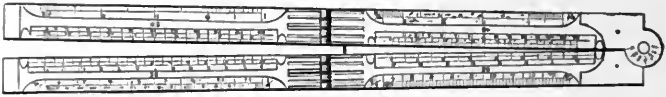


FIG. 309.—*Civil engineer's rule.*

657.—**Civil Engineer's Rule** is made fourfold in both boxwood and ivory, Fig. 309. The most convenient size is 1 inch wide. Some of the profession prefer them narrow for lightness—$\frac{3}{4}$ inch; and some wide for strength—$1\frac{1}{4}$ inches. This rule is generally well made, with German-silver joints with outside joint plates. The divisions placed on the rule outside are inches in eighths and tenths; the inside, the ordinary architects' scales, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, and four chain scales, 20, 30, 40, and 50. A 10 is got by halving the 20; 60, by doubling the 30. A protractor reading to 5° is divided on the head. With silver joints and in fine ivory this rule is often made a presentation instrument.

CHAPTER XIV.

STATIONS OF OBSERVATION — PICKETS — FALSE PICKET — PERMANENT STATIONS—REFERRING OBJECT—HELIOTROPE —HELIOSTAT—HELIOGRAPH—SIGNALLING—MORSE ALPHABET—NIGHT LIGHTS—OIL LANTERNS—MAGNESIUM LAMPS.

658.—*Stations of Observation* vary materially according to the extent of the survey and its purpose. For geodetic works stations are raised at great expense, often in masonry or solid woodwork. For ordinary local or civil surveys the stations are commonly formed of single poles set up vertically, which vary in dimensions according to the extent of survey and difficulties which may be encountered—by various obstructions to direct vision by woods, lakes, marshes, etc. The apparatus that may be useful in the work of the civil engineer only will be considered here.

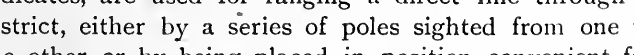


FIG. 310.—*Ranging pole or picket.*

659.— **Pickets or Ranging Poles**, as the name indicates, are used for ranging a direct line through a district, either by a series of poles sighted from one to the other or by being placed in position convenient for triangulating by the theodolite where the country is open, or free from many buildings, trees, or other convenient landmarks.

The picket (Fr. *piquet*) is a straight, slightly tapering pole shod with wrought-iron or steel. It is generally made of about $1\frac{1}{8}$ inches diameter and is painted in alternate feet red and white with an enamel paint that will not soil the hands or take dirt from them. The shoes should be made with strap-pieces, so that the picket, which is generally made of yellow pine for lightness, should not be liable to break off at the shoe in use. Fig. 310 represents the lower part of a picket as made by the author: *B* black, *W* white, *R* red. It is usual to have six pickets at least out in use with a theodolite in open country.

660.—**False Picket.**—For the placing of a picket it is usual to clear the sod with a small spade where possible, so as to suspend the plummet from the theodolite into the hole made by the picket to triangulate from its position. In marshy lands and under many conditions this is not easily done. It will generally be found more expeditious to carry about one of the author's false pickets to place directly in the hole from which the picket is removed, which saves the trouble of removing

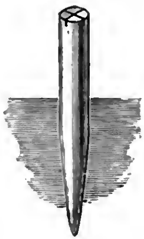


FIG. 311.—*False picket.*

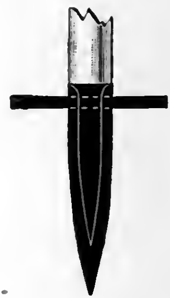


FIG. 312.—*Spur-shod picket.*

the grass. This is shown in Fig. 311. It consists of a wooden peg, upon the top of which a cross is sawn to represent the axis. This cross is filled in with a veneer of ebony and the whole is polished over to keep it clean. It will be readily seen that any picket accidentally broken will make a false picket. In setting up the theodolite over it the plummet is brought to verticality with the centre of the cross. In moving the false picket the original picket is easily replaced if required in the same position for continuing the work.

661.—**Spur-shod Picket.**—Much stouter poles than may readily be pressed in by hand, as for instance, of 2 inches diameter, may be driven into the ground by having a spur or cross-bar of steel, about 7 inches long and about $\frac{3}{8}$ inch diameter, placed through the pole, say at 1 foot distance from the point. This form is much used on the Continent. This picket may be jerked down for a certain distance by pressure of the foot on each side, and then jerked home to the ground by standing upon it, to make a 10-feet or 12-feet pole stand sufficiently rigid for temporary work.

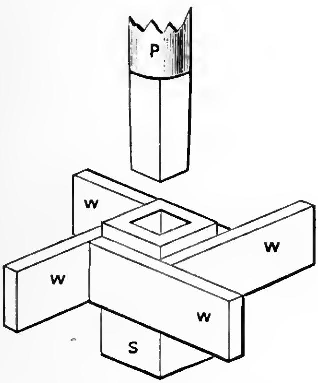


FIG. 313.—*Socket for station pole.*

662.—**Permanent Stations** are commonly constructed upon hill-tops or other commanding positions. A very general way is to set up a long pole of fir or other wood at command, from 10 feet to 20 feet in height according to the circumstances. Occasionally it is desirable to remove the pole and place the theodolite centrally over its vertical position. A very good way to do this is to have a slightly tapered, wooden socket Fig. 313 *S* constructed of stout boards, say $1\frac{1}{2}$ inches thick, made into a hollow square with a cross of boards *W W W W* fixed to it. The socket is placed in a hole dug out entirely below the ground, and is rammed in and fixed as an ordinary gate post. The pole *P* is squared at the end to fit the tapered socket up to shoulders which are formed by leaving the other part of the pole round. The socket for a 15-feet pole should be 18 inches deep; for a 20-feet one, 2 feet deep. Where these poles are properly prepared they may be jointed together in two or more parts for portability. Bunting flags, red and white, about 18 inches by 9 inches, may be fixed at the tops of poles. In fixing the socket the pole should be erected in it to be able to keep it constantly vertical during the ramming. A plummet suspended at arm's length, at a distance from the pole in two positions at about right angles to each other from the centre of the pole, will provide a means of keeping the pole erect during the fixing of its socket. The socket hole upon lifting the pole out, forms the centre for erecting the theodolite over its position.

663.—**Referring Object.**—It is found to be desirable that all arcs taken by the theodolite from an important station should contain one point in common, for which the best defined object to be found at a distance may be selected. Colonel Clark, of the Ordnance Survey, recommends as a referring object two rectangular plates of metal placed with their edges parallel to each other in the vertical plane, at such a distance apart that the light of the sky seen through the opening appears as a vertical line of about 10″ in width. The best distance for this object is from 1 mile to 2 miles. Two pieces of board, fixed a small distance apart by ledges screwed thereon, answers the same purpose. The description fully conveys the method without illustration.

Stations Visible at Great Distances are formed by means of reflection of the sun's rays or by artificial light.

664.—**Heliotrope**, or *heliostat* as it is sometimes called, may be any form of mirror to throw the sun's ray in a constant direction or to a distant station at a time of day fixed for making observation. The instrument is uniformly constructed with a small glass mirror with plane surface. The angle of divergence of the extreme

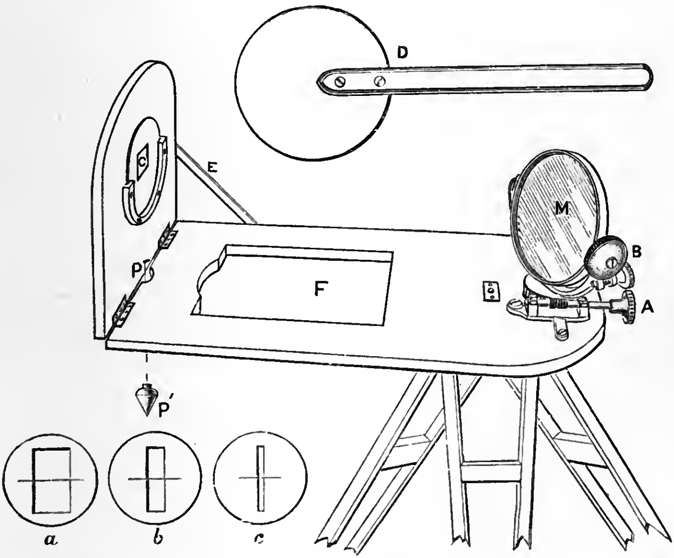


FIG. 314.—*Stanley's heliotrope.*

rays in the reflection is the same as that subtended by the sun's diameter at the position of the mirror, that is, of about 32 minutes of arc. This divergence is sufficient to render the reflector visible at a great distance. The plan upon which the author has constructed this instrument is shown in Fig. 314. It consists of a reflector *M*, formed of a plain glass mirror of about 5 or 6 inches in diameter, placed in a metal tray. The mirror is centred vertically upon an axis to which a worm wheel *B* is attached upon one side; that works into a tangent screw which is moved by a milled head so as to place the mirror at any angle to the horizon. The mirror and its vertical adjustment just described are carried by a fork which is erected from the base board of the instrument upon a socket joint which permits the mirror to be turned about. Upon the lower part of the fork above its socket another worm wheel is constructed centrally to the axis. This works into a tangent screw attached by fittings to the base board. The tangent screw has a long shank leading to a milled head *A*. By means of the milled heads the mirror may be set to any position, so as to throw the reflection of the sun in any required forward direction. A small hole is cut through the silver in the centre of the mirror to sight the position to which the sun's reflection is directed.

The Base Board, which is of inch mahogany about 20 inches by 10 inches, is supported upon a very firm tripod stand, as that described for a plane table art. 595. At one end of the board a sighting screen of mahogany, 10 inches by 10 inches and $\frac{3}{4}$ inch thick, is hinged so as to be held erect by means of a stay bar *E*. In the centre of the screen an opening is turned out $3\frac{1}{2}$ inches diameter, and a frame-piece of half circle only is placed over this. The frame-piece is grooved out at the back so as to hold discs, shown *a b c* in the figure.

The Discs a b c, which are of thin brass, have openings respectively $\frac{1}{4}$, $\frac{3}{4}$, and $1\frac{1}{2}$ inches wide, so as to reduce the width of the line of light which appears through them when the reflection of the sun is thrown from the back. These have each a fine wire stretched across them to indicate the centre. A fourth disc, not shown, has a double cross of wires to indicate the centre only.

To Pack the Instrument, the screw is turned down the index frame, falling into the opening *F;* the mirror with its fork is lifted out and secured to the surface of the base board by buttons; and the whole apparatus is put in a canvas case. Its weight without tripod stand is 8 lbs.

665.—*To Use the Heliotrope*, the station on which the sun's light is to be thrown is sighted by looking through the small hole in the centre of the mirror, and adjusting the base board until the station appears in the centre space of the disc opening. The mirror is then turned towards the sun by means of the milled heads until its image, reflected upon the back of the screen, appears central with one of the discs which is intended to be used. All parts of the stand and fittings being made quite firm, the attendant moves the milled heads, as required, to follow the apparent motion of the sun, at intervals of five minutes or less. It must be observed that the centre of the slit in the disc represents the station visible to the observer. This point must therefore be plummed to the station point in setting up the instrument. A part of the screen at *P* is cut away to admit the suspension of a plummet.

