THE

EVOLUTION OF MINE-SURVEYING INSTRUMENTS.

BY

DUNBAR D. SCOTT AND OTHERS.

COMPRISING THE ORIGINAL PAPER OF MR. SCOTT ON THE SUBJECT, TOGETHER WITH THE DISCUSSION THEREOF, AND INDEPENDENT CONTRIBUTIONS ON THE SUBJECT.

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PREFACE.

THIS volume contains by no means the whole of the discussion elicited by the original paper of Mr. Scott. Additional contributions, received too late for introduction here, will be found in the *Transactions* of the Institute, to which the reader is referred. This circumstance is, however, less to be lamented than if it had been possible, by a little longer delay, to close the whole discussion, leaving nothing to be corrected or added. But the subject is one of those which will never be exhausted; and there would be greater cause for regret if the issue of this volume should be construed by practising mine-surveyors and the designers or makers of surveying-instruments as an intimation that further statements of fact, argument or criticism would not be welcomed by the Council of the Institute. I trust that such a misunderstanding will be effectively prevented by the appearance in Vol. XXXI. of the *Transactions* of the interesting additional papers of Mr. H. D. Hoskold, to say nothing of minor contributions on the subject, none of which have been included in the present volume.

It is believed, nevertheless, that the material here presented comprises, in compact and convenient form, information of sufficient scope and value to warrant the issue of the book by the Institute.

R. W. RAYMOND,
Secretary.

CONTENTS.

THE EVOLUTION OF MINE-SURVEYING INSTRUMENTS.

BY DUNBAR D. SCOTT, PHŒNIX, MICH.

THE development in the perfection of mine-surveying instruments has been by no means rapid, as it has depended somewhat on the details of construction borrowed from astronomical and geodetic theodolites, largely on the restrictions laid down by mining companies and the prejudices of mine managers themselves, but more than all on the methods used in conducting surveys and the importance attached thereto.

Mine-surveying, in some form or other, has been practiced from the very earliest times; but it has never kept pace with the other branches of surveying, or even with the art of mining itself, and cannot be recognized as an exact science until shortly before the beginning of this century.

The works of Hero of Alexandria, who lived in the second century B.C., are still extant, and contain descriptions of a rectangular sighting-instrument, which he invented and called a *diopter*. His improvement upon this simple construction, which possibly he devised for use in the Greek mines for rough leveling-purposes and for laying out any angle, must be considered, says Hübner,* as the origin of the highly perfected theodolite of to-day.

Whether this instrument came into general use during the first centuries of the Christian era, is not recorded; in fact, no writer undertakes to tell how mine-surveying was conducted until 1556, in which year Agricola expounds the principles of mining and metallurgy in his *De Re Metallica*, devoting the entire fifth chapter to the practice of mine-surveying (see Fig. 1).

In mediæval times those who possessed any knowledge of engineering skill made strenuous effort to keep their art a secret, partly on account of the miners' proverbial conservatism and partly for their own personal aggrandizement, and were, in

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* *Mittheilungen aus dem Markscheidewesen*, von Werneke, Freiberg, 1887.

consequence, superstitiously regarded as sorcerers of the kind who were expert in the use of the divining-rod.

Indeed the superstition of this period was so potent in its in-

Fig. 1.

Facsimile from *De Re Metallica*, Georgius Agricola, Basel, 1556, constituting the frontispiece of Bennett H. Brough's "Treatise on Mine-Surveying," London. 1888.

fluences that the hazel-twig, in the hands of a sensitive medium, was accepted at that time with greater confidence than the most scientific mathematical deduction then possible.

Dr. Raymond published, in 1883, a very complete and interesting paper on "The Divining-Rod,* in which reference is made to all the best works on the subject, both ancient and modern. In the study of the history of the subject, he says:

"It will appear that divining-rods were first used in antiquity mainly or wholly for moral purposes; that in the Middle Ages their employment was for a long period confined to the discovery of material objects; that towards the end of the seventeenth century the moral use was again asserted, and that in the eighteenth century the divining-rod was relegated to the material sphere and assumed the comparative modest functions in the discharge of which it still lingers among us."†

And after showing that the rod itself serves, at most, to exhibit the results of nervous sensibility and unconscious muscular contraction on the part of the operator, he adds:‡

"To this, then, the rod of Moses, of Jacob, of Mercury, of Circe, of Valentine, of Beausoleil, of Vallemont, of Aymar, of Bleton, of Pennet, of Competti —even of Mr. Latimer—has come at last. In itself it is nothing. Its claims to virtues derived from Deity, from Satan, from sympathies and affinities, from corpuscular effluvia, from electrical currents, from passive perturbatory qualities of organo-electric force, are hopelessly collapsed and discarded. A whole library of learned rubbish about it, which remains to us, furnishes jargon for charlatans, marvellous tales for fools and amusement for antiquarians; otherwise it is only fit to constitute part of Mr. Caxton's *History of Human Error*. And the sphere of the divining-rod has shrunk with its authority. In one department after another it has been found useless. Even in the one application left to it with any show of reason, it is nothing unless held in skilful hands; and whoever has the skill may dispense with the rod."

Agricola says the subject is open to much dispute; states the evidence on both sides briefly, but with admirable clearness; and, while he declines to enter upon a discussion, "neither permissible nor agreeable," of the virtue which may be imparted to the rod by spells and incantations, he inclines his reader to skepticism. In the quaint wood-cut accompanying this chapter, his "good and sober" miners, who have studied nature, are already digging ore, while the man with the rod is yet preparing to discover it.

Fig. 2 is taken from the *Cosmographia Universalis* of Sebastian Munster, published at Basel in 1550. "This geographical work," says Dr. H. R. Mill, "deals only vaguely with mining,

* *Trans.*, xi., 411. † *Ibid.*, p. 413. ‡ *Ibid.*, p. 445.

and I fancy the cut of the *virgula divina*, to which little reference is made, must have been copied from some earlier work."

The Latin treatise on mining engineering by J. F. Weidler (Wittenberg, 1726) deals at length with this supernatural method; and even so clever an engineer as Beyern let superstition get the best of his mathematics. As late as 1749 he claims that thorough instruction in mining engineering involves the application of the divining-rod, though he was intelligent enough to insist that, "if there is a difference in the findings of the twig and compass, then more dependence must be placed in the compass than in the twig."

FIG. 2.

Ancient Representation of Divining-Rod.

It is recorded in Chinese annals that in 2364 B.C. the Emperor Hou-ang-ti, or Hong-Ti, constructed an instrument for indicating the South, which, Dr. Gilbert says,* was brought from Cathay to Italy in 1295 by the renowned Marco Polo.†

Flavio Gioja, of Amalfi, some ten or fifteen years later, was doubtless the first European to mount this magnetic needle in a box, but the use of the stationary or *Setz-compass* (Fig. 3) in mine-surveys is first described in the work of Agricola.

An instrument of this original type, bearing the date 1541, is still preserved at the Neudorfer mines in the Harz. Concerning it, Prof. Brathuhn says:

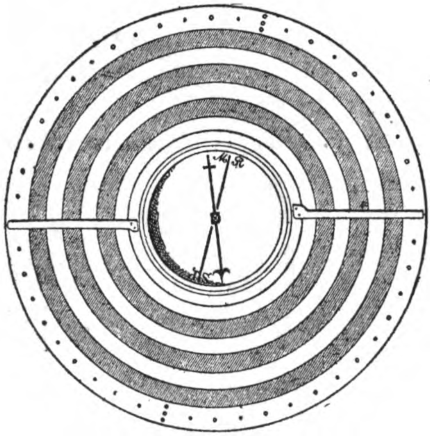
"The 5.5 cm. compass-box fits into the center of a wooden disk 16 cm. in diameter and 2 cm. thick. About it are three concentric grooves filled with wax of

* *Colcestrencis . . . de Magnete* Gulielmi Gilberti, London, 1600.

† Bailly, *Histoire de l'Astronomie Ancienne*, Paris, 1775, p. 122.

different colors. Upon the bottom plate of the compass-box is drawn only a meridian line, marked at its ends M. R. (Meridies) and S. P. (Septentrio). When in use, the compass and disk were put into the circular cavity of a wooden box, and mounted by means of a hole beneath upon a simple staff.

FIG. 3.



The Setz-Compass.

"The disk was turned until the needle became coincident with the meridian line; then the pointer that revolved about its fiducial edge was brought into the direction of any course, as nearly as could be judged by the eye, and a mark was made in one of the wax circles to indicate its azimuth with the meridian.

"The course was then measured and recorded with the characterized mark and the color of the wax circle in which it was made. The survey was then reproduced on the surface, commencing usually at the mouth of the shaft, to determine the proximity of the underground workings to the boundary-lines."

Fig. 4 is copied from a drawing of that period, and represents an authorized engineer, commissioned by the government of Saxony, engaged in conducting a survey with this instrument.

FIG. 4.

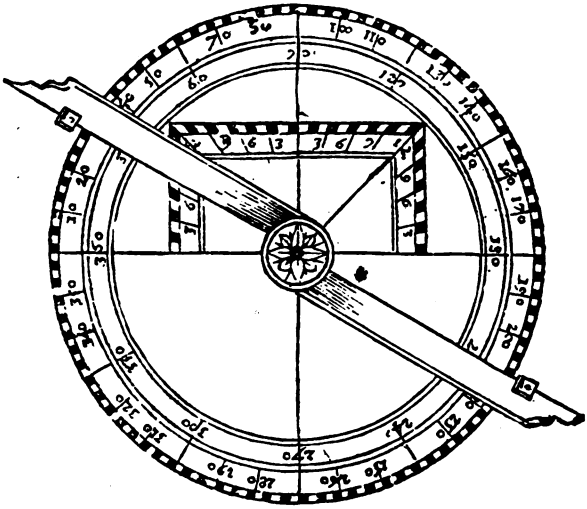
Surveying with the Setz-Compass.