666.—The heliotrope was much used in India for the great trigonometrical survey. Colonel Thuillier states from experiment that "A heliotrope of 9 inches diameter answers for 90 to 100 miles. For nearer distances it is much too bright to be observed through a telescope, and the light must be diminished in the following proportion. For distances of 2 or 3 miles (the usual distance of a referring mark) an aperture of 0·25 of an inch will answer, and for longer distances about 0·1 of an inch of aperture per mile of distance will suffice, viz., an inch for 10 miles, 2 inches for 20 miles, and so on, provided always the apparatus is carefully adjusted and the man who works is alert and skilful." *

* "Manual of Surveying for India," page 478, 1875.

Practically the discs here described will give all the variation required. In less favoured climates than India more opacity will be found in the atmosphere, and larger apertures required than those just stated.

667.—*Signalling with the Heliotrope.*—A thin wooden bat *D* is moved over and off the outside front of the open disc aperture, following the rule of Morse signals, which will be presently described for the heliograph.

668.—**Heliostat.**—Is a similar instrument to the heliotrope, but the mirror or mirrors are moved by clockwork, so as to keep the sun's reflection in a uniform direction throughout the day. This instrument is delicate and not well adapted to field work.

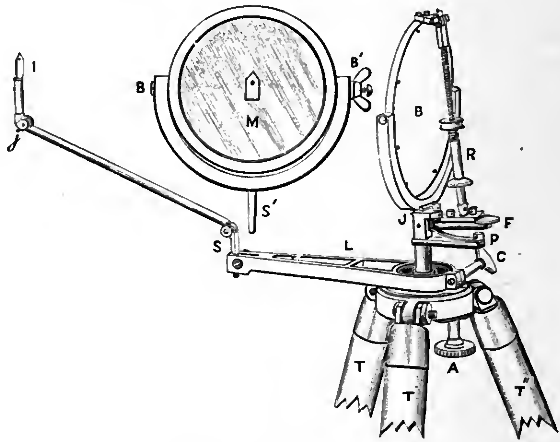


FIG. 315.—*Heliograph.*

669.—**Heliograph.**—This instrument is the invention of Mr. H. C. Mance,* since improved by Major Macgregor, Colonel Bonham, and others. It was intended, and is used, for a military signalling apparatus, but it is also employed in place of the heliotrope for surveying; from its portability, where very great precision by limiting

* Patent No. 3390, October 1874.

the area of light reflection, is not required. The construction of the instrument is shown in Fig. 315. *B* is the back of a plain, circular mirror of 5 inches diameter, which is supported upon pivots upon a fork frame *J*, the lower part of which forms a socket. The socket is furnished with a thumb-screw to secure the mirror and its frame when placed upon a cone projecting from apparatus connected with the base plate formed on the top of the tripod head. The cone is erected upon a disc or wheel cut at its edge in teeth and centred upon the axis of the tripod head. The wheel is revolved by means of a pinion connected with a milled head *A* which moves the mirror and the entire apparatus above in horizontal revolution.

The Sighting Arm L is attached to a collar fitting projected from the tripod head. This may be fixed in any horizontal direction by means of the tangent clamping screw *C*. The arm *L* has a supplementary extension by the piece *S j*, which is jointed at the position of these letters, as also by a socket fitting into the arm. The termination of the extension is a sighting point *I* formed of a thin blade of metal. The arm and its fittings permit the sighting point *I* to be set in any direction or elevation to follow the inclination of the land.

The Sighting Vane is a piece of white metal, upon which there is placed a black dot termed the *sighting spot*. A small circle, about $\frac{1}{5}$ inch diameter, is left unsilvered in the centre of the mirror, which does not reflect the sun's rays. It therefore causes a small disc of shadow in the centre of the reflection of the mirror, which is termed the *shadow spot*. The shadow spot is made to appear upon the sighting spot when the instrument is adjusted to throw the sun's image upon a distant station.

The Supplementary Mirror M is similar to that already described, centred also on pivots and placed in a fork frame. This is mounted on a cone S' which fits into a socket at S, when the extension arm J is removed. This mirror is intended to receive the image of the sun when placed towards the back of the pointing of the instrument to throw the sun's image from the mirror M to B, to signal by double reflection, when the sun is at a forward angle to the distant station. The coincidence of reflection is taken with this mirror by the reflection of a piece of paper pasted on its centre of the same form as the index I.

670.—*Telegraphing Apparatus*, called technically *flashing* apparatus. This consists of a rod R which is hinged to the top of the mirror at its upper end and also to a lever which forms a Morse key at the lower end. The rod is formed of a screw of about half its length, which passes into a female screw tube so as to shorten or lengthen it as required to direct the reflection of the sun's rays by turning the milled head above R, which forms a part of the tube. The Morse key is hinged at J to the stem of the instrument, and is kept up to a fixed stop by means of a spring P extended by an arm from the stem of the instrument, so that pressure upon the disc F moves the key down to its stop P, and also tilts the mirror to throw its reflection off the observing station during the pressure.

The Tripod of the Heliograph $T\ T'\ T''$ consists of three circular mahogany legs $1\frac{1}{8}$ inches diameter and about 4 feet 9 inches long. The legs are capped with sockets carrying collar-pieces which are attached to the tenon-pieces of the head. The head forms a box for the revolving apparatus, which remains attached to it when the mirror apparatus and arm are removed. The tripod head is protected when out of use by a leather cap which is attached by a strap to one of the legs. The weight of the tripod is 6 lbs. In fixing the tripod for use it should have the legs extended nearly 60°, and the toes should be firmly pressed into the ground. At windy stations it is as well to dig holes and sink the toes, or to have a heavy stone suspended under the centre of the head.

671.—*The Case for the Heliograph* is made of solid leather with separate divisions for mirrors, arm, and sight. A spare mirror is sometimes packed in the same case that the instrument may not be thrown out of order by accidental breakage. A strap is provided with the case to go over the shoulder. The instrument weighs 5 lbs. complete in its case. Great care should be taken to observe the arrangement and position of the parts of the instrument before taking it from its case, as it is always packed closely.

672.—*To Use the Heliograph with a Single Mirror.*—In this case the reflection is direct. The instrument is approximately directed by looking through the mirror from behind, directing the arm *L* and the sight *I* to cut the distant station, and then clamping the screw *C*. After this is done the exact position is found by placing the head nearly in *front* of the mirror, with the back to the distant station with which it is intended to communicate. Then to adjust the mirror, if required, and move the eye until the distant station appears reflected in the exact centre of the mirror. After this, without moving the head, finally to adjust the sight vane *I* until the reflection of the sighting spot is brought exactly in line with the centre of the mirror and appears reflected upon the image of the distant station. The sighting spot is then in direct line between the distant station and the centre of the mirror in whatever direction or inclination the mirror may be afterwards placed to reflect the sun's image. Care should be taken not to disturb the stand nor arm in future movements of the mirror.

673.—*To Adjust the Mirror*, stand behind the instrument and adjust the vertical screw *R* and the horizontal pinion A until the black spot, as it appears on the mirror from the reflection of the hole through it, appears upon the centre of the point of the sight vane surrounded by a ring of bright reflection from the silvered surface of the mirror. The distant station will then receive the reflection, which must afterwards be kept constantly upon it by gently moving the screw R and pinion A, following the apparent path of the sun.

674.—*To Use the Heliograph with Two Mirrors*, which is necessary when the sun is shining towards the distant station and its image can only be projected by double reflection, the second mirror is placed upon the end of the arm in the socket S. This has a white paper vane cemented upon it, as shown at M. The mirror B is placed roughly facing the sun. The mirror M is turned towards the distant station upon which it is intended to direct the rays, being careful at the same time to observe that the two mirrors do not intercept each other's rays. Now from the back of the mirror M we look into the mirror B, moving the head until the centres of the two mirrors appear in a line with the eye. Then without moving the head, adjust the direction and inclination of M until the reflection of the distant station appears in the centres of the mirrors. Now clamp the mirror M in this position, from which it must not be moved so long as it is required to keep the same station in communication.

To keep the reflection following the sun a position is taken at the back of the mirror B, and this mirror is worked as before described, when it is used singly, by the milled heads, only that in the present case the paper vane M takes the place of the metal vane I.

675.—*Telegraphing by the Heliograph.*—The communication is made by the alternate pressure and release of the Morse key F, each pressure throwing the reflected image of the sun off the observing station. The Morse alphabet, which is universally used, consists of rapid touches represented by dots, and pressures of at least four times the time of a touch represented by dashes. The following arrangement forms the alphabet :—

A	- —	N	— -
B	— - - -	O	— — —
C	— - — -	P	- — — -
D	— - -	Q	— — - —
E	-	R	- — -
F	- - — -	S	- - -
G	— — -	T	—
H	- - - -	U	- - —
I	- -	V	- - - —
J	- — — —	W	- — —
K	— - —	X	— - - —
L	- — - -	Y	— - — —
M	— —	Z	— — - -

The time between the words is double that of a dash. Many other signs are commonly used for figures, etc., for which the reader may consult "The Manual of Instructions in Army Signalling." The same system is used for signalling by flags; and by stopping off light of lamps this system is most valuable for the surveyor in new countries for information of forward ground and other matters.

676.—**Lights for Observations by Night.**—Under many conditions an observation of a distant station may be much more conveniently and accurately taken at night by observation of a luminous object of limited area. For this purpose the arc light, lime light, blue signal light, and other lights have been employed. For the civil engineer where regular stations are not erected, as with geodetic work, oil lights or the burning of magnesium ribbon are the most convenient.

677.—**Oil Lanterns.**—In the great trigonometrical survey of India large reverberatory lamps were used, which were furnished with Argand burners with circular wicks about 2 inches diameter. The back arc of rays was reflected by a parabolic reflection 12 inches in diameter and 4·9 inches in depth. The lamp was enclosed in a strong box with a plate-glass face 12 inches in diameter, with apertures to admit sufficient air and chimney to carry off fumes. The box was constructed to form a packing case for conveyance of the apparatus.*

678.—The oil lantern which will be found most convenient to the civil engineer will be one of the same form of construction as the bull's-eye lantern, but much larger—6 inches square is a good size. This may be made to go on the same tripod as the heliograph, and will take its place for signalling by night, or telegraphing by the Morse signals by use of the bat described art. 667. A 6-inch bull's-eye lamp with treble wick may be seen well in clear weather 5 miles to 10 miles off. A railway signalman's hand lamp forms a very good signal, or even an ordinary 4-inch bull's-eye is very useful in working over new countries.

679.—**Magnesium Lamp.**—The intense light given by burning ribbon magnesium, and the extreme lightness in weight of this material, renders it of special value for night signalling. Magnesium ribbon is now sold at a very low price (about two shillings per oz.), and 1 oz. will give a continuous intense light, visible at 30 miles, for over an hour, whereas for a night signal arranged to be given at a stated time, fifteen minutes is amply sufficient for a single observation.

This lamp, shown Fig. 316, is provided with clock-work that delivers the ribbon continuously for about ten minutes at the rate at which it burns. This rate is

* For full description and plate, see "Everest's Measurement of the Meridional Arc of India," Introduction, page cxv.

regulated by a pair of brake wheels which are brought together with the necessary pressure to retard the rate by a spring in turning the milled head shown at *R*. The ribbon upon delivery turns upwards, following the curvature of its coil, therefore it supports itself well at a melting temperature when it is alight. The ribbon is only paid out during the time that the detent shown at *S* is pressed downwards by the thumb, so that upon release of this pressure the light goes out when it is thought to have been burning sufficient time for an observation to be taken. The parabolic reflector which forms the front of the lamp is silvered, and should be kept clean. The clockwork is wound up by the key at *W*.

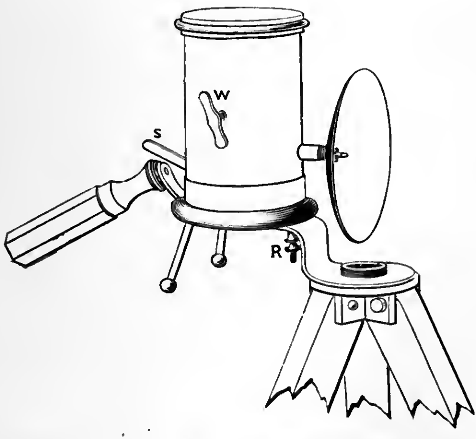


FIG. 316.—*Portable lamp for burning magnesium ribbon.*

The lamp has an *adapter* formed of a thin plate of metal attached to its under surface. This may be made to fit the top of any tripod of the heliograph, theodolite, or other instrument, in a manner to bring the centre of the flame to the former position of the centre of the instrument.

680.—*To Refill the Lamp with Magnesium.*—The cross key *W* is taken off by unscrewing it in turning to the left hand; the covering case then lifts off and a reel will be seen by the side of the clock in the centre of the lamp. This reel pulls off stiffly, as it has a spring fitting to clip the arbour of the clock upon which it turns. When the reel is off, its one loose side or cheek is removed, and then a cleft will be seen in the periphery of the wooden axis boss. A short piece at the end of the ribbon is bent to hook form and put in the cleft. The reel is then wound with sufficient quantity of ribbon to fill it to the edges of the cheeks. It is then replaced on its axis. The free end of the ribbon is now passed through the channel connected with the brake wheels and out to the front of the reflector. The cover being replaced and the cross key screwed on, when the brake *R* is adjusted it is again ready for use.

A good supply of ribbon would be about 1 lb. If it is for abroad this is better to be kept sealed in separate 1-oz. tin boxes.

681.—*For Using the Lamp.*—An intense flame is necessary for lighting the lamp—that of a small spirit lamp is the best. The exposed part of the ribbon is liable to corrode and become very difficult to light. If the lamp has not been used for a long time it is better to waste a few inches of the ribbon to avoid this difficulty. It lights better also at all times if the end of the ribbon be scraped bright with a pocket knife. If too long a length of ribbon comes forward during the burning by the speed of the clockwork, close up the screw *A* a little—if too little, release it. Occasionally the ribbon that has been on for a sea voyage is too corroded to work. It is then better to put on new ribbon fresh from its sealed case. If the weather is windy the lamp should be shaded.

682.—*For Telegraphing*, a handle *H* is put to the lamp. The lamp being very light, it can be moved by the hand quickly sideways, or up and down, behind any object so as to be obscured for a second of time and shown out again for a second, by which the Morse signals may be given with sufficient rapidity.

CHAPTER XV.

MEASUREMENT OF ALTITUDES BY DIFFERENCES OF ATMOSPHERIC PRESSURE — HISTORICAL NOTE — MERCURIAL BAROMETER — CONSTRUCTION — OPERATION — ANEROID BAROMETER—CONSTRUCTION—VARIOUS IMPROVEMENTS—HYPSOMETER.

683.—*Historical Note.*—The observation that the atmosphere decreases in density with increase of height is due to Alhazen the Saracen, about A.D. 1100. By this he explains that a ray of light entering the atmosphere obliquely follows a curvilinear path, bending towards the denser strata, or concave towards the earth. He showed that a body will receive difference of pressure in a rare and a dense atmosphere, and calculated the height of the atmosphere to its final attenuation would be from his data nearly 58½ miles. The practical instruments that have been devised for measuring altitudes, by the differences of pressure due to the weight of superincumbent atmosphere, are the barometer, aneroid, and hypsometer. The barometer was invented by Torricelli about the year 1640. Its principle was demonstrated and first applied to altitude measurement by Pascal in 1647. The aneroid barometer was suggested by Conti in 1798, and said to be devised as a practical instrument by Vidie in 1808. The hypsometer or boiling-point thermometer, which depends for its boiling temperature upon the pressure of the atmosphere above the liquid which surrounds it, was suggested by Fahrenheit in 1724, experimented with by De Luc 1772, and brought to its present practical form by Regnault about 1840. At the present time (1890) the aneroid is almost exclusively used by the civil engineer, as this instrument if made with great care is sufficiently reliable, more portable, and not so delicate in use as the others. So that it is only when very great precision is desired, or when the one instrument is used as a check upon the other, that the mercurial barometer or the hypsometer, or both are now employed. At the same time it must be understood that the aneroid barometer scale is in a certain degree arbitrary, as the divisions at best are only made up from a certain number of points taken from observations of the mercurial barometer placed simultaneously with the aneroid under an air pump, and therefore its errors comprise those of the particular mercurial barometer with which it is compared, with those also due to the difficulties of the comparison and of making subdivision afterwards in the same relative proportion by copying to the scale of the aneroid.

684.—**The Mercurial Barometer.**—The principle of the barometer is generally understood. If a glass tube closed at one end, 33 inches long, say of $\frac{1}{4}$ inch or over in bore, be filled brimful of mercury and the point of the forefinger be firmly pressed on the surface of the mercury, the tube may be inverted without the admission of air. If the covered end of the tube be now plunged in a basin of mercury and the finger slowly withdrawn from under the tube beneath the surface of the mercury, the mercury will sink in the tube to about 30 inches from the surface of that in the basin—that is, if the experiment is performed at about the sea level. The empty space in what now becomes the top of the tube is termed a *Torricellian vacuum.*

In removing the pressure of the atmosphere from its surface in the tube, which in the above experiment produces the barometer, the pressure of the atmosphere then falls only upon the exposed surface of the mercury in the *basin,* or what is technically termed the *cistern.*

This pressure is equal per area, according to hydrostatic laws, to the upper surface area of any equal column of mercury that the barometer may contain. Therefore the weight of the column of mercury in the tube, if cylindrical, above the surface of that in the cistern, is the same as that of a column of air of equal size reaching upwards to the full height of the atmosphere. In fact the one exactly balances the other, and it is by the difference of the weight or quantity of air above the barometer *per area* of bearing surface that it is possible to ascertain the altitude of its position by means of the height of mercury in the tube, after proper allowance is made for sudden changes of conditions of the atmosphere itself from time to time, capillary attraction of the tube, temperature, etc.

685.—The mean height of the barometrical column in Great Britain, at sea level and at 32° Fahrenheit, is about 29·95 inches. A cubic inch of mercury at this temperature weighs 0·48967 lbs. Therefore

$$29{\cdot}95 \times 0{\cdot}48967 = 14{\cdot}66 \text{ lbs.}$$

gives the mean pressure of the atmosphere on each square inch of surface of the earth in this latitude. Nearer the tropics the pressure is greater, near the poles, less. It can be shown that as the heights ascended by the barometer increase in arithmetical progression, the pressure upon the mercury diminishes in geometrical progression.

686.—**Mountain Barometer.**—The barometer used for measuring altitudes, to which the above term has been applied, is now made only upon Fortin's plan, in which the bottom of the cistern wherein the glass tube is plunged is made of fine, close-grained leather, the best for the purpose being a stout kid. The pores of the leather must be sufficiently fine not to admit of the escape of the mercury and yet at the same time sufficiently soft and pliable to transmit the exterior pressure of the air. Fortin's construction permits the cistern to be closed entirely secure from leakage of mercury in whatever position the barometer may be placed. The closing is effected by means of an adjusting screw Fig. 318 *F* which by its pressure decreases the capacity of the cistern and forces the mercury up the tube, or adjusts it to a given height, so that the scale of the barometer may be read correctly from a given point *X* placed within the cistern. To prevent injury to the tube the adjusting screw is made of a length just sufficient to force the mercury to fill it, so that when it is closed home there is no jar or percussion of the mercury in carrying the barometer. The details of the mountain barometer may be best followed by the illustrations.

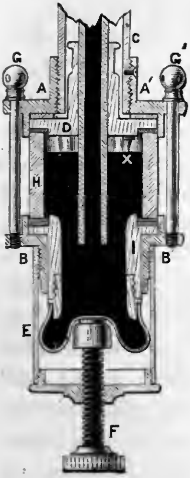
687.—*The Glass Tube* is made of mild flint glass thoroughly annealed and sufficiently stout to resist all the strain and percussion that may occur with fair usage. One end of the tube is slowly sealed by the blow-pipe, so that the closed end may be as strong as the other parts.

688.—*Mercury—Filling the Barometer Tube.*—The mercury of commerce is generally impure, and it contains occluded air. For standard and mountain barometers the mercury should be distilled in an iron apparatus, at just its boiling heat, leaving about one-sixth of the mercury in the still. The tube, which should be perfectly clean, is left about 12 inches too long for the barometer. It is charged with clean mercury for about 36 inches in height. It is then boiled in a special circular charcoal stove, in the centre of which there is a vertical iron tube of 2 inches diameter. The barometer tube is introduced from the bottom of the stove, to heat about 4 inches of the top of the mercury only. The tube remains in this position till the mercury boils. It is then elevated for another 4 inches and again brought to boiling point, and so on until the end of the tube is reached. Under this process the air and some impurities rise to the surface of the mercury, and the tube is considered to be properly boiled. The end of the tube is then cut off to its proper length and inserted in the cistern, in which there is left sufficient clean mercury to complete the barometer.

689.—The lower part of the barometer tube, after it is filled, is attached to a thin boxwood socket of about an inch in depth by means of hot, thin glue. This socket-piece is afterwards bound over with sewing silk, which is again covered with glue, and is finally varnished so as to form an elastic, secure fitting upon the glass. The socket-piece is secured to a wide boxwood collar Fig. 318 *D*. Upon the under side of the collar an ivory gauge peg *X* is inserted, which forms the index point for reading the lower surface of the mercury, upon the Fortin principle.

690.—*The Cistern.*—The glass sighting tube Fig. 318 *H* of the cistern, through which the mercury and gauge point *X* are visible, is made about $1\frac{1}{2}$ inches long and from 1 inch to $1\frac{1}{2}$ inches internal diameter, the glass being of $\frac{1}{8}$ inch to $\frac{1}{5}$ inch in thickness, ground square at its ends. The upper end of the glass fits upon the boxwood collar *D*, with the interval of an India-rubber band to make the fitting air-tight. The lower end of the glass tube fits upon a boxwood collar *I*, with an interval of a turned leather collar. The boxwood collar prolonged forms the lower part of the cistern. This has a second boxwood collar screwed upon it, to which the leather bag *E* is attached by silk and glue. A stout leather capping plug is glued upon the lower end of the bag, upon which the boxwood cap of the adjusting screw *F* presses for adjustment of the mercury, or to close the tube.