In another place in Agricola's work is represented a nude surveyor making observations with a circle of wood, nearly equal in diameter to his own height, which he holds vertically, and which is provided with a weighted index-pendulum.

In these two crude yet ingenious appliances we have, no doubt, the origin of the *Hangcompass und Gradbogen* that came so universally into use throughout the mining districts of Europe.

In 1571 Thos. Diggs, the son of Leonhard Diggs, published in England his *Pantometria*, in which are described several instruments for surveying purposes. His masterpiece is what he called the *theodolitus* (Fig. 5), perhaps derived from *theodicœa*, taken in the sense of perfection, as being a most per-

FIG. 5.



Diggs's Theodolite.

fect instrument.* In the 27th chapter, called *Longimetria*, he says:

"It is but a circle divided into 360 grades or degrees, or a semicircle parted into 180 portions, and every of those divisions in 3, or rather 6, smaller parts. . . . The index of that instrument, with the sights, etc., are not unlike to that which the square hath : In his backe prepare a vice or scrue to be fastened in the top of some staffe, if it be a circle, as heere: let your instrument be so large that from the center to the degrees may be a foote in length, more if ye list, so that you not erre in your practices."

For steep upward sighting, he used an artificial horizon.

In the same year Diggs published his *Stratiaticus*, in which he says that while he had access to certain of Roger Bacon's

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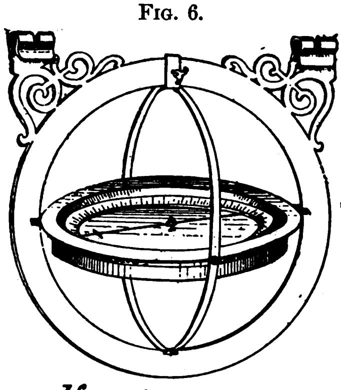
* This derivation is given by Stanley in his work on *Surveying Instruments.* Bauernfeind says (vol. i., p. 288): "It cannot be said with certainty how the word 'theodolite,' as applied to angle-measuring instruments, originated. It was used in England as early as the sixteenth century, and probably had its origin there. Prevailing opinion, formerly, assigned its derivation to two or three Greek words, one of which was λίθος (stone), and basing it upon this derivation the word should be written *theodolith.* But more recent archæological research proves that any attempt to associate the word as we now have it with the Greek is a mistake, as it is more probably a corruption of 'the alidade' by the English from *al'idade*, the Arabic term applied to the radius of the astrolabium."

unpublished MSS. he discovered a letter from his father, describing a method of "viewing distant objects by placing perspective-glasses at due intervals." This was certainly an application of the principles of the telescope, which he, no doubt, like others, had discovered by personal research and experiment.

The period of the casual invention of the telescope is involved in some obscurity. Though there is ample evidence that the ancients of Ovid's time knew something of it, its introduction as a philosophic instrument probably belongs to Friar Bacon, who conducted his experiments in Paris, and died at Oxford in 1294. Its construction and uses were handed down through the generations as a secret, like all other "works of iniquity" that aimed at an advance in science. Later, in 1590, when Jensen, the spectacle-maker, showed his improved instrument to Prince Maurice, he was required, under severe penalty, to divulge no information concerning it, so that only the prince should be aided by it in his warfares; but Galileo, having had it described to him in 1608, constructed at Padua a telescope of three diameters' power, and presented it to the Doge of Venice. It was not until about this year that the opticians of Holland made the practical application of the telescope possible, and inaugurated a new era in the science of astronomy.

FIG. 6.

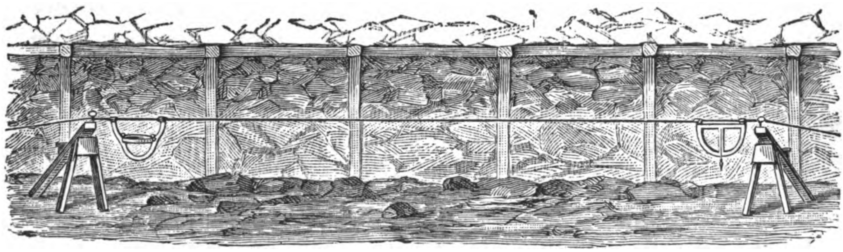


Kreuzhängezeug nach Rössler 1686.

The first systematic and exclusive treatise on mining engineering was the *Geometria Subterranea* of Nicholas Voigtel (Eisleben, Saxony, 1686), in which the methods and instruments described exhibit, after a lapse of 130 years, a natural development yet small improvement over those of Agricola. In fact, mine-surveys were conducted on the continent, and probably also in England, by Agricola's primitive means, until Balthazar Rössler, in 1633, invented the method of suspending from a taut hempen cord a gimbal-compass (Fig. 6) and clinometer, by which the magnetic bearing, inclination and length of any course were at once determined with comparative ease.* The accuracy of this system, which Voigtel describes, depended largely upon the perfection of graduation, the precision possible in reading the clinometer, the catenary curve of the cord on long courses (augmented by the weight of the instruments hung upon it), and the surrounding attractive influences upon the magnetic needle; but it is certainly the first method for the determination of the angular value of precipitous grades without correction for mechanical imperfections in the apparatus.

In 1681 Thomas Houghton published a small treatise upon subterraneous surveying in the Derbyshire mines,† in which he described a use of strings, plumbs and compass very similar to the method of Rössler, except that the *dial*, in a long rec-

FIG. 7.



Surveying by Rössler's Method.

tangular box, was applied by hand to the side of a string, held by two persons, and afterwards measured with a rule.

The method of Rössler, or some adaptation of it, prevailed throughout Europe with remarkable tenacity up to the beginning of this century; and even to-day, at some mines, no other instruments are used; while at others the use of these, in conjunction with the theodolite, is not infrequent. For about eighty years the prestige of the method was undisputed, though it underwent various modifications to suit the conditions of practice. Hempen cords gave way to brass chains; but these (like Gunter's, of 1620, which was substituted for Houghton's rule in English collieries) were found to elongate by tension and friction, so that frequent adjustment became necessary. The catenary curve of the cord, chain or wire was always a matter of

* *Die Entwickelung der Markscheidekunst*, M. Schmidt, Freiberg, 1889.

† *Rara Avis in Terris*, T. Houghton, London, 1681.

perplexity until about 30 years ago, when Prof. A. von Miller-Hauenfels, of Vienna, deduced rules for the suspension of the clinometer in positions to indicate the exact grade between the two stations.

In 1775 Hofrath Kästner designed a quadrant-clinometer, which was suspended from the ends of an index-arm bearing a vernier-scale. The plummet was still used, but only for the purpose of insuring the verticality of the zero-point.*

In 1877 Schneider designed a complete circle of aluminum, dispensing with the plummet entirely, and substituting an alidade with opposite verniers, the verticality of which was determined by a bubble on its lower arm.†

The hanging-compass also underwent various reforms in fruitless attempts to employ it successfully in the presence of iron. Up to 1749 it had not been materially changed from its original construction. The works of both A. Beyer, of Altenberg, and F. W. von Oppel, of Dresden, published in that year, contained nothing new in instrumental construction; but each introduced the use of sines and cosines in the calculations.

In the second edition of Beyer's work, as revised by Lempe in 1785, appeared, for the first time, an illustration of the now common form of hanging-compass (see Fig. 7), said to have been made by Schubert of Freiberg.

The most notable modifications of this instrument are comparatively recent, and include the adjustable forms of Braunsdorpf (1834), Lendig (1846), Reichelt (1856), Osterland (1860), Lehman (1873), Plamineck (1878), Fuhrman (1879), and Penkert (1880).

In the earliest times mine-plans were rare and rude. The object of most surveys was to retrace on the surface the contour of a subterranean opening. "Underground," says Houghton, "the dial is guided by the string, but on the surface the string is guided by the dial." But as the importance of maps became more obvious, the hanging-compass was so modified that the compass-box might be removed and transferred to a brass protractor-plate, where it was clamped in exact position, and the survey was plotted with the same instrument used in making

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* *Lehrbuch der Praktischen Markscheidekunst*, O. Brathuhn, p. 34.

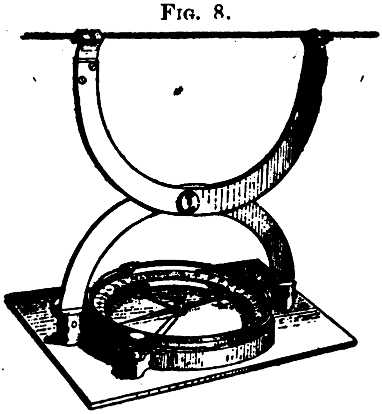
† *Oesterr. Zeitsch. für Berg- und Hüttenwesen*, 1877, p. 367.

it. This method is described in the first edition of Voigtel's work (Eisleben, 1686), and is also spoken of in *The Exact Surveyor* by J. Eyre (London, 1654) as though it had been customary many years previously. Describing the circumferenter of that day, Eyre says:

"For portability this instrument exceedeth any other, and is usually made of wood, containing in length about eight Inches, and in breadth about four Inches, and in thicknesse three quarters of an Inch, the left side whereof is divided into divers equall parts, most fitly of twelve in an Inch, to be used as a scale of a protractor, the Instrument of itself being fitting to protract the plat on paper by help of the Needle, and the degrees of Angles, and length of Lines taken in the Field."

The idea is creditable; but its benefits are questionable, in view of the fact that the magnetic influences are not the same in the office as in the mine. Moreover, for plotting-purposes, the delicacy of a 3-inch needle in a circle graduated to only ½° is not beyond reproach. Since 1801, the protractor-plate itself has been so provided with adjustable tangent-semicircles (see Fig. 8) that it could be used for both purposes; but, though widely used by mining-captains in Germany, it does not permit very accurate work.