691.—*The Cistern Casing*, which is of brass, consists of upper and lower collar-pieces, Fig. 318 *A A'* and *B B'*,



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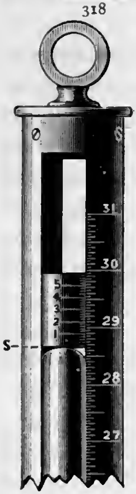

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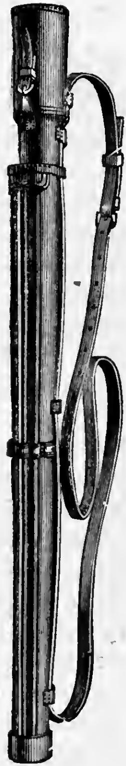

320

FIG. 317.—*Mountain barometer erected for use.*
FIG. 318.—*Section through the cistern.*
FIG. 319.—*Vernier reading, showing gauge point S.*
FIG. 320.—*Sling case for carrying.*

and their attachments. The upper collar is fixed to the casing tube of the barometer. In the inside of this collar a leather washer is placed, which comes above the boxwood collar on the glass tube *D* and makes soft contact between these parts. The lower collar has been partly described with the cistern. This has a brass tube *E* screwed upon it, which covers the bag and lower part of the plug of the cistern. The lower closed end of the covering tube is formed into a nut for the adjusting screw *F* which is placed in the axis of the tube. There are four bolts or screws *G G′* which bring the two collars of the cistern casing towards each other, support the lower part of this casing, and produce a pressure between the boxwood collar on the barometer tube and the top of the glass sighting tube with the intervening rubber collar, so that the mercury at this point is secured.

692.—*The Stem, or Barometer Casing Tube*, is made of brass, about $\frac{3}{4}$ inch diameter. This has a slot down two concentrically opposite sides, of about $\frac{1}{4}$ inch in width, from near the top of the tube downwards for about 20 inches. The tube is graduated along one open edge next the slot in inches and tenths, which are again subdivided to twentieths, and figured to read from 13 inches to 32 inches of mercury, as shown in detail for the upper part in Fig. 319. The same space is divided into centimetres and millimetres if this measure is used. Within the outer tube an inner tube of about 12 inches in length fits telescopically to move with a soft, smooth motion. This inner tube carries one vernier at top and one at bottom Fig. 317 *r r′*. The top vernier, shown Fig. 319, is placed above a slot in this tube which corresponds with the outer tube, so that the level of the mercury can be seen below the top vernier-piece at *S*. The verniers are divided into 50, so that reading into the 20 they give reading 50 × 20, or 1000 to the inch. The inner tube carries a rack about 11 inches long, which moves by a pinion fixed upon a *cock-piece* Fig. 317 *m* on the outer tube in the same manner as before described for telescope racking art. 81. Two *stay-pieces* placed over the outer tube hold the slots firmly at equal opening. A ring is placed at the head of the barometer to suspend it in a room, to be used, if required, as an ordinary meteorological barometer, as shown at the top of Fig. 319.

693.—*Mounting of the Barometer.*—The barometer is mounted upon a tripod formed of three light tubes with steel points, as shown Fig. 317. These screw in a collar which is packed in the cap of the leather case. The collar has two opposite screws which screw into a second collar, which is also held by two opposite points at right angles to the first. The points of the screws form axes in the manner of a Hook's joint, which permit the barometer to take a vertical position by the superior gravity of its cistern and lower parts.

694.—*The Thermometer*, shown at Fig. 317 *t*, has its bulb brought as nearly as possible in contact with the glass tube enclosed in the casing tube. It is commonly divided with both centigrade and Fahrenheit scales. Correct observation of the thermometer is necessary to be made with every observation of the barometer, as the specific gravity of the mercury, and consequently the height of the column, depends for its correct determination partly upon this.

695.—*Packing Case* Fig. 320 is made of solid leather lined with thick felt to fit the barometer. The legs are placed in packings outside the case. In packing for carriage the screw of the cistern is turned tight home, so that the mercury has no possibility of movement. The barometer should always be carried in an inverted position, as this precludes the possibility of air getting into it, and even tends to exclude, by the jarring motion of carrying, any air that may have accidentally become occluded. A strap is attached to the case for holding it over the shoulder.

696.—*Reading the Barometer.*—It will be observed that the mercury against the sides of the tube presents an upward curved appearance, due to the resistance of the glass to perfect contact, and the cohesion of the mercury in what is termed capillary action. This *beading*, as it is termed, varies according to whether the mercury is rising or falling. It is therefore always necessary before taking an observation to *raise* the mercury, by turning the screw F, until its surface just touches the peg X, to make observations uniform. The reading is taken by slowly lowering the index-piece by means of the milled screw until light is just excluded between the fore and back index surfaces, as shown Fig. 319 at S, and the highest point of the surface of the mercury. The inches, tenths, and half-tenths (·5) are read on the scale, and the thousandths on the vernier. Thus suppose the scale reads 26·45 and the vernier 25 = 25 thousandths, the reading will be—

$$\begin{array}{r} 26{\cdot}45 \\ {\cdot}025 \\ \hline 26{\cdot}475 \end{array}$$

For altitude the upper and lower stations are taken, and the difference subtracted for difference of barometrical scale.

697.—*Differences of Altitude in Feet taken from Barometrical Inches.*—Complete barometrical tables for this comparison will be found in Molesworth's and other engineers' pocket-books in use by all engineers. It is therefore unnecessary to occupy space with them. A very approximate rule may be given, which was proposed by Mr. R. Strachan in the *Meteorological Magazine* as follows:—

"Read the barometer to the nearest hundredth of an inch; subtract the upper reading from the lower, leaving out the decimal point; and then multiply the difference by 9, which gives the elevation in feet. Thus:—

Lower station, ...	29·25	inches.
Upper ,, ...	28·02	,,
	123	
	9	
Elevation, ...	1107	feet."

698.—*Capillarity.*—For meteorological observations a quantity must be added to the reading equal to the resistance of the tube in capillary action to the rise of the mercury. This is greater in an unboiled tube than in one in which the mercury is boiled. For altitude measurements with a single barometer, or with two barometers with equal tubes, it may be neglected, as it will be equal in all parts of the tube. Where two barometers of different bores are used, the following table gives the correction:—

Correction of Capillarity to be Added to the Reading.

Diameter of Tube in Inches,	·6	·55	·5	·45	·4	·35	·3	·25	·2
Unboiled Tube, Inches, ...	·004	·005	·007	·01	·01 4	·02	·025	·04	059
Boiled ,, ,, ...	·002	·003	·004	·005	·007	·01	·013	·02	·029

699.—*Temperature Correction.*—As the mercury increases in temperature it becomes specifically lighter, therefore rises higher in the tube under equal atmospheric pressure. The temperature is indicated by the thermometer, shown at Fig. 317 *t*. The expansion of mercury for 1° Fahr. is 0·000101; but the brass tube also expands 0·0000104, and it is the difference between the two expansions we require, the mercury expanding about 7·15 more than the brass. If we subtract from the reading ·00014 of the observed altitude for every degree of Fahrenheit above 32°, the correction will be practically very near. Thus for a single reading—thermometer, 52° Fahr.; barometer, 30 inches

$$-(52 - 32) \times 30 \times 00014 = \cdot 084,$$

making the true reading 30 inches $-\ \cdot 084 = 29\cdot 916$ at 32° Fahr.

Tables for correction without any calculation will be found in Molesworth's and other pocket-books.

700.—*Gravity Correction.*—The force of gravity decreases as we ascend to a higher level in proportion to the square of the distance from the centre of the earth. It follows that the force of gravity as we ascend at the equator diminishes at a less rapid rate than at the poles. Its amount is always small—on an average it may be taken at about 0·001 inch of mercury per 400 feet of ascent.

Time.—Humboldt discovered that the barometer varied within the tropics at different hours of the day. This has also been found to be general to some extent in all countries, depending upon many conditions. It is only important for consideration of altitude measurements, that it is advisable if possible to take the upper and lower stations simultaneously by a pair of barometers for exact determination of altitude.

701.—**Aneroid Barometer.**—The first introduction of this instrument in this country was by Pierre Armand, le Comte de Fontainmareau.* This instrument consisted of a vacuum chamber as its prime mover. The chamber was made a flat, cylindrical box with its upper surface of thin metal, with corrugations covering its surface in concentric rings. The chamber was filled with a number of spiral springs which resisted the pressure of air, to prevent the collapsing of the corrugated surface when the chamber was exhausted, and so placed the surface in equilibrium with the pressure it received from the atmosphere. The movements under

* British patent No. 10157, April 1844.

varying pressures were multiplied up by gearwork and levers so as to make a small movement of the corrugated surface evident in the extent of motion of an index hand reading upon a dial.

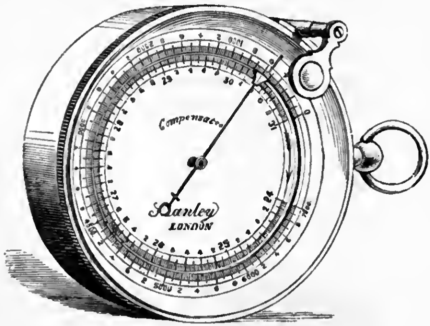

FIG. 321.—*Stanley's civil engineer's aneroid.*

The instrument practically in its present form was devised by Lucien Vidie from 1848 to 1862.* In this instrument the vacuum chamber, which is a thin, flat, circular box, is corrugated equally on both sides, so as to obtain double area of active surface under atmospheric pressure to that of the older form. It has the surfaces drawn apart by an exterior spring, the points of communication or tension of the chamber being placed at the centre of its corrugated sides only.

702.—The construction of this aneroid is shown in Fig. 322, which is of a 5-inch instrument, aneroids made for surveying being of two sizes, 3 inches and 5 inches. *A* is a solid plate of metal $\frac{1}{8}$ inch in thickness, termed the base plate; *B* the vacuum chamber, circularly corrugated on both sides, made of thin, hard-rolled German silver containing a large percentage of nickel.

* British patents—No. 13332, November 1850; and No. 682, March 1862.

An axis is projected from the lower side of the chamber, of about $\frac{1}{5}$ inch diameter. This is tapped with a screw and screwed firmly down into the base plate with a counter nut. On the upper side of the vacuum chamber the axis is projected upwards to receive the tension of a strong, very flexible spring D above it, to be described. A bridge-piece $E\,E$ of steel of strong section strides over the vacuum chamber. This piece has a stout arm-piece projecting from it towards A, which is secured to the base plate by a screw that is left open to a hole indicated near A through the outer case of

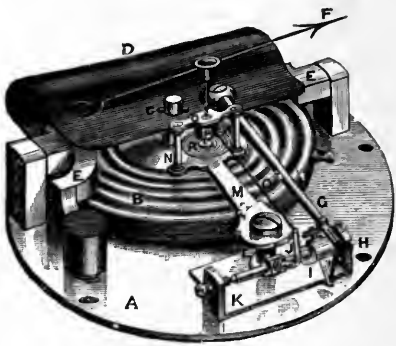

FIG. 322.—*Perspective view of the interior of an aneroid.*

the instrument, by means of which the bridge-piece can be rocked so as to produce more or less tension of the spring D upon the vacuum chamber for final adjustment. The bridge-piece has two points of rigid support in right line, which form a primary—adjusted when the instrument is made—of the spring *contra* to the pull of the vacuum chamber. The *main spring D* is made of fine, thin steel, carefully tempered, as broad as the chamber. This spring is constructed so that by its elasticity it may have sensitive movement under the pull of 10 lbs. to 15 lbs. per inch of active surface of the vacuum chamber. It is upon the perfection of this spring as much as upon the construction of the vacuum chamber that the sensitiveness of the instrument depends. The upper axis of the vacuum chamber is secured by a cross cotter pin *C* which gives an exact point of resistance and yet secures flexibility of the spring at the junction. This cotter pin is placed in the centre of the three points of support of the bridge-piece *EE*. A *lever arm* *G* is fixed to the main spring *D* upon a stout plate of metal which is in direct connection with the point of tension of the vacuum chamber. It is the small movement of this lever arm (about ·01 inch at the chamber) that gives motion to the indicating apparatus. The lever moves a crank arm on the axis *H K*, which communicates through the axis to a second crank arm placed at right angles to the first *I*. This pulls a chain *Q* attached to the arm *J*. The chain is wound round a small drum fixed upon the axis which carries the hand near *R*. The drum keeps the hand in one direction *contra* to the pull of the chain by a hair spring *R* which is just sufficient to overcome the friction of the axis of the hand *F*. The hand and drum and their fixings are carried by the plate *M*, which is a light piece of brass projected from a stiff standard fixed from the base plate *K*. The compound lever apparatus described moves the point of hand about five hundred times the amount of movement of the first fulcrum of the lever at the chamber.