FIG. 8.



The Compass-Protractor as used for Mine-Surveys.

The constancy of the magnetic needle has been questioned only in times which must be considered as recent, compared with the long period of its use; but long before angular or trigonometrical surveying had been presented as the only rational method, the variable susceptibility of the needle to magnetic influences had been the subject of investigation and discussion important to the mining engineer, who had no alternative in localities of strong attraction but the use of the very instrument most affected thereby. The earliest astronomical observations to determine the secular variation were made in Paris in 1541, when the needle pointed 7° E. of N. By 1580 it had reached a maximum of 11° 30′, when it began to recede, reaching the true meridian in 1666. The yearly variation then became westward until 1814, when a maximum of 22° 34′ was attained!

Bennett H. Brough says:

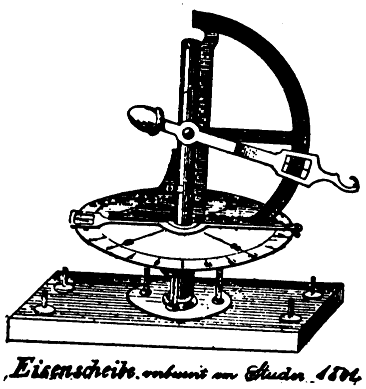
"There can be no doubt that in times past a neglect of this variation has led to errors involving great loss and serious danger. . . . . Regular observations were not made until the middle of the seventeenth century; but there is a passage (which, however, is so obscure that its meaning is doubtful), apparently referring to the declination of the needle, in the oldest treatise on mining, an extremely scarce work, written in German and published in 1505. No copy of the first edition of this 'well arranged and useful little book,' as the anonymous author calls it, is known to exist."

In 1763 Isaac Prince, of Bonsal, in his *Miner's Guide or Complete Miner*, says, with respect to magnetic surveying:

"The knowledge of ye quantity of this Declination, which is pretty near ye same one year as another and sometimes differs very little for many years together, enables us to adjust ye Needle in such a manner as if it had no Inclination at all. Though ye knowledge of this Inclination has hitherto been fruitless, it is to be hoped yt some time or another some advantage or profit may be discovered by its regularity."*

Annual and diurnal variations were also studied and dealt with as intelligently as the time and place permitted; but general efforts to remedy the erratic and deceptive demeanor of the needle in the presence of iron finally resulted in the invention and introduction in Germany of the *Eisenscheibe* or iron disk. The first forms of this instrument were described in the third edition of Voigtel (1713), though L. C. Strum, of Frankfort, had proposed the use of the astrolabium for the miner as early as 1710.† Fig. 9 represents the design of J. G. Studer, of Freiberg, which is somewhat of an improvement over the original forms, though its principal features are the same. The disk, as will be noticed, was graduated, like the compass of that day, into

Fig. 9.



* Quoted from *Cantor Lectures on Mine-Surveying*, B. H. Brough, London, 1892, p. 9, in *Surveying by the True Meridian*, E. W. Newton, F.G.S., Falmouth, 1895.

† *Vier Kurz Abhandlungen*, Leon. Chr. Strum, Frankfurt, 1710.

twenty-four hours, the twelfth hour marking the N. and S. cardinal points. In conducting a survey by its use, two, and preferably three, instruments were employed; one being set up at each adjacent station. The indicator-arms were then tied together with a stout cord, first on one side, then on the other, observing the interior angles. In the same way the angles of inclination on the vertical arc were noted; and then the last instrument was brought forward to establish a new station. Later, each hour was subdivided into fifteen equal parts, so that each division corresponded to a degree of the sexagesimal system, making it, as compared with the compass, a most reliable instrument for this work; indeed, it is con-

FIG. 10.

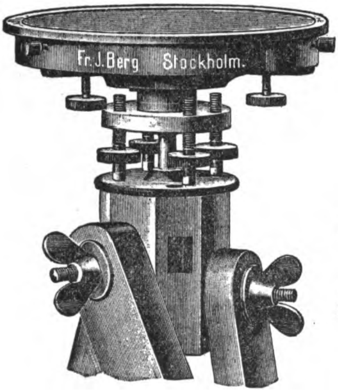
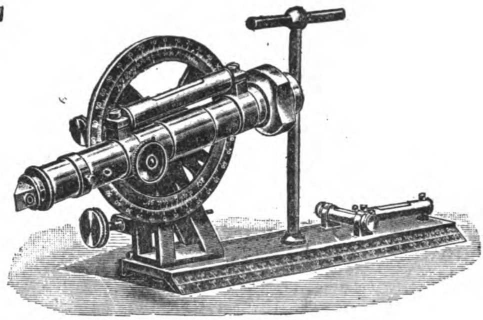


FIG. 11.



Modern Swedish Mine-Tripod and Alidade.

sidered by German authorities to be the predecessor of the perfect mine-theodolite now in general use.

The same feeling seems to have prevailed also in Sweden, where we find mining engineers, near the beginning of the nineteenth century,* discarding the compass entirely in their magnetic iron-mines, and substituting the graphic method of conducting mine-surveys by plane-tables of a peculiar make, which, with rare exceptions, has been in use ever since.

The invention of the plane-table is generally attributed to Prætorius in 1537; but Leonhard Zubler, in the first published account of it (1625), credits its origin to Eberhard, a stone-mason.

* *Handladning uti Svenska Markscheidereit,* Horneman, Stockholm, 1802; also, *Reise durch Skandinavien,* J. F. L. Hausmann, Göttingen, 1811–19, vol. v., pp. 115–126.

Who introduced it into Sweden for mine-surveys, Prof. Nordenström is unable to determine; but the earliest instruments, no doubt, were of rude construction, with only a sighted alidade. I present here (Figs. 10 and 11) a modern tripod, showing the clamping-ring by which the paper is held in position while receiving the plot. The telescopic alidade does not differ from those in general use in other countries for surface-work, except that its vertical circle is full, reading to minutes, and the base-rule that carries the bubbles has the linear subdivisions engraved along the edge.

The Rapid Traverser of Henderson, of Truro, Cornwall, introduced in 1892, is very similar to this mode of construction, except that its alidade is pivoted at the center, instead of being free to move in any position. The survey cannot be plotted in the field, as by the Swedish method. Disks of celluloid, or preferably white enameled zinc, are employed, and the direction of each course or draught is marked upon one of the five concentric circles engraved upon its surface. This instrument and method, it seems, will eventually supersede in Cornwall such magnetic surveys as caused the recent casualty in Wheal Owles mine at St. Just.

The magnetometer of Prof. Robert Thalén of Upsala and that of Tiberg are the only other Swedish instruments that have come to the writer's notice. Thalén's is called a simplified modification of the magnetic theodolite of Dr. Lamont;* but in reality the association is very remote, consisting only in the so-called sinus-method of using it, which has been borrowed from Lamont.† It is a simple compass-instrument, having a magnet upon an arm in the line of sight, so arranged that, by its application and removal at the proper time, the azimuth of each course is obtained.

Tiberg's (1880) is almost identical with this, except that the compass-box is set in bearings upon low standards, and occasionally made to revolve in a vertical position for use as a dip-needle, in determining the location of magnetic ore-deposits.

In *Wärmländer Annaler* of 1888, Mr. Sjogren describes some

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* *L'Industrie Minière de la Suède*, G. Nordenström, p. 22. (A translation of the methods here described occurs in *Mines and Minerals*, Scranton, Pa., November, 1898.)

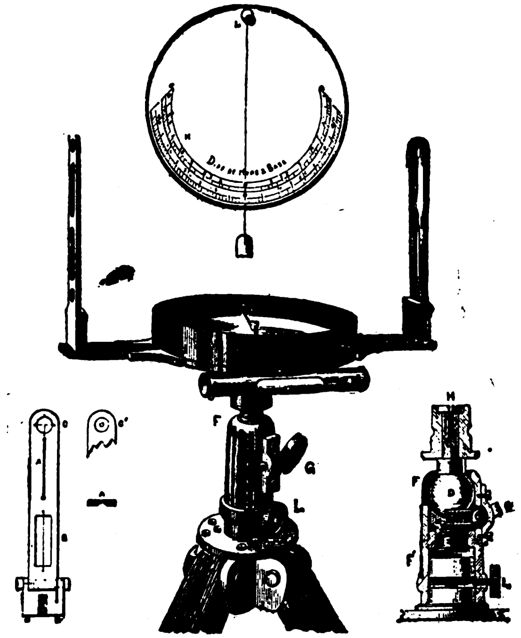
† *Sur la recherche des Mines de fer à l'aide de mesures magnétiques*, R. Thalén, 1877.

very creditable work of this kind, done with Tiberg's instrument at Persberg.

In England the magnetic needle and Houghton's methods were adhered to, amid recurring failures and disasters, with a loyalty that prevails even to-day in some parts of Cornwall.*

In 1778 Dr. W. Pryce declared that methods similar to Houghton's were still in vogue.† He says:

FIG. 12.



Old English Miners' Dial.

"The instruments used are a compass without gnomon or style but a center-pin projecting from the center of the compass to loop a line to, or stick a candle upon, fixed in a box exactly true and level with its surface, about 6, 8 or 9 inches square, nicely glazed with a strong white glass, and a cover suitable to it hung square and level with the upper part of the instrument; a 24-inch gauge or two-foot rule and a string or small cord with a plummet at the end of it; a little stool to place the dial horizontally; and pegs and pins of wood, a piece of chalk, and pen, ink and paper."