703.—*Compensation for Temperature.*—This is a somewhat difficult matter, which is generally brought about by several modifications of parts. Some ordinary aneroids will move upwards about $\frac{1}{10}$ inch of mercury by a rise of temperature of 8° centigrade only. This is caused principally by the increase of temperature softening the spring to render it less rigid, and the softening of the vacuum chamber to render it more flexible or sensitive to atmospheric pressure. Some little difference is also caused by the unequal relative expansion of the lever, arms, spring, and chain, these parts being of steel and brass. Compensation can be made in the lever arm *G* by making this curved and of two unequally expansive metals, as zinc and steel, so that the curvature increases with increase of temperature and the lever shortens. Compensation can also be partially made by making the base plate in two metals—iron and brass, so as to press the standards fixed through the two metals nearer or further apart with temperature changes. But the whole subject is too technical to be entered into in our limited space, as it depends so much upon the construction of the instrument, which is modified in various ways by different makers to make this correction.

704. — *Dial and Hand.* — From the delicacy of the structure of the aneroid it becomes evident that no two instruments can be made to exactly the same rate of movement; therefore each instrument has to be separately graduated if it is intended to measure altitudes with it approximately. However close or open the scale may be, it becomes closer as greater altitudes are ascended, the density of the atmosphere as a gaseous fluid decreasing in geometrical progression as the altitude increases in arithmetical progression. From this we can understand that any attempt to put a vernier to the index hand is a mistake, although it may appear to act fairly well at a certain point of the scale. The best and possibly only correct method of dividing the scale is to put at first a false scale to the instrument, and to read this scale by the index hand with a microscope under an air pump, compared at every half-inch of height of the column of the mercury by the gauge attached to the pump. When this is carefully done, a zero point is taken of the position of the index hand at the atmospheric pressure at the time, as indicated on the false scale. The proper scale, as it appears upon

the dial, is divided from the position of the readings of the false scale, the two scales being superimposed upon a special dividing machine. The dial is afterwards figured and finished.

705.—The ordinary method of reading the aneroid is to let the index hand read over the divisions. The author devised a plan he has used many years, of fixing a small plate of aluminium upon the point of the hand level with the scale, which is raised on a step to read it upon its inside edge, to a fine line on the aluminium. By this means error of parallax in reading is entirely avoided. The author also places an adjustable magnifier to move over the index for reading. This last improvement is now followed by other makers. A pointer also revolves with the outer rim to show the last reading before ascent or descent.

Instruments made with care in the points just indicated must necessarily become expensive. Where the aneroid is to be used as a weather-glass, or even as a travelling companion to judge of approximate heights in climbing mountains, such care is not needed, and the instrument may be produced very cheaply of useful quality. On the other hand, where precision is required, a delicately made aneroid will indicate movement in raising or depressing it 2 feet or less, when holding the instrument horizontally in the hand and giving a light tap on the glass with the finger-nail before reading.

706.—*The Altitude Scale* is generally placed near the periphery of the dial: it is the all-important part to the surveyor. This scale is set out from a mean of atmospheric pressures at sea level, which is generally taken from Sir George B. Airy's tables, which give the extreme pressure of 31 inches barometric pressure for zero at sea level. With this pressure altitudes are taken at intervals according to those tested under the air pump, and the intermediate divisions are graduated to scale. These index points are shown in the table below for a few points:—

Table of Altitude with Barometrical Scale.

Height in Feet.	Barometer in Inches.	Height in Feet.	Barometer in Inches.
0	31	6,000	24·875
250	30·717	7,000	23·979
500	30·436	8,000	23·125
750	30·159	9,000	22·282
1000	29·883	10,000	21·479
1500	29·340	11,000	20·706
2000	28·807	12,000	19·959
2500	28·283	13,000	19·236
3000	27·769	14,000	18·535
4000	26·769	15,000	17·853
5000	25·804		

It may be generally observed that the more open the scale the less altitude can be obtained by a single revolution of the hand; therefore the fewer points can be taken per 1000 feet. Thus, with an altitude barometer reading to 3000 feet, readings can be pointed at every 250 feet; with one of 6000 feet, at every 500 feet; and over this, at every 1000 feet.

707.—*Movable Altitude Scale.*—In this the altitude scale revolves so as to be able to set it at zero for ascending from any point. As the barometrical scale diminishes, it is necessarily inaccurate, and cannot therefore be used upon a surveying aneroid; but the plan is pleasant for approximate measurements for amusement in making ascents. It is only mentioned here for the reason that the inaccuracy of the movable scale is not always recognized.

708.—*Adjustment of the Aneroid.*—There is a screw at the back of every aneroid about under the point *A* Fig. 322, by means of which any aneroid may be brought to the reading of a mercurial barometer at the position the mercury may be in. Where a good instrument has been set by the maker to a standard barometer, it is not wise to alter it frequently if it keeps in good working order for altitude measurements unless it is again set by a standard. On the other hand, however well the aneroid may have been made it works gradually to a slight change, caused by the smooth wearing of parts in action. It is well to have an aneroid, after one or two years wear, cleaned and adjusted. It will then, if a good instrument, work well for many years.

709.—*Directions for Measuring Altitudes.*—Turn the outer rim of the instrument until the index carried thereby reads to the same point as the index hand. Raise the magnifier until the reading comes in sharp focus. Hold the instrument as nearly horizontal as possible, and tap the case lightly with the thumb-nail two or three times, so as to overcome any slight friction of its mechanism. This places the action of the works in equilibrium. Write down the observation as it now reads in the pocket-book, taking thousands from the right hand (large figures), hundreds from the right hand (small figures), tens from the lines to the left of this, and units from observation of the position of the index line in the space between the last and the next line. Say this observation reads 2465. Whether we ascend or descend, the instrument acts similarly. We will now presume we ascend to the height we require to ascertain, and take a second reading, 1945; the difference between these numbers, $2465 - 1945 = 520$ feet, is the number of feet ascent. It is necessary, where exact measurement is required, to take the reverse reading, as the atmospheric pressure may have changed. We now descend, taking the last observation, 1945, and find the reading at the first position 2463 instead of 2465, that is 2 difference, which proves that the atmospheric pressure has decreased. If we take half this difference $= 1$ and correct the first deduction, $520-1=519$ will give us the correct measurement, subject only in this instance to the irregular possible fall of atmospheric pressure, which will not in many instances, if the times of observation have been nearly equal, be a quantity worthy of consideration. It is not necessary to make any correction for the height of the observer in positions above ground, as the instrument must be placed at a uniform distance from the eye to obtain the reading. In mines it will frequently be necessary to measure the heights from the ground at which the observation is made.

710.—*Various Improvements in the Aneroid.*—It is uncertain whether any great internal improvements have been made in this instrument except by Vidie at various times. Many attempts have been made to increase the length of scale to obtain more open reading. These attempts have all been in the direction of increasing the difference of space between the fulcra of the levers or by additional gearwork, producing thereby a greater multiplication of the small unit of displacement of the axis of the vacuum chamber beyond the normal + 500, which is already great. The multiplication has been taken up to + 2000 or more. This increases the difficulty of manufacture and certainty of permanent action. Many of these plans were tried by Vidie and abandoned. A plan of Vidie's * of giving the hand three or four revolutions, and to register this upon a spiral scale upon the dial, also by counting on a second dial the number of revolutions, has been repeated with slight variation by E. T. Loseby in 1860 † and by Major Watkin later. Vidie's plan of drawing back the hand to read the spiral has been modified also by Major Watkin in a manner which may be a little less frictional.‡ These plans are again on their

* Patent No. 13332, May 1850.
† Patent No. 3454, December 1862.
‡ Patent No. 3425, March 1886.

trial. It is the author's present opinion on the subject (1890), knowing the delicacy and skill shown in Vidie's work, that little improvement is likely to be obtained by magnification of the small motion of the vacuum chamber by mechanical means, which must necessarily be by a process delicate and highly frictional. Attempts, he thinks, may otherwise be successfully made in the magnification of the small motion of the hand in a frictionless manner by optical means to obtain clearer definition.

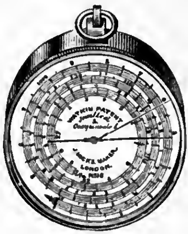

FIG. 323.—*Watkin's patent aneroid.*

An improvement was made in the aneroid in one direction by the late Thomas Cooke* by replacing the chain by a thin gold band upon and leading from the drum. This obviated the small difference of rate of displacement due to separate jointed links as they leave the tangent of the drum. It is said however to cause a little springiness at this point, where it should be very dead, which somewhat minimizes the improvement; so that it has not been very generally adopted.

711.—**Bourdon's Aneroid**, invented by C. Bourdon in 1849.† The motor of this instrument consists of a flat, oval tube bent into a circular form. This tube opens to greater and lesser curvature by difference of external pressure upon it. The small motion given at one free end of the tube is multiplied up by gearwork.

* Patent No. 2714, October 1865.
† Patent No. 12889, December 1849.

This instrument is found to act most delicately as a steam gauge; but experience has shown that it is not so sensitive or durable for indicating atmospheric pressure as the vacuum chamber aneroid last described.

712.—**Hypsometer**, *or Boiling-point Thermometer.*—That water or any other liquid boils at a certain temperature, according to the amount of atmospheric pressure surrounding it, is easily observed by placing a cup of boiling hot water under the receiver of an air pump. At first the surface will remain still, but as the pressure of air is pumped off it may be made to boil time after time until it arrives at a low temperature. The temperature at which the water boils as the air is rarified may be easily followed by observation of a thermometer immersed in the cup of water; and at the same time, if a barometer be placed in connection with the receiver it will indicate the pressure, from which the scale of differences may be practically made. For the civil engineer this instrument accompanied by the aneroid is in every way superior to the mountain barometer, which must necessarily have a three-feet tube, as the hypsometer is much lighter, more portable, and less liable to injury, and perhaps, from the uncertainty of keeping a pure vacuum in the barometer, safer as a means of observation.