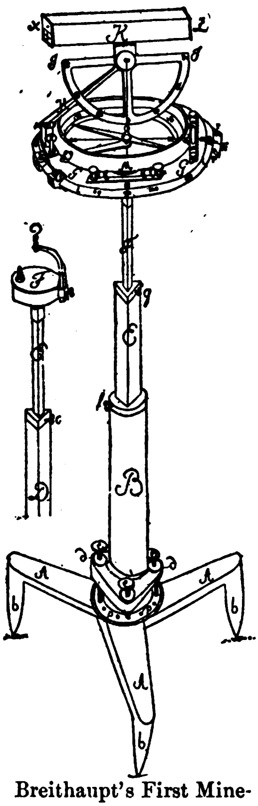
Later (about 1785), extended sights were added; the little three-legged stool no doubt became the tripod; and, with one or two other slight improvements, we have in England, just

* *Proc. Royal Cornwall Polyt. Soc.*, 1893.

† *Mineralogia Cornubiensis*, W. Pryce, London, 1778, pp. 202–213.

before the beginning of this century, the type of dial shown in Fig. 12, in a modernized form, as made by W. F. Stanley, of London. Who is responsible for its conception as a whole is not known—probably no one particular person, as too many years were required to bring it to even its original simple construction; but Adams must have improved upon it; since an instrument similar to this is described in his *Geometrical Essays* of 1803. It originally had no bubbles, but was considered level when the needle floated freely.

FIG. 13.



Breithaupt's First Mine-Theodolite.

The early makers were, however, in the habit of partly counter-sinking two spirit-levels in the compass-box if desired; but these were not recommended, because, by reason of their small size, they were seldom accurate, and the operator could not test them, or even adjust them if they were known to be untrue.

In the English dial shown in Fig. 12 the socket is slotted down on one side (F) so as to permit the limb to be turned vertically, making the sights horizontal. In this position, after the long bubble beneath the compass is made level, the compass-box cover is adjusted and the very small plummet, suspended from its top by a hair or silk thread, is made to read zero on the graduations. The sights can then be tipped up or down, and gradients up to 45° can be determined approximately. It will be noticed that the graduated cover, as in most other English dials, has the correction for declivity marked upon it, so as to save the operator any calculation in this particular. Lean began this practice in Cornwall in 1825, receiving a prize of thirty guineas for his borrowed improvement.

In 1798 H. C. W. Breithaupt, of Cassel, introduced an instrument which may be justly designated the first of mine-theodolites. Fig. 13 is reproduced from the original drawings of the inventor by the courtesy of his heirs, F. W. Breithaupt & Son.

In his book,* Herr Breithaupt described the use of this instrument in a new system of surveying, which he himself first practised in the Reichelsdorfer copper-mines of Hesse.

Jesse Ramsden had already (1760) constructed a circular dividing-engine in London, in response to the urgent demands of geodetic engineers for circles of greater accuracy than those heretofore graduated by hand; and M. Pierre Vernier, of Burgundy, had long since (1631) published in Brussels a description of the micrometer-scale which now bears his name. We must note here, parenthetically, that Vernier's scale was adjusted by hand until Helvetius, the celebrated astronomer of Danzig, invented, about 1650, the clamp-and-tangent movement. Applying these precedents, Breithaupt circumscribed a compass with a carefully divided circle, read by Vernier-plates; invented an arrester that should clamp the needle when not in use; superimposed an adaptation of the clinometer that was surmounted by a sighting-tube; and supported this compact combination upon a sort of telescopic tripod-stand, which could be adjusted for height by means of set-screws at the side.

Fig. 14.

The Jones Circumferenter.

Instead of using two or more instruments, as was customary in employing the *Eisenscheibe*, he designed a signal-lamp, two of which were used interchangeably with the instrument. These instruments, which sold for 8 carolin ($33.70), he made himself, and felt the necessity of economy so strongly that he made a plain sighting-tube to take the place of a telescope.

In the same year Prof. Guiliani, of Vienna, constructed a mine-instrument which he called a *Katageolabium.* Like the *Graphometer Souterrain* of Gen. Komarzewski, it was closely allied to the *Eisenscheibe.*

In England the same spirit of economy and consequent simplicity of construction has always prevailed. In 1796

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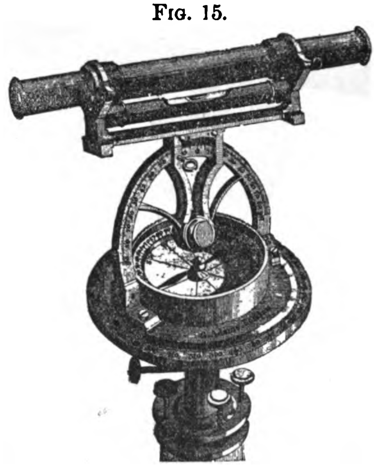
* *Besehreibung eines neuen Markscheidinstruments,* Kassel, 1800.

W. & S. Jones, of London, introduced a circumferenter (Fig. 14), which, in addition to the ordinary compass, was provided with a 10-inch brass circle, divided into single degrees and read by the "*nonius*," as they were then called in England, to 5 minutes of arc. In offering this instrument to the engineering profession, Mr. Jones said: "The error to which an instrument is liable, where the whole dependence is placed on the needle, soon rendered some other invention necessary to measure angles with accuracy; among these the common theodolite, with four plain sights, took the lead, being simple in construction and easy in use."*

It was fitted with one pair of fixed and one pair of movable sights, like Henderson's dial (1869), and "marks the date," says Mr. Newton, "of the first attempt in England to conduct underground surveys, in the presence of iron, with any degree of accuracy."

FIG. 15.



Simple English Theodolite of last Century, now commonly known as Lean's Dial.

Elliott Bros. made such an instrument for Fenwick in 1822,† but on account of its expense this construction was not much used until Lean began to employ vernier-circles in 1836 in the Cornish mines.

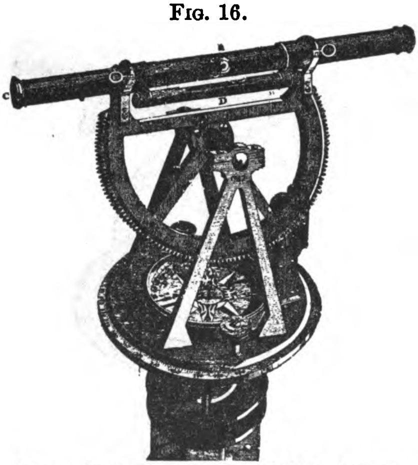
So far as available evidence can be relied upon, what is now commonly known as "Lean's dial" was the first telescopic mine-instrument ever introduced; but there is some doubt concerning this fact. Fig. 15 is taken from the *Geometrical and Graphical Essays* of George Adams, published in 1797. It is there said to be intended as a fair sort of cheap theodolite. Lean's grandson can furnish no authentic information; but it is known that when it was first used in mine-surveys, and made for Captain Lean by the Wilton Works of St. Day, the vertical arc and telescope were removed for common sights and replaced only for surface-work. In accordance with

* Adams's *Geometrical Essays*, revised by Jones, London, 1797, p. 223.

† *Treatise on Mathematical Instruments*, J. F. Heather, London, 1849.

the prevailing custom, the sights alone were used underground. The dial was set up only at alternate stations; the back- and fore-sights were read with the needle; and the bearings were assumed to be correct. The centers of vertical shafts simply became intermediate stations; but if an inclined shaft was encountered, a cross-staff was set up in it, so that one pair of sights were directed at a candle-light in the bottom; then the dial was set up in a drift and made to bear upon the other pair. In this way the magnetic bearing of the shaft was calculated by adding or subtracting 90°. "Many miles of dialing have been done," says Franklands, "by this rapid but blindfold method, with no means of closing the survey." It was not thought possible, at that time, to connect the surface and underground surveys by anything but magnetic bearings, so that the telescopic attachment to the so-called Lean dial can hardly be considered the antecedent of Breithaupt's first telescopic mine-transit (made in 1832), though it has been widely used in more recent years for such purposes. Since 1871, E. T. Newton & Son, of Camborne, have made the Y's of the telescope interchangeable with the arc or the sights. By thus mounting the telescope upon the limb just over the compass-box, the instrument becomes a substitute for the Gravatt level, which has found great favor in the English colonies.

Fig. 16.



Seven-inch English Theodolite of Last Century.

It is a recorded fact that the general design of this dial came from the standard model English theodolite, to which it bears a strong resemblance. This instrument is rarely used in English collieries on account of its cost; but its construction has long since been such that vertical sights from one side were possible. The prolongation of an inclined shaft alignment, however, can be accomplished only by reversing the telescope in its bearings or by revolving 180° upon its horizontal limb.

Why it is that English engineers adhere to this model has always been a source of wonder to the American profession; for, in the relationship of the telescope to the vertical circle, it is one of the most extreme of eccentric types. Its retention, however, must be well merited, or it would have been supplanted by the transit-principle of Ramsden in 1803, or by the concentric model of Sir George Everest (1837), which practically became obsolete twenty years ago. But whatever it has to commend or to disqualify it, the important developments in English engineering-instruments must be followed with this theodolite. In Gardener's *Practical Surveyor* (1737) we have descriptions of this theodolite, much improved and brought to nearly its present form by Jonathan Sissons, an optician of London (Fig. 16).* It was not perfected, however, until 1760, when Ramsden sensitized its graduated "brain," and John Dolland sent pure light coursing through its telescopic "soul." Dolland discovered the construction of an achromatic telescope in a compound objective of two kinds of glass (in direct antagonism to the principles laid down by Sir Isaac Newton), by which both spherical aberration and errors arising from varying refrangibility were in a great measure overcome. While this discovery was very important in the manufacture of geodetic and astronomical instruments, "the most perfect objectives were not made," says Thomas Dick, "until after the improvements of Dr. Blair, of Edinborough, Rodgers, of London, and Fraunhofer, of Munich, in the first quarter of this century"†—just before telescopic instruments came into general use for mine-work.