713.—The modern form of instrument is shown in Fig. 324. The boiler shown immediately over the lamp is filled about half full of rain water by lifting off its covering tube *C*. The covering tube has a smaller tube, about 3 inches long and ½ inch diameter, leading upwards from it, through which the thermometer bulb is passed into the boiler. This tube is covered by the *jacket J*, which is formed of four telescope tubes that are extended, as shown in the figure, for use, but which close up quite compact when the instrument is put in its case. The upper drawer of the jacket tube is about ¾ inch diameter, so that the tube enclosing it passes over the leading tube when the apparatus is closed. The lamp, which is filled with pure spirit, draws out from the bottom of the outer casing *O*. It carries a wick holder with screw cap, and this again has a covering cap to secure the spirit perfectly when the instrument is carried about. The inner casing *A* is perforated with holes to admit air at the level of the body of the lamp. When the lamp is lighted and complete for use it is placed vertically in its outer case *O*, which is jointed in two parts and perforated by large holes surrounding it top and bottom: the bottom holes are covered with wire gauze. By this arrangement the flame is not seriously disturbed by wind or rain.

714.—*The Thermometer*, upon which the action of the instrument depends, has a stout stem about 6 inches long and $\frac{1}{4}$ inch diameter, with a very fine, flat, oval bore about ·01 inch wide and not much over ·005 inch in thickness. The stem is divided very openly for about 25° below 100° centigrade, each degree being subdivided into 10—or 45° below 212° if Fahrenheit scale is used, with each degree divided in 5. The divisions are filled in with lamp-black, and the stem is backed with white enamel to give clear reading. The thermometer *T* when in use is surrounded by a vulcanized India-rubber collar *I* which slips over its stem to adjust it to position in the boiler tube as shown.

In placing the thermometer in its jacket, it is important to hold it erect to be sure it passes into the leading tube from the boiler, as there is generally just room for it to catch by the side of this tube, where if it were pressed down it would break the bulb. When the thermometer is out of use the rubber collar is removed, and it is placed in a tubular metal case which is lined with India-rubber tubing, so that no jar can injure it.

The whole apparatus when closed is carried in a solid leather case, Fig. 325, which contains divisions for the separate parts of the apparatus and a strap for passing over the shoulder for carrying it. Fig. 325 is the case of a hypsometer slightly different from Fig. 324.

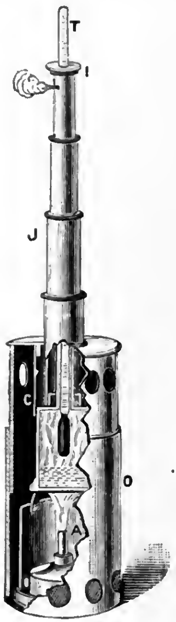

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FIG. 324.—*Hypsometer, or boiling-point thermometer.*
FIG. 325.—*Case for hypsometer.*

715.—*Use of the Hypsometer.*—Saussure calculated, from data of his ascents of Swiss mountains, that the temperature of boiling water decreased 1° centigrade for every 978·5 feet of ascent, where the mean temperature of the atmosphere was estimated at 0°, or freezing point. If the temperature of the surrounding atmosphere be taken as 5·5° centigrade, the ascent per degree of that scale is

1000 feet. This becomes, therefore, the most convenient data to calculate from, allowing 3·9 feet per 1000 per degree centigrade for temperature above or below 5·5° centigrade at any two stations of observation, of which the difference of level is required. Thus:—If at the first station the temperature of air is 15·6° centigrade, the boiling point 95·5° centigrade; second station temperature of air 14·1° centigrade, boiling point 94·2° centigrade, the barometrical pressure of the lower station being taken as a constant, or referred to the aneroid for correction. Then $15{\cdot}6^\circ - 5{\cdot}5^\circ = (9{\cdot}1)\,(3{\cdot}9) = 29{\cdot}2 + \text{dif}\ 95{\cdot}5 - 94{\cdot}2 = (1{\cdot}3)\,(1000) = 1329{\cdot}2 - \text{dif external temperature}\ (15{\cdot}6 - 14{\cdot}1)\,(3{\cdot}9^\circ) = 1323{\cdot}4$ difference of level in feet.

716.—Sometimes the thermometer is divided to Fahrenheit degrees, subdivided in 5 to read by interspace and line to ·1°. This may be changed to centigrade for use of the above formula by taking 32° lower than the reading and multiplying by $\frac{5}{9}$. Thus—

$$60^\circ \text{ Fahr.} = \tfrac{5}{9}\,(60 - 32) = 15{\cdot}55^\circ \text{ centigrade.}$$

The calculation proposed by Lefroy is, however, simpler for Fahrenheit scale. To allow for diminution of boiling temperature, with height from 212°, with barometer at 30 inches, take 511 feet of altitude for the first degree and + 2 for each succeeding degree. Thus, taking height of first station $= h$ corrected for 212° Fahr., 30 inches barometer, remembering decrease of barometrical pressure acts the same as increase of height. Then:—

211° boil point $h + 511$ feet.
210° „ $h + 511 + 513 = h + 1024$ feet.
209° „ $h + 511 + 513 + 515 = h + 1539$ feet.

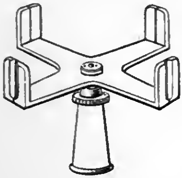
The boiling point, as with the barometer, is best taken by two instruments at upper and lower stations simultaneously; or fair approximation may be got by equal time observation up and down from the mean, by the method given art. 709 for the aneroid. It is better also for the aneroid to accompany the hypsometer as a check upon it.

CHAPTER XVI.

MISCELLANEOUS SURVEYORS' AND ENGINEERS' INSTRUMENTS, APPLIANCES, AND ACCESSORIES — CROSS STAFF — GIRTH STRAP FOR TIMBER MEASUREMENT — GIRTH TAPES — TIMBER MARKER—SLASHING KNIFE—BILL-HOOK—PORTABLE SAW — RECONNOITRING GLASS — TELESCOPE — SUN SPECTACLES — WHISTLES — PIONEER TOOLS — SKETCH BLOCK BOOK — CAMERA — GEOLOGICAL TOOLS — CHARTOMETER — WEALEMEFNA — OPISOMETER — BOUCHET'S CALCULATOR — SLIDE RULES — FULLER'S CALCULATOR — ENGINEERS' POCKET-BOOKS — CHRONOMETER — OUTFITS.

717.—**Cross Staff.**—Those of Tycho Brahe and of Gunter were very elaborate affairs, consisting of a pair of notched cross bars sliding on a divided rod which gave directions to form any angle in a quadrant from the eye by sliding the bars further from or nearer to it. The surveying cross staff, after better instruments were invented to take angles, became a cross at right angles, sawn upon a disc of wood and supported upon a staff which was pressed into the ground. This was used by looking along the saw cuts to take offsets to the chain, and for setting out buildings. The fixed cross-head was much improved by making it a cross of metal with turned-up ends, down the centre of which vertical saw cuts were made at right angles Fig. 326. This, in the author's opinion, is still the best form.

Cylindrical heads superseded the open cross-head. The modern instrument in use is the French form Fig. 327, which is made of octagon brass tube. This is cut with alternate sight slit and opposite window, with vertical hair on each of four rectangular sides of the octagon. On the other four sides there are plain slits subtending 45° to those first mentioned. The octagon tube is mounted upon a socket-piece which fits upon a conical pointed staff. The defect of this cross-head is the closeness of the slits, due to the small diameter of the tube, which renders the direction given for sighting uncertain.



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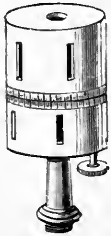

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FIG. 326.—*Open cross-head.* FIG. 327.—*French form.*
FIG. 328.—*Adjustable cross staff head.*

718.—**Adjustable Cross Staff Head.**—The cross staff head is sometimes made cylindrical, in two parts Fig. 328. The upper part is centred upon the lower so that the upper series of sights move to any angle in relation to the lower. In this construction a wheel is cut about the axis of the upper part, which works into a pinion in the lower part, so that the upper part may be revolved horizontally by it. The meeting planes of the two cylinders are divided, the lower into degrees and the upper with a vernier. The vernier is almost an unnecessary refinement, as the sighting distance from slit to hair is only about 3 inches, and no very great exactness can be got in the sighting. This instrument has commonly a magnetic compass upon the upper surface. It is about as expensive as the semi-circumferenter Fig. 180, and very inferior to that instrument from the extreme closeness of the sights. Its use is inferred.

Many of the following articles, briefly described, may be beyond the direct province of this work; but the utility of these implements for completing the equipment of a surveyor or engineer for special work it is hoped will be sufficient apology for their introduction. The subject can scarcely be treated except as quite desultory matter.

719.—**Timber Girth Strap.**—The direction for removal and estimate of the value of timber often falls into the hands of the surveyor. The height of standing timber may be taken by a rod art. 652, or a pair united by a link art. 655, or by the apomecometer art. 560. The girth is most conveniently taken by a leather girth strap, of which there are various patterns; but that illustrated below, Fig. 329, is perhaps the most popular

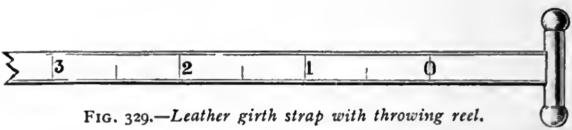


FIG. 329.—*Leather girth strap with throwing reel.*

form. This strap is made of two strips of bullock's hide 1 inch wide, thinned down to about $\frac{1}{8}$ inch in thickness; the two pieces are stitched together to make it 12 feet to 14 feet long. The strap is divided by lines in inches, but figured in units at every 4 inches = single inches of quarter-girt. The figures and lines are stamped in. A brass weight, shown at one end of the strap, is thrown by the strap with a swing round the standing tree, and encompasses it in a second of time. The weight is caught by the hand and the strap brought up to it to read the quarter-girt. The *quarter-girt* gives roughly the equal sides of a square; as, for instance, if a quarter-girt reads 10, the size of the tree is $10 \times 10 = 100$ inches, or 8·4 cubic foot-inches per foot run.

Some surveyors prefer a hook instead of a weight, as being more convenient to measure close timber. This is shown Fig. 330. The hook is stuck into the bark and the tree is girted by walking round until the hook is met.

FIG. 330.—*Leather girth strap with clutch hook.*

720.—**Girth Tapes**, similar to measuring tapes Fig. 282 are occasionally used, but these are more convenient for felled timber. Tapes for the purpose are made from $\frac{3}{4}$ inch to 1 inch wide, and 6, 12, and 24 feet long. They have the ordinary feet and inches on one side and quarter-girts on the other.

It is customary to allow 1, $1\frac{1}{2}$, 2 inches, and sometimes more for bark, according to the species of tree and the custom of the country.

721.—**Marking off Timber.**—For this a special tool with a gouge point, Fig. 331, and strong buck-horn handle, termed a *timber marker*, is used for standing timber intended to be felled. The contents of the tree are sometimes marked with the marker upon it if for sale, good bark allowance being made in cases of difficulty of extraction from the wood, etc. A plain knife is usually put with the marker, which is useful as a food knife.

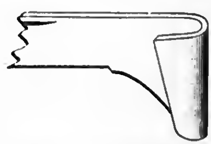


FIG. 331.—*Timber marker, nearly full size.*

722.—The author makes a very small, neat surveyor's knife, with marker, for the waistcoat pocket, Fig. 332, which combines—M tree marker (small); S screw-driver for small screws of instruments; P tommy pin for turning capstan heads; *F* file for sharpening lead of Faber's artist's pencil, when this is used for the field-book; and *E R* two penknife blades. The knife is similar to the

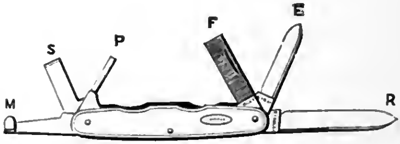
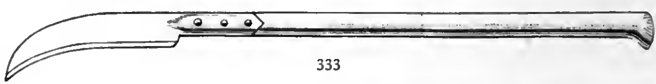


FIG. 332.—*Surveyor's pocket knife.*

author's architect's knife, which is well known. The tree marker is not strong enough for constant work.

723.—**Slashing Knife—Bill-hook—Axe.**—In new countries, where sight way has to be obtained for the survey through forests and jungles, one or more of the tools illustrated below are most valuable as a part of the surveyor's equipment. The slashing knife Fig. 333, which is over a yard long, wielded by a strong fellow



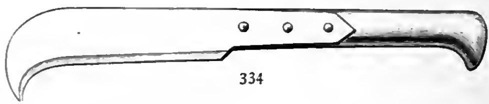


FIG. 333.—*Slashing knife.* FIG. 334.—*Bill-hook.*

will remove light brushwood very quickly. Where the wood is close and of larger growth, the bill-hook Fig. 334 is better; and with thickset timber the axe becomes necessary. The well-known Canadian axe is found to be the best.

724.—**Portable Saw.**—The author's patent saw will be found of the utmost value occasionally for cutting sight way through forest and jungle Fig. 335. Owing to its extraordinary portability it can be used for many purposes where an ordinary saw could not be carried. For surveyors it will be found of great use for felling trees, especially as by its use they can be cut level with the surface of the ground. It is made of hardened steel plates rivetted together in double series. The rivets are sufficiently loose to form joints. Each plate is shaped on one side to form a pair of saw teeth cutting in opposite directions. A cross handle at each end of the

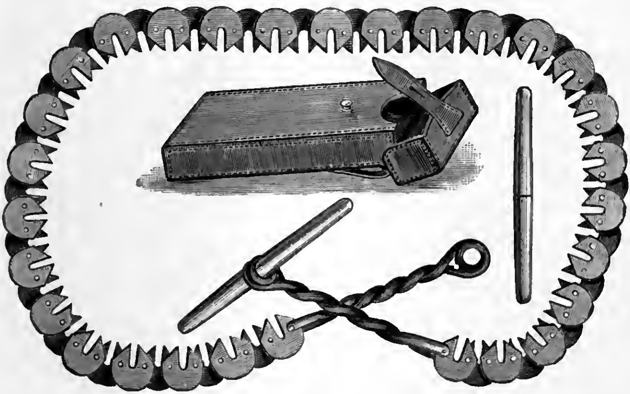


FIG. 335.—*Portable saw.*

saw fits into a ring for use. The handles are withdrawn from their rings for packing. For inaccessible trees, etc., ropes may be attached to the rings in place of the cross handles. This saw is equal to a 6-feet cross-cut saw. Weight complete, only $2\frac{1}{4}$ lbs., including case, which measures over all $1\frac{3}{4}$ by 4 by 8 inches. Two men with this saw may cut a tree down, 12 inches in diameter, in about 10 minutes.

725.—**Reconnoitring Glass.**—At present it is customary to use a binocular field-glass in preference to a telescope. The telescope gives greater penetration from its higher power; the field-glass is preferred for its wider field of view. The field-glass the author has supplied to the Indian Government has neutral-tint glasses centred on the eye-pieces to take off the glare when looking towards the sun Fig. 336. These have also hinge joints between the pair of bodies, which permit

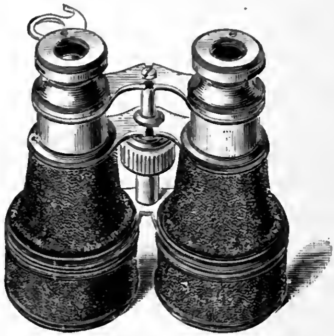


FIG. 336.—*Reconnoitring glass, India pattern.*

adjustment of distance of centres to the distance of the eyes. The object-glass should be 2 inches, not over this. Where a telescope is used, the 30-inch—the original, not the present—India military telescope is to be recommended Fig. 337. This is portable, has a sling

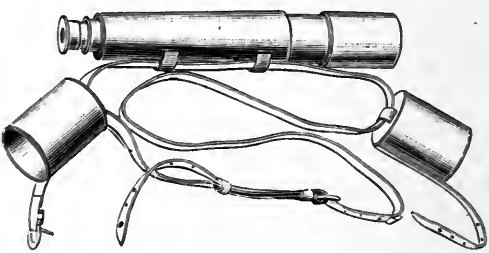


FIG. 337.—*Army telescope.*

case and a good 2-inch object-glass. For lightness, aluminium bodies are preferred by many for both field-glasses and telescopes, but at present (1890) the price of this metal is very high.

726.—**Dome Spectacles—Bogles.**—Spectacles of neutral tint are most comfortable for general wear in sunny or snowy countries. The dome or shell form is generally preferred. Where there is hot dust, gauze sides are to be preferred. There is a very cheap form with gauze sides, which holds on the head by an elastic band, termed *bogles*. These are rather hot to the face, and the band after a time becomes sticky. The spectacle form is much better. The glasses are made in various shades to choice: some very dark, or even black, the latter being made for viewing and tending arc lights.

727.—**Whistles** made very powerful are much used in exploring abroad to bring the party together, and for signalling generally by sound, using the Morse signals art. 675.

728.—**Pioneers' Tools.**—A small set of these is often very useful to the surveyor in new forest countries. The common set consists of a claw-hammer, wood-chisel, stone-chisel, pincers, screw-driver, gimlet, and brad-awl. The leather case is 8 by 4 by $2\frac{1}{2}$ inches; with strap it weighs $1\frac{3}{4}$ lbs. This may be supplemented by a small American saw, cutting both edges, about 20 inches long, and the axe previously described, with a few pounds of wire nails. The tools serve for marking trees or rocks, erecting signals, temporary covers, etc.

729.—**Sketch Block Book—Camera—Pocket-book.** In reconnoitring no better information can be given of a track than forward sketches from commanding station to station. Sketch-books about 7 inches by 5 inches are generally found sufficient. The drawing-paper should be thin, and the pocket large enough to contain all the separate sheets as they are taken off after completion from the block by the penknife. The sketches may be made with pencil, or a mapping pen and one of the liquid Indian inks, which may be conveniently carried in an excise bottle Fig. 100; or if the surveyor is a colourist a light box of moist colours and a water-bottle will often leave pleasing sketches as reminiscences. Quite recently the camera with dry plates on light tissue has been much used for reconnoitring. Pocket-books with section lines to $\frac{1}{8}$ inch or $\frac{1}{10}$ inch scale are sometimes used to give approximate plans to scale of buildings, etc., where required, as well as the ordinary field-book record.

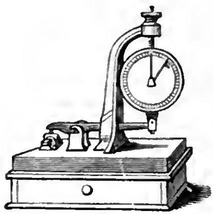


FIG. 338.—*Mann's cement tester.*

730.—**Cement Testers** are made in various manners, generally to test the cohesion of the cement as a homogeneous body. Mr. Mann's cement tester Fig. 338 goes on another principle—it tests the adhesion of the cement to stone, which appears to the author its most important function.

731.—**Geological Tools**—*Acid Bottle*—*Blow-pipe*—*Touch-stone.*—Where countries are prospected for railways it often becomes important to examine the rocks, both to detect the softer rocks for cutting and to find limestone suitable for mortar. A geological hammer, weight about 2 lbs. to 3 lbs., is the ordinary tool. This, with a chisel and sailcloth bag with strap, is all the necessary appliance. In searching for limestone a small bottle of sulphuric acid sewn up in a leather case is useful. A dipper is blown on the stopper of the bottle, and a single drop of the acid will detect limestone by the bubble of froth it produces. Where minerals are to be examined a small blow-pipe apparatus is necessary. This should be accompanied by a book of instructions. Where the surveyor has not been trained to use the blow-pipe, one with constant blast should be employed. For examination for precious metals a touch-stone and two-acid bottle—sulphuric and nitric—for silver and gold, are useful. The metal is merely rubbed on the stone and the acid applied. If the metal is base the acid removes it from the surface of the stone.

732.—**Wealemefna—Chartometer—Opisometer.**—The wealemefna is a very neat form of space runner invented by Mr. E. R. Morris, which is found a very convenient instrument for measuring distances on maps

FIG. 339.—*Chartometer.*

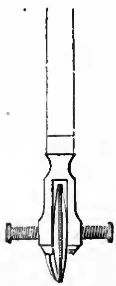


FIG. 340.—*Opisometer.*

in prospecting. It is very small and light, and may be, if desired, attached to the watch chain. It gives distances run over in inches and eighths, to be afterwards calculated to the scale of the map. This instrument has in a large measure superseded the chartometer with shifting scales Fig. 339, and the opisometer Fig. 340, which is formed of a spur wheel at the end of an ivory handle running upon a screw. The opisometer gives measurement by reversing its run upon the scale of the map.

733.—**Boucher Calculator**, the invention of M. Alex. E. M. Boucher, engineer, of Paris.* This is

* Patent No. 4310, November 1876.

one of the most convenient pocket calculators a civil engineer can desire, being only of the size of an ordinary watch. This instrument was formerly made in France for this country in a very slovenly manner. It is now made in London of sound work and accurate centring. Manloves are the patentee's agents, but the instrument can be had of any optician Fig. 341. It has face back and front. On the front is a logarithmical scale in four lines, being on the whole equal to 15 inches of straight scale. This produces a more open scale than the ordinary slide rule. There are two index hands, one on the central axis and one fixed upon the side of the

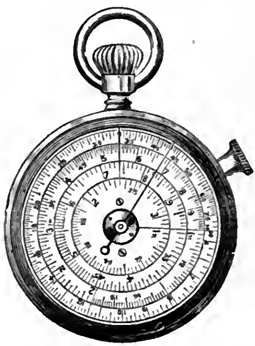


FIG. 341.—*Boucher's calculator.*

case. The central hand revolves by the turning of a milled head at the side of the case. The entire dial revolves by the milled head placed under the handle, as the winder of a keyless watch. By means of the motions of the milled heads upon one face, any operations in addition, subtraction, multiplication, division, and proportion can be performed to four places of figures; and upon the other face trigonometrical calculations. The simplicity of the performance of the instrument may be best inferred from the description given for its use by the inventor in his patent, which is as follows.

"For 'addition' the exterior circle is used:—Bring the first number under the index, follow with the needle the zero of the dial, then bring the second number under the needle, and the index will point out the sum.

"For 'subtraction' the exterior circle is also used:—Bring the greatest number under the index, carry the needle over to the smaller and bring the zero under the needle, the index will indicate the remainder.

"For 'multiplication' the interior circle is used:—Bring the first factor under the index, follow the zero with the needle, bring the second factor under the needle, and the index will point to the product.

"For 'division' the interior circle is used:—Bring the dividend under the index, carry the needle over the divisor and bring back the zero under the needle, the index will point to the quotient.

"For 'proportion' the interior circle is also used:—As the index and the needle will indicate the two terms of a ratio or proportion, all the numbers which are brought under these points will be on the same proportion or ratio to each other.

"For 'logarithms,' upon bringing a given number upon the interior circle under the index, the latter will indicate on the exterior circle the decimal part of the logarithm of this number.

"For 'powers' and 'roots,' take the logarithm of the number, multiply it or divide it by the exponent, according as a power or a root may be required, and bring the product or the quotient (taken upon the outer circle) under the index, which will point out on the inner circle the power or the root required.