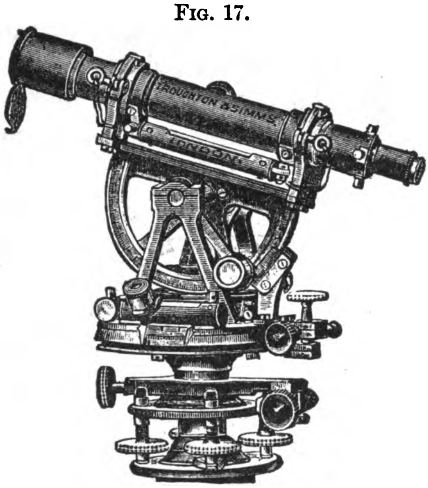
Lean's dial, then, might have had a practically achromatic telescope. It might also have been provided with a diaphragm and cross-hairs; for Huygens discovered that any object placed in the mutual focus of the two lenses of a Kepler telescope (1611) appeared as distinct and well defined as any distant body. Following this established theory, in 1669 Jean Picard, Marquis Malvasia and others crossed silken fibers in the mutual focus of their astronomical instruments; and these, while generally acknowledged to be too large for the work required, were

* This particular figure represents an instrument made by Ramsden, Jones, Adams, and others, after the general style of Sissons.

† *The Practical Astronomer*, Thomas Dick, LL.D., New York, 1846.

used, in lack of something better, for a century or more. In 1755 Prof. Fontana, of Florence, proposed the use of spider-webs, though it is said they were not put into practical use until Troughton secured for this purpose the webs of the geometrical spider, at the instance of David Rittenhouse, of Philadelphia, who was then constructing the first American telescope.

FIG. 17.

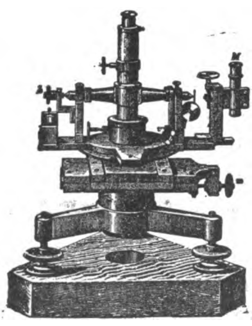


Modern English Theodolite.

At the time the telescope begins to play some part in the construction of mining instruments we find it, so far as possibilities are concerned, a very perfect device; but as the use of fine-quality lenses entailed considerable extra expense, and as almost any contrivance was considered good enough for surveys in dirty little underground passages, we find at that time generally only poor-quality and low-power telescopes in use.

For the precise shaft- and tunnel-work involved in the construction of the Great Western Railway in 1843, Bourne was probably first to use the high-class English theodolite, shown in Fig. 17, in connecting the underground- and surface-surveys through the vertical shafts.

FIG. 18.



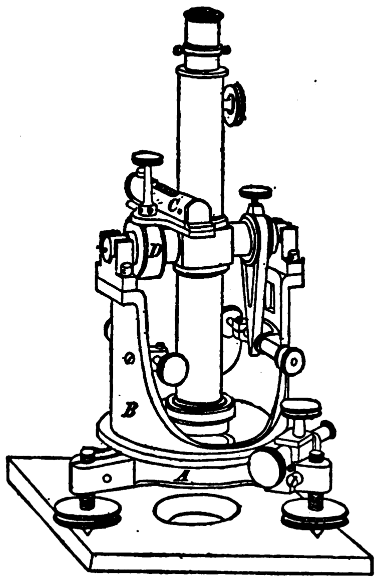
Hassler's Instrument with Perforated Vertical Axis.

Since that time, and doubtless before it, the ideal instrument for nadir-sighting has been considered one in which the vertical axis of the concentric type should be enlarged and perforated sufficiently to permit such observations.

In 1824 F. R. Hassler, Superintendent of the U. S. Coast Survey, designed such an instrument (Fig. 18), which, as subsequently improved by General Ibañez, was pronounced by the European Degree-Measuring Commission to be perfect for the purposes intended.* It had two slow, independent lateral motions, like the sliding stage of a microscope, by which the cross-hairs could be brought exactly over a point in the aligned base-line to insure perfect parallelism in the subsequent setting of the metallic measuring-rod. As its use was restricted to geodetic engineering, it has no special application here, but is inserted only to establish the priority of the invention.

Prof. Viertel first used the telescope of an eccentric theodolite for conducting surveys in vertical shafts, by suspending a plummet through the diopter; but as the instrument was not steady enough, and the plummet was centered only with great difficulty, the method was abandoned as impracticable.

FIG. 19.



Nagel's Nadir-Instrument.

Prof. A. Nagel, of Dresden, had a nadir-instrument (Fig. 19) constructed without vertical axis, which could be centered over a shaft with great precision by means of a center-plug in the base, which was afterwards removed to leave the opening free for the purpose designed. The adjustment of his instrument was the same as that of any ordinary theodolite. To obtain a true vertical sight he first set a plate of mercury under the telescope somewhat below its focal distance. Its surface must necessarily be a perfect horizon, and under a fair illumination will reflect the image of the cross-hairs. When they are brought exactly to coincide with this reflection, the optical axis of the telescope will be truly vertical if it is originally in perfect adjustment. It was his practice to revolve the telescope 180°, and repeat the operation, rectifying any defect at the bottom of the shaft, upon a mechanical stage which was pro-

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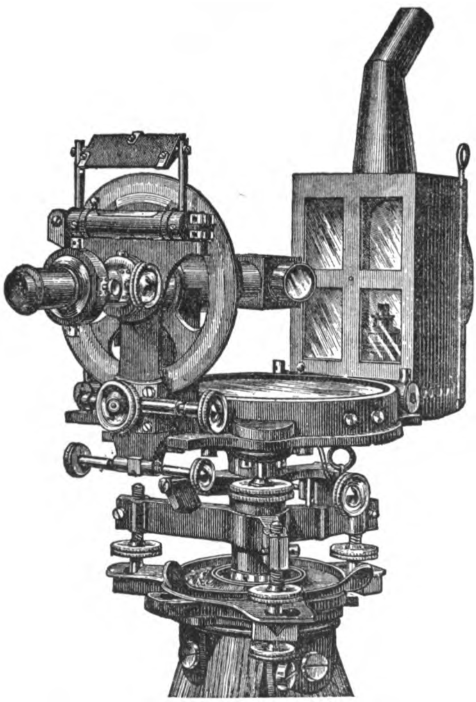
* *Die Landmessung*, Dr. C. Bohm, p. 605.

vided with co-ordinate micrometer-scales to determine the mean projection. The experiments of both Viertel and Nagel were recorded in *Der Civilingenieur* of 1878.

In 1876 H. D. Hoskold submitted plans to Troughton & Simms for a similar instrument; but the plans having been lost in Paris, its introduction in England was allowed to lapse.* This firm, however, in 1885, devised an instrument (Fig. 20) that is very remarkable among the instruments of its class. Its *single* axis of revolution was perforated by a hole $\frac{5}{8}$-inch in diameter, which provided a sufficiently large opening without the necessity of increasing the size of the base, so as to be heavy or out of proportion.

FIG. 20.



Troughton & Simms Prismatic Nadir Dial.

The $4\frac{1}{2}$-inch needle was supported at the top of the perforation upon a sort of little flat trident, and was never removed for nadir sighting. It absorbed, of course, some rays of light, but did not interfere with an otherwise perfect view. The broken telescope, which was focused by movement of the ocular, was so placed that its prism came directly over the perforation, and vertical sights could be made by setting the vertical limb to the zero of its vernier, which, in turn, was insured for verticality by the long bubble upon its arm. This vernier was illuminated by the reflection of a mirror, so placed above it as to deflect the light from the large lamp opposite, which was designed to counterbalance

* *Trans. Am. Soc. Civ. E.*, xxx., 153, 1893.

the weight of the telescope and vertical circle. The outer circumference of the compass-ring was graduated, and could be read to minutes by opposite vernier-plates that were rigidly attached to the compass-box. The circle was first placed at zero and held by the pin, with looped string, shown protruding below, and the telescope moved in azimuth by means of the large thumb-screw, also shown below the compass-box.

The instrument had no plummet. In ordinary traversing the instrument was set up at any convenient position, and the station-point sighted in afterwards through the axis.

Its makers volunteer the information that there never has been much of a demand for this instrument, and that it is now no longer made. This was, perhaps, because of the inconvenience of the broken telescope in general work and the conditions that prevented observations in dips greater than 45° and less than 90°.

All such instruments have generally been allied with the straight-line or tunnel-transits. In 1877 Buff & Berger made such an instrument for G. H. Crafts. The base, having the shape of a horseshoe, was mounted upon three leveling-screws. This instrument was used for the shaft- and tunnel-work of the Dorchester Bay sewer, for the city of Boston, and afterwards to re-establish the boundary between Massachusetts and New York.*

In 1887, E. A. Geiseler, now Assistant United States Engineer at Savannah, Ga., designed plans for a nadir-instrument in which both the graduated circles and compass-box were to be retained. He proposed that the vertical axis be slightly increased in diameter and perforated with a hole $\frac{3}{32}$-inch in diameter. Its upper orifice was in the base of the compass-box and ordinarily contained a plug, so designed as to support the needle. When vertical sights were necessary, the plug with needle was carefully removed and set just to one side, by means of a lever-arm operated from outside the compass-box. The invention received editorial comment in the *Engineering News* and *Railroad Gazette* at the time, but was not executed until the following year, when the F. E. Brandis Sons, of Brooklyn, constructed an instrument on these prin-

* *Jour. Ass. Eng. Societies*, vol. iii., No. 9, 1884.

ciples, with some modifications to suit the ideas of their customer. The perforation was made 1½ inches in diameter and the compass-box was dispensed with entirely. In its place was supplied a trough-box compass suspended from the horizontal axis in a manner similar to that described in the works of Prof. Weisbach.* The plummet was suspended from a hinged plate below, which, when released, permitted a clear vertical sight with the main telescope. The length of the vertical axis was reduced, owing to its large diameter; but this did not make a well-proportioned lower base, and the instrument never was duplicated.

Fenwick, of Durham, was the first to introduce in England (in 1804) a general system of mine-surveying by observing only the magnetic bearing of the first course. He points out in his work that as mines are now becoming more skillfully and economically developed, a more scientific system of engineering is essential. "The general use of the magnetic needle," he says, "in subterraneous surveys has been found to be a great source of error on account of ferruginous substances, which exist in all mines, attracting the needle; whence, in general, old surveys and plans are found to be extremely defective." For these reasons he suggests that, except in beginning the survey, the use of the needle be abandoned, and declares it much to be regretted that the general use of the compass still prevailed and mapping was conducted on the original diagrams through scores of years without any consideration for secular variation. He further says: "If the student be acquainted with the application of spherical trigonometry to astronomy, he will find the following method of finding the true meridian to be greatly preferable . . . ." But herein lies the secret of the survival of the compass, which could always be relied upon as indicating a relative direction. What did most of such men as were engaged in digging ore from the earth know or care about the sciences, or how to consult and interpret the Ephemeris?

It was lack of education and a want of the means for the diffusion of knowledge, as exemplified in our colleges and institutes of to-day, that made these primitive, simple and unreliable methods so enduring. Fenwick no doubt found his adherents;

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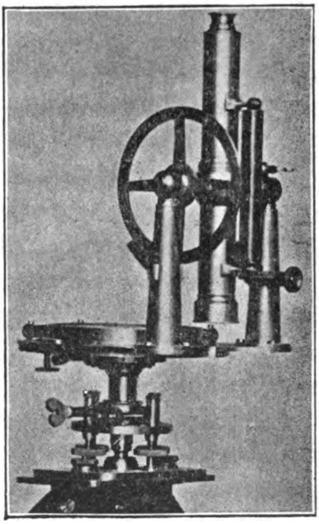
* *Die Neue Markscheidekunst*, J. Weisbach, Braunschweig, 1859.

but in the early part of this century dialing with the needle alone predominated in England, as well as in America, where such engineering as was necessary was performed with some foreign type of dial or hanging-compass.

In recent years the hanging-compass has been re-designed by Queen & Co., of Philadelphia, and is said to be still indispensable to certain surveyors in Virginia and Pennsylvania.* The excuse for employing the hanging-compass in cramped and tortuous channels to-day, however, seems absurd; for the transit can be made to do the most reliable work, even when removed from the tripod, anywhere a man can take it.

FIG. 21.



Draper's Mine-Transit.

The earliest American instruments were descendants, as it were, like the American people, of English ancestry, with an infusion of German and French influences, which have ever since combined with natural American skill to make them the resultant of the most approved appliances and methods.

William J. Young, established in Philadelphia in 1820, introduced the first American type of transit in 1831, probably after that of Ramsden (1803), who introduced the transit principle in small English theodolites at that time. The earliest American engineers objected to the intricacies of the ordinary English theodolite for reasons already stated; but "most of these," says Mr. Young, "who had only local training, could not understand the superiority of vernier-circles over the compass-sights for seeing past or around a tree or other obstruction!"

Young's first transit was graduated to read by vernier inside the compass-box to 3′; the needle was 5 inches long, and the telescope 9 inches long and of low power.

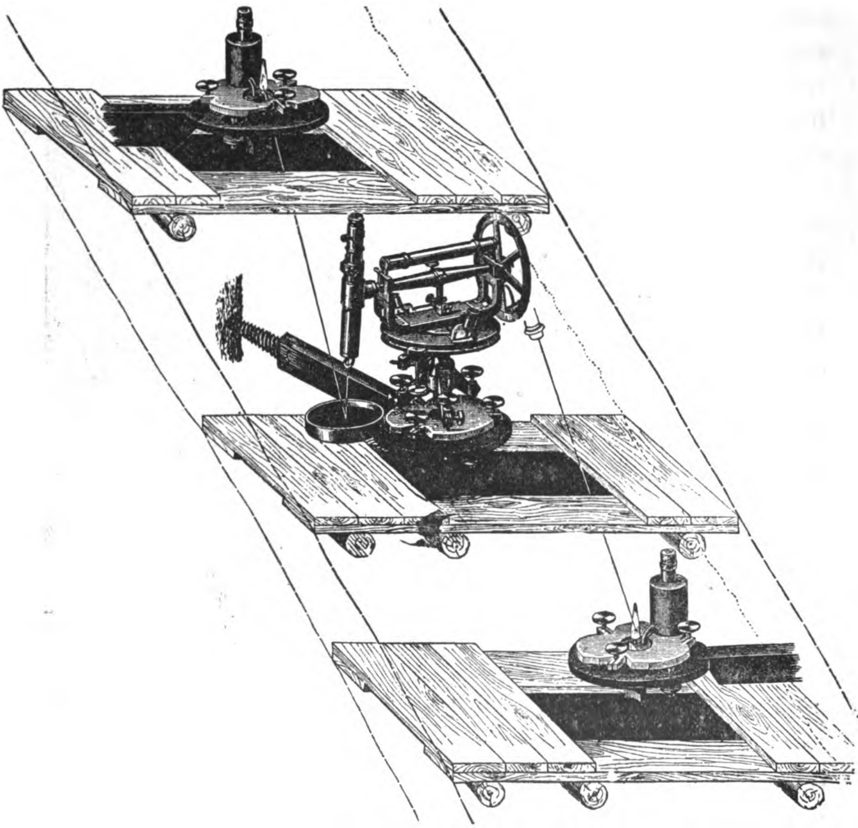
The first distinctive mine-transit that ever appeared in Amer-

* *Eng. and Min. Jour.*, vol. lii., p. 125, Aug. 1, 1891.

ica was introduced by Edmund Draper (established in Philadelphia, 1815), about the year 1850. Fig. 21 is reproduced from a photograph kindly loaned by F. C. Knight, his successor, who says:

"It had full vertical and horizontal circles, each of which was read to minutes by one vernier. The upper horizontal plate was extended somewhat beyond the

FIG. 22.



Borchers' Eccentric Instrument, in an Inclined Shaft. Instrument and Lamps Supported on "Freiberg Brackets."

compass-box, ending in two piers that supported the pillars of the telescope. The open space between them permitted true vertical sights or the observation of any angle between the horizon and nadir, without any correction for eccentricity beyond the mere mechanical addition of the telescope's distance from the instrument's center to the base component. The telescope's power was 16 diameters."

Considering the times, the design of this pioneer instrument is both original and praiseworthy, and in some respects is superior to the eccentric model of Prof. E. Borchers (Fig. 22), which he introduced in 1835 for special surveys in inclined shafts. Zenith instruments in Germany had for some time previously been constructed with eccentric telescopes, but had never before this date been used in mines. In his work on mine-surveying* Borchers says that while the ordinary theodolite (since 1832) has been employed for most mine-work, this instrument is most convenient for inclined shafts, though not intended for magnetic observations.

The first instrument of this kind was made for him by Breithaupt. Both circles were 16 cm. in diameter and graduated to read 20″. The hub of the telescope was rigidly attached to a flattened extension of the horizontal axis by four screws, and the optical axis was made to be exactly at right angles to the axis of revolution by lateral movement of the small cylinder that contained the eye-piece and diaphragm. The intersection of the cross-hairs was then made to coincide with the optical axis thus established, independently, by the usual methods.

He used an artificial horizon in taking steep upward sights to an 84° limit, and recommends it as being convenient and portable, but his enthusiasm never became contagious. Observations were made first on one side, then on the other; a mean was deduced, and the true inclination was calculated, without any correction for eccentricity, which in the longest courses amounts to only two or three seconds. One of the most interesting features about this instrument is the mountings, known since the improvement of Prof. Dr. Schmidt, in 1882, as the "Freiberg brackets," upon which the instrument and signal-lamps rest without being clamped. They have taken the place of the tripod to a considerable extent in Germany, for, without much effort, they can be screwed into the timbering and perform duty in low places where tripods could not be set up. The stand had been made of wood until 1885, when wood was exchanged for metal that would not wear.

In that year Prof. Chrismàr, of the Schemnitz School of Mines, introduced a support consisting of two hollow wrought-iron pipes, with steel teeth at the outer ends, and sliding one within

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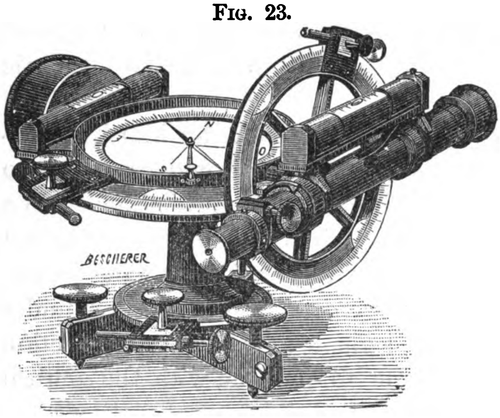
* *Die Praktische Markscheidekunst*, E. Borchers, Hanover, 1870, p. 131.

the other, in such a way that they could be firmly clamped between drift-timbers at distances varying from three to seven feet, and not interfere with the passage of tram-cars or trucks. The theodolite-stand was then clamped to the center, making a combined weight of sixteen pounds.

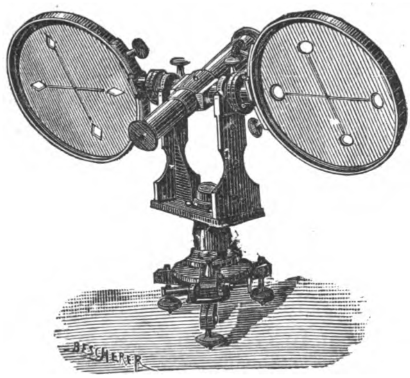
This was similar to the support of Kawerau (1862), whose staves slid vertically side by side, being clamped by girders. To this the bracket was attached, and arranged to move by jointed arms in three directions to facilitate centering.

FIG. 23.



Combes's Theodolite, with Eccentric Signal Targets.

FIG. 23A.



In 1845 Prof. C. Combes, of the Paris School of Mines, introduced in France a modification of the eccentric theodolite which has been in general use there ever since, until in late years it is being replaced by the concentric telescope; for however well this or any other such instrument may be constructed, the number of parts and the eccentricity of the telescope, which must be counterbalanced by a weight, are permanent causes of derangement. Fig. 23 shows a 16 cm. circle, modernized pattern, built by H. Morin, of Paris; but "the original," says M. André Pelletan, "had no compass, but a large horizontal circle graduated to read 30″, surmounted by a delicate striding level, as in Borchers' theodolite." This style of mounting the telescope prostrate upon the vertical circle was first practised by Prof. Morin, of Paris, in 1634, when he attached a telescope to the movable index of a graduated arc for the purpose of measuring the diameter of fixed stars.

It is customary in Germany, France and other foreign countries to use with the eccentric theodolite a twin target, which operates interchangeably with the instrument. It is called *Doppelsignal* by the Germans and *viseur de mine* by the French, and is so constructed that each target is as far removed from the center of the signal as the telescope is from the center of the instrument. This provides against any necessity for correction in reading horizontal angles, whether the telescope is used on one side or the other, normally or reversed. In setting it up, upon its own tripod, the assistant, after leveling it by means of the box-bubble between the standards, directs the sighting-tube at a light held at the instrument.

Combes's instrument, as well as all others in France, at the option of the engineer, is graduated by the sexagesimal system common in America and most European countries, or by the centesimal system, in which each quadrant contains 100 grades (as adopted in 1801 at the suggestion of Laplace when the metric system of weights and measures was proclaimed legal and compulsory).

The division of the circle into 400 degrees for compasses and mine theodolites is still of doubtful benefit, as the minute spaces are made to correspond to only 32.4 sexagesimal seconds, while the centesimal seconds are so diminutive as to be practically impossible in small circles.

A want of uniformity in denominate nomenclature also tends to retard its progress. The logarithmic tables of Borda (1801), Plauzolis (1809), Gauss (1873), and Gravelius (1891), are all at variance in this respect; but the proposal of Prof. S. Jordan in 1891 to write, for instance, 24^{g} 86^{c} 50^{cc}, seems to deserve general adoption.

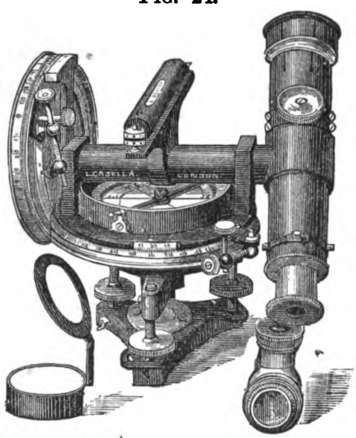
In America the decimal system of graduation was introduced by S. W. Mifflin, C.E., for construction-work on the Pennsylvania Railroad, after the methods of M. Minot, engineer for the Orleans Railroad, who in 1856 popularized in France that system of railroad engineering known as tacheometry.

For about thirty years, Young has made transits in which one vernier reads the sexagesimal circle in sixtieths, etc., and the opposite one in tenths and hundreds; but except, perhaps, for railroad work, in which the tangential deflection of curves can be laid out with facility, the French system of graduation has never met in America the favor accorded to the metric system of weights and measures.

While considering the eccentric type of mine-theodolite, it may be well to notice here, though not in exact chronological order, its introduction and application in England.

In 1869 Louis Casella, of London, introduced a small portable instrument for Alpine and military surveying (Fig. 24), by which good results have been obtained, not only in the determination of astronomical time and latitude, but in shaft-work in the British mines.

FIG. 24.



Casella's Portable Theodolite.

Its circles are only 3-inch, graduated to read minutes, the vertical circle being placed opposite the telescope, to aid somewhat in making the equipoise perfect. It is mounted upon the tribrach locking-plate, introduced by Everest with his theodolite in 1837, and since possessed of greater popularity than his instrument. This miniature theodolite, weighing only $3\frac{1}{2}$ pounds, with the pocket mine-theodolite of Breithaupt (1869) with 8 cm. circle, having a total weight of 1.7 kg., and the aluminum mine-transit of Keuffel & Esser, weighing only 2.1 kg., are about the smallest instruments we have to deal with. The only strong argument in their favor is their portability, but efficiency ought not to be sacrificed in this way for a novelty.

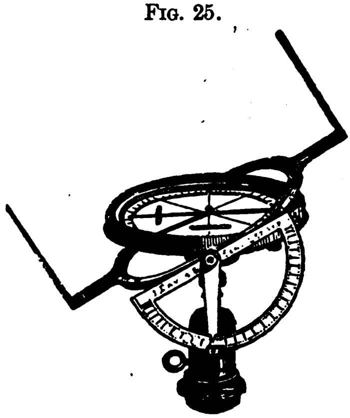
J. Winspear, of Hull, in 1870, made an eccentric instrument for Hoskold, to which was given the distinctive name of *Angleometer*. It differed from Casella's model in that the compass-box was raised somewhat above the horizontal plates so that the axis, connecting the telescope on one side with the vertical circle on the other, should pass between. The long axial bubble being then placed on the side nearest the vertical circle, the compass was left perfectly unobstructed, as we find it in Prof. Combes's model. Combes's theodolite was the lowest form, because, in placing both telescope and vertical circle on one side, it had no need of a horizontal axis.

The *Angleometer* received an award at the London Exhibition of 1872, where there was also displayed with it a plain compass-dial, with plain sights on one side and semicircle opposite.

The use of the eccentric telescope has by no means become general in mine-surveying in England, but important and very satisfactory work has been conducted with it. Horizontal angles are usually repeated, first on one side, then on the other, to obtain a mean reading; but if only on one side, in platting, a small circle is drawn to scale about the station equal in radius to the eccentricity of the telescope, and the courses laid out tangentially to this by use of the English system of platting with the parallel ruler.

Within the present century greater improvements in mine-surveying methods and the instruments used in conducting them have been achieved than in all the previous history of the world; but by far the greater share of this century's progress has occurred during the past fifty years. A hundred years ago an engineer could err occasionally with good and sufficient reason. To-day there is absolutely no excuse for anything but perfect results.

FIG. 25.



Hedley's Dial.

America and Germany have been perhaps more largely instrumental in perfecting the apparatus used in mine-surveying in this period than England, though the latter is entitled to a just share of credit in an endeavor to perfect the construction of the dial or circumferenter, so as to obviate the necessity of using the more expensive theodolite.

In 1850 John Hedley, H. M. Inspector of Mines, being convinced of the inconvenience of the vertical arc on Lean's dial in obstructing frequently a clear reading of the needle, caused John Davis, of Derby, to construct an improved model (Fig. 25). Its principal feature was the swinging limb, by which vertical sights up to about 50° could be observed and read upon the index of the vertical arc at the side, leaving the face of the compass quite unobstructed. With the Hedley dial, the miners' chain of 10 fathoms or 120 links still continued to be the means of linear measurement, and gave the early surveyor nearly as much trouble in attempting to correct for its cumulative and compensating errors as for the vagaries of his needle. It was (and is still) made with the ten end-links of brass,* and when used for measuring is laid on the floor and each chain-length marked with a piece of chalk, the entire course being represented by so many fathoms, feet and inches.

In chaining up slopes the plumb-line was still used, as on the surface. This is the very earliest method of conducting measurements on inclined planes, and gave rise to the practice, yet widely followed in Europe, of conducting surveys in inclined shafts by successive plumbing and leveling. The several lengths of the plumb-line are recorded as the vertical components, and the several distances from the base of one plumb to the point of suspension of the next make up the horizontal aggregate.

In France and Germany special appliances have been made to perform this work. That of Mr. O. Cséti, of Hungary, is no doubt the most recent.† Briefly, it is a small leveling telescope fastened by a sliding and clamping collar to a hollow square rod of 0.67-inch section and 5 feet long, that may be suspended from any station. From the top downward the rod is graduated to cm., while the vernier on the sliding collar determines vertical distances with great precision. Lengthening-bars are also supplied. Its total weight is 5 kg.

While speaking of the English chain, it must be noted here that the chain of Rittenhouse, which comprised 80 links or 66 feet, was quite generally used in American mines until Eckley B. Coxe and others started a reformation, some twenty-five years ago, in favor of the steel band that has now practically consigned the chain to President Cleveland's "innocuous desuetude." In 1874 Dr. R. W. Raymond said: "While so much improvement in recent years has been made in mine-instruments, the chain remains unaltered. Nothing can be inherently more objectionable, as a standard of measurement, than a chain composed of links that wear by friction,"‡ and, we may add, connecting-rings that elongate by tension.

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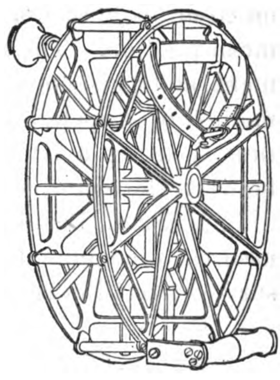
* *Colliery Management*, J. Hyslop, Wishaw, 1870, p. 23.

† *Berg- und Hüttenm. Zeitung*, vol. liv., p. 391, Nov. 8, 1895. ‡ *Trans.*, ii., 224.

In the first American steel tapes the points of graduation were marked by impressed figures on white solder, or by small brass rivets; but etched graduations and figures now predominate. The 500-foot tape used by the writer is one made by Keuffel & Esser, of New York, and exhibited by them at the World's Fair. It is $\frac{2}{10}$ of an inch wide, graduated at every foot throughout its entire length, and wound on a gun-metal reel, the convenience of which will appear obvious by inspection of the illustration, Fig. 26.

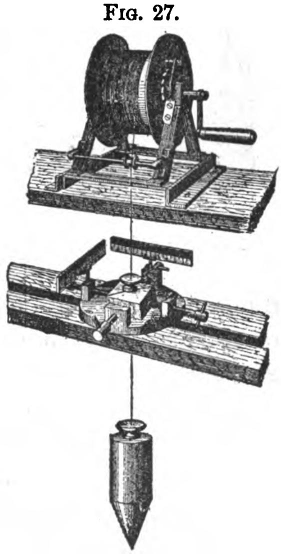
FIG. 26.



Skeleton Reel for Long Mine-Tapes.

With the Hedley dial went the continuance of the practice of connecting the surface- and underground-surveys by magnetic observations, which operation was greatly facilitated by its rocking limb. In 1856, however, Arthur Beanlands, C.E., undertook a purely astronomical method of accomplishing this result by use of the theodolite alone; but the observation of stars from the bottom of a vertical shaft was attended with such difficulty that he projected an alignment, first from above, then from below, by the use of lights, with excellent results.*

FIG. 27.



Schmidt's Centering Apparatus.

Thirteen years before, Thomas Baker, C.E., had suggested and used a method (held in derision by colliery-surveyors at that time) of suspending from a straightedge two fine copper wires by heavy weights in mercury, and completing the survey with the theodolite and interchangeable tripods and targets.†

The accuracy of this method has always been somewhat impaired by the extremely short base from which to work, and the inevitable

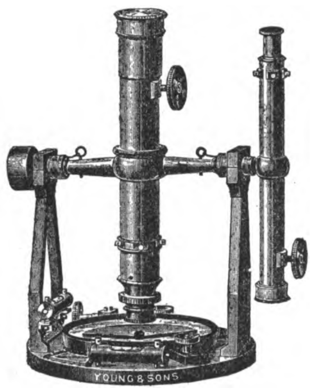
* *Trans. North Eng. Inst. M. E.*, vol. iv., p. 267.

† *Subterraneous Surveying*, Fenwick and Baker, 1888, p. 40.

oscillation in the wire; but the centering-apparatus of Prof. Dr. Schmidt (1884), Fig. 27, has regulated the method to a nicety. The vibrations are carefully measured by repeated observation on co-ordinate scales, and the wires are finally clamped in exact mean position. The instrument is then ranged into their alignment, and presents a means only less accurate than the later method of suspending one wire in each of two vertical shafts, thus securing a length of base limited only by the distance between the shafts.*

In England, Beanlands is usually credited with having first used the theodolite to connect the underground and surface-surveys; but Bourne's method of 1843 and Borchers' of 1835 certainly are entitled to precedence. In fact, we may nearly always look to Germany for the beginning of all important steps in the advancement of mining engineering.

FIG. 28.



Early American Method of Mounting Side-Auxiliary.

The eccentric telescope of Borchers was found so convenient for the purposes intended that it was employed by American engineers as a side-auxiliary, which could be attached to concentric instruments at will, and removed when not in use. The first American types were of simple construction. The horizontal axis of the main telescope was perforated with a hole large enough to permit a spindle, conjugate with the hub of the auxiliary, to be inserted and held fast by pins (see Fig. 28), such as are used in the Y's of a level.

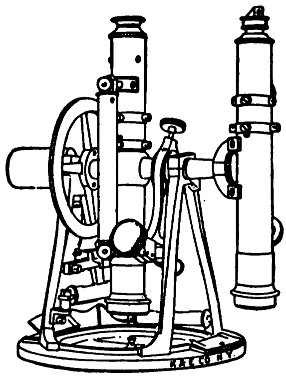
Adams, in his *Geometrical and Graphical Essays* of 1791, says: "In the present state of science it may be laid down as a maxim that every instrument should be so contrived that the observer may examine and rectify the principal parts; for however careful the maker may be, it is not possible that any instrument should long remain accurately fixed as it came from the manufacturer." But we find in these first forms (see, for instance, Fig. 29) no means of testing the adjustment of the side-auxiliary; and the startling fact must be recorded that,

* *Methoden der Unterirdischen Orientirung*, M. Schmidt, Berlin, 1892.

almost up to the present time, the adjustment of all auxiliary telescopes has had to be assumed as correct upon the guarantee of the maker, at the risk of their working loose on their bearings.

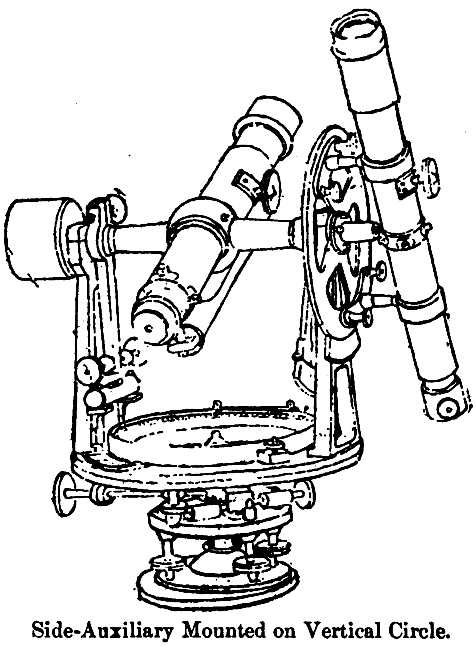
When side-auxiliary telescopes first came into use in America, new instruments were always equipped in the manner just described; but when engineers who had been using simple concentric instruments caught the contagion, they sent their transits to the factory to receive this valuable adjunct. In such cases it was customary with the house of Young to mount the side-telescope upon the vertical circle by means of set-screws and clamping-plates, in the manner shown in Fig. 30. In the event that the instrument had not been provided

FIG. 29.



Keuffel & Esser's Concentric Instrument, with Side-Auxiliary.

FIG. 30.



Side-Auxiliary Mounted on Vertical Circle.

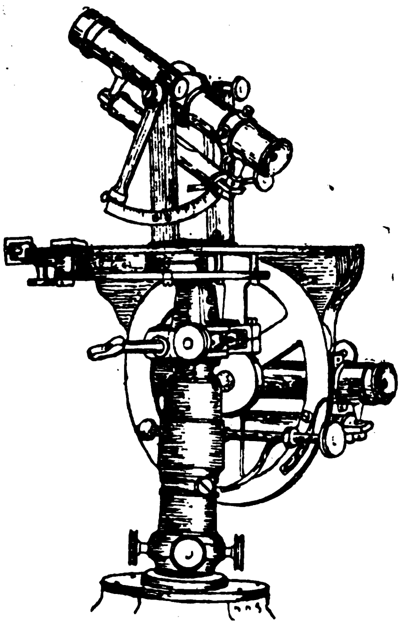
originally with a full vertical circle, one was permanently attached to an improvised prolongation of the horizontal axis.

The adjustment of such an appliance was no easier that when it was mounted on a spindle, but the method presented the advantage of holding the auxiliary more firmly in the position in which it was placed.

The shifting tripod-head, shown in Fig. 30, was made by Young in 1858, and has been ever since a most valuable convenience to mining engineers.

As the German method of mounting eccentric telescopes had its influence upon the early manufacture of American side-auxiliaries, so also we may notice the effect of the French types in the model (now obsolete) presented in Fig. 31, which was known as the "Lake Superior" pattern, and used in 1858, when the copper-mines of that region first became valuable.

Fig. 31.



Lake Superior Pattern.

The upper plates were not unlike those of an ordinary transit.

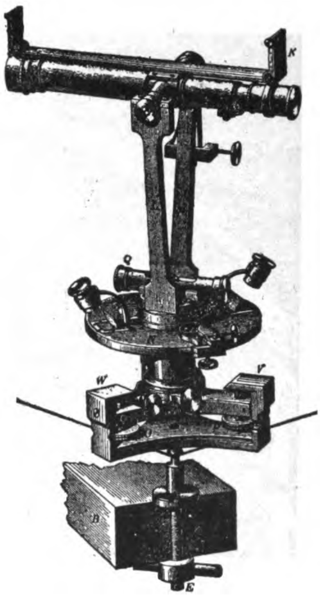
The smaller upper telescope was intended only for general work, and provided simply with a short 60°-arc and loose vernier-arm, as first made by Young in 1850.

This style of vernier may be clamped in any position, and by repetition made to read any angle up to 90°. The vertical plate was similar in shape to the horizontal, to which it was attached. It was always at hand for vertical observations, but its additional weight, its exposed position and delicate construction, conspired to insure the rejection of this instrument in favor of the regular concentric types.

In the meantime, some progress had been made in Germany with a view to supplement, at least, the hanging-compass with such instruments as could be made to verify it, and even to supplant it. In 1861 Prof. Junge, of Freiberg, invented his *Goniometer** (Fig. 32).

The inventor apologetically announces: "This instrument will be found a great convenience for use with compasses in mines, if, however, it shall not furnish some means of attraction;" but being himself convinced of its superiority, he recounts among its advantages: First. All that can be accomplished by use of a compass can be determined by the goniometer. Second. It can be used anywhere in the mine, and even to great advantage in inclined shafts, if the conditions are not too cramped. Third. The accuracy in reading angles is more pronounced, and gross errors cannot be committed, etc.

FIG. 32.



Junge's Goniometer.

The horizontal circle was small, as compared with the height of the standards, and graduated to read minutes of arc. The instrument had no vertical circle, as the old method of cords and suspended clinometer was adhered to, with the early mode of setting up instruments of this class. A plank was wedged between the walls, and a hole bored in which to set and clamp the spindle of the instrument, as illustrated more fully