"To use the trigonometrical dial:—Bring the needle of this dial over the angle of which the sine or tangent is required, and read upon the other dial (indicated by the needle) the natural trigonometrical line upon the inner circle, or its logarithm upon the outer circle."

The book of instructions sold with the instruments gives gauge points from which calculations are made as with the slide rule.

734.—**Slide Rules,** of which there are great varieties, are of too complex a nature to enter into, except very briefly, in our limited space, besides which, general descriptions have been often given. Those that have been specially arranged for the surveyor only will be mentioned here. The ordinary logarithmical scales of Gunter (1619), known as *Gunter's lines*, are placed upon most slide rules. The arithmetical lines are lettered *A*, *B*, *C*, *D*, and *E*. *A*, *B*, and *C* are alike: these are technically termed *double radius log. lines*. They are used for all processes of multiplication and division. *D* is termed a *single radius log. line*. *C* and *D* are used together for cubing and extracting cube roots, proportions, etc. The *E* line, not originally a Gunter's line, but found early in the century on several rules, is termed a *triple radius log. line*. The numbers of the divisions on this line are the cubes of the numbers of the corresponding divisions of the *D* line, with which it generally works. All these lines work reciprocally together, giving most complex calculation by simply setting them to numbers or gauge points of which given solutions are required, as for instance, the first four lines in combination give answers to such questions as:—To divide by a number two numbers multiplied together, one of which is squared; to divide the product of two numbers by the square of a third number, etc., each of which calculations is performed at a single setting. By inversion of the slide *A* to *C* the reciprocal of a given number is found, also the mean proportional between two numbers, the fourth term in inverse proportion, etc. Trigonometrical calculations are performed by the lines of sines, tangents, etc. Instructions are to be found in the books supplied with the rules, and as a part of many works; but many of the most complete books are now out of print—Bevan's, Bayley's, etc. Routledge's slide rule book is best known. Hoare's slide rule book is perhaps the best in print.

735.—*Bayley's Slide Rule*, one of the best, is 12 inches long and only 1 inch by $\frac{1}{4}$ inch in width and thickness; weight, under $1\frac{1}{2}$ ozs. It has two sides, each of which turns over and works on both faces. These contain lines of single, double, and treble radius; sines, tangents, and line of numbers.

Hoare's Slide Rule contains single and double radius lines on two slides. A very useless slide rule is published with the book, but a useful copy of this may be had in boxwood, 9 by $1\frac{1}{4}$ by $\frac{1}{4}$ inches.

Gravet's Slide Rule is machine-divided and very exact. It contains a turn-over slide with double lines of single and double radius, *A* and *D*, on one side, and sines and tangents on the other. It has a sliding rider which carries over any point from one side of the slide to the other. The back is covered with a printed table of gauge points.

A great number of slide rules are made for special purposes only: some of these are very useful to the civil engineer.

Ganga Ram's Slide Rules.—No. 2 gives thickness of retaining walls, level-topped and surcharged, of all shapes and heights, and under all conditions. No. 3 gives strains on girders of all kinds, plate, braced, lattice, and warren, of many forms and all spans, with bending and shearing strains, with book of instructions.

Hudson's Slide Rules give strength of shafts, beams, and girders; pump duty; and computation of horse power in engines.

Honeysett's Hydraulic Slide Rule (new) gives discharge of water from channels and pipes of different forms and inclinations.

Sheppard's Slide Rule has duodecimal lines, double reading, for squaring timber.

Young's Slide Rule (new) is designed for squaring and valuing timber simultaneously, which operations it performs in a very expeditious manner.

736.—**The Slide Rule** of Prof. Geo. Fuller, C.E., Fig. 342, presents perhaps the highest present refinement of this class of rules, capable of greatly facilitating the numerous arithmetical calculations of the civil engineer. Its range is greater than most calculating machines, as besides the operations of multiplication and division, squaring and cubing, which many instruments perform, results requiring the reciprocals, powers, roots, or logarithms of numbers can be quickly and easily worked out by its use.

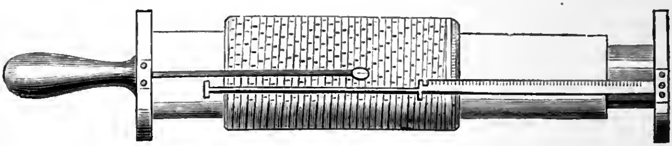


FIG. 342.—*Professor Fuller's calculating slide scale.*

The rule consists of an outer cylinder that can be moved up or down, and turned round upon the cylindrical axis that is held by the handle. Upon the outer cylinder a single, spiral, logarithmical scale is continued from end to end the total length which makes the scale 500 inches long. This is graduated into 7250 divisions. One index is fixed to the handle. A second index is attached to an inner tube blocked out by a flange to read upon any part of the scale; so that altogether there are three tubes which work together telescopically, by means of which the indices may be set to any position on the graduated cylinder. Stops are placed so that the indices may be brought to zero. By these means, the indices being set to any of the gauge points, the logarithmical scale moving by itself will maintain the same proportion for any numbers. In this rule a single log. radius is repeated by coincidence of indices, so that its scale of divisions, 42 feet 8 inches long, if compared with an ordinary double radius slide rule, becomes equal to a slide rule of 85 feet 4 inches long. The ordinary 12-inch slide rule has about 80 divisions to each radius, so that it is easily seen how much more exact quantities may be brought out with a rule of 7250 divisions. It is a most valuable rule for calculations for the tacheometer. Copious tables of gauge points for civil engineers are printed upon the central tube, which is supplemented by a book of instructions.

Thacher's Slide Rule. — This contains a longer scale than Professor Fuller's, but the system is not quite so simple. Full printed instructions are given in the book supplied by the inventor, Mr. Edwin Thacher, of Pittsburg, U.S.A., or of the author, who is his agent for this country.

737.— **Pocket Sets of Chain Scales.** — These are made 3, 4, 5, and 6 inch. Three of 6 inch form the ordinary set. The chain scales, if three only, are 10, 20, 30, 40, 50, and 60; if six they generally contain the same scales with feet equal to the links. An extra scale with the Ordnance or other scale of the country is found also useful for measuring from maps or plans. Some civil engineers prefer the pocket scales made wide with quite square ends, to be used as offsets or for sketching. These scales are generally made in ivory and placed in light morocco or russia leather cases. The numbers of divisions of the scales should be stamped on the ends to prevent the wrong scale being drawn from the case.

738.—**Anemometers** are used by mining engineers for testing the ventilation of mines. The original and best-known form is that of Biram Fig. 343. This instrument is held in any current of air, and the velocity of the current is registered by the motion of oblique fans, by means of ordinary decimal gearwork on five dials giving feet and multiples by 10. Lowne's anemometer Fig. 344 is of similar principles of construction, but it is arranged in portable form to go in a pocket case. Another well-

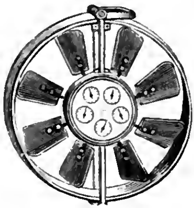


FIG. 343.—*Biram's anemometer.*

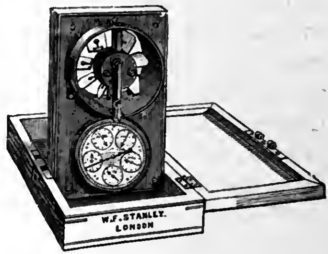


FIG. 344.—*Lowne's anemometer.*

known form is Casella's anemometer, built upon the same principles. It is customary to take the velocity of current for one minute by a watch, there being a detent provided in most instruments to start and stop the motion of the hands upon the dials.

739.—**Pocket-books.**—Few British surveyors are without Molesworth's pocket-book. This contains all the useful tables and notes of reference valuable to the civil engineer in his ordinary work—weight, 5 ozs. Many pocket-books have been built on the same plan. Hurst's pocket-book contains all matters of reference for the town surveyor among buildings. Trautwine's "Civil Engineer's Pocket-book" (American) is the most complete, but it is of double the weight of the Molesworth. Spon's "Engineer's Tables for the Waistcoat Pocket"—weight, little over ½ oz.—is a very useful little book. Francis's "Tables and Mems. for Surveyors and Land Agents" is of the same form—weight, under 1 oz. Wheeler's "Valuer's Pocket Assistant" is useful for estimating values. There are several pocket-books of curve tables, that of General Boileau being the original. Gallott's "Universal Curve Tables" are perhaps the most compact and demonstrative—weight, $2\frac{1}{4}$ ozs. with memo. paper.

Technical Books are published on special subjects which are often relative to the country or special conditions of work abroad, minerals, etc. It is very useful to possess such of these as may be required abroad, and the note is only made here as a reminder.

740.—**Sling Case for Drawings.**—The most convenient method of carrying a map or drawings for public works in execution, is to have a solid leather case similar to a telescope case. This is best if made with the cap or lid of the same length as the body: it can then be

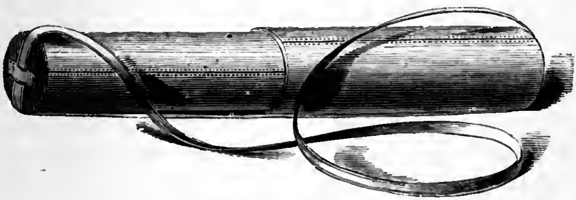


FIG. 345.—*Sling case for drawings.*

drawn out any distance according to the length of the rolled drawing. If thought more convenient, and the map or drawings are heavy, a strap may be added to pass over the shoulder Fig. 345.

741.—**Chronometer.**—May be any form of watch with compensated escapement. At present the prices run high for this class of work; but from the simplicity and moderate certainty of compensation it does not appear that this should be necessary for the production of a good working instrument for the surveyor in new countries to keep his longitude. Where a chronometer is used it is better to keep it without alteration to Greenwich time. If there is a gaining or losing rate this will most probably remain equal in equal times, so that corrections may be made *pro ratâ* for all observations till a check can be taken with certainty at a town observatory.

742.—**Outfit of a Surveyor for Work in a New Country.**—The ordinary items of strong, dust-coloured clothing, good boots, saddle, firearms, etc., do not come within the province of this work. The instruments he will require will depend partly upon the nature of the country and the kind of work to be done. If for prospecting only, light instruments are commonly selected—the sextant, or box sextant with glass artificial horizon, good pocket chronometer, *telescope*, aneroid barometer, prismatic compass, and clinometer. If a general survey is to be made, the first instrument of importance is the theodolite, the 5-inch being the most usual. With this six pickets, land chain and arrows, a steel tape for testing, and a linen tape. If for survey in mineral districts, a good mining-dial is required, with all accessories of chains, etc. If for railway work, a 5-inch theodolite, a good level, staves, six pickets, clinometer, and prismatic compass. In all cases, field-books, drawing instruments, supply of papers, drawing boards, square, parallel rule, pencils, Indian ink, colours, stencil plates, and other matters for office use, of which the established optician or trader will give full instructions from his experience.

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149	,, Stanley's patent, 6-feet,	2	0	0
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409	,, Telescope, ...	1	10	0
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411	Troughton's ,, ...	1	5	0
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413	,, in case, ...	1	10	0
413	Clinometer, De Lisle's reflecting, ...	3	3	0
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464	Beam Compasses and 10-feet Rod, to ·001 foot,	4	10	0
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PAGE		£	s.	d.
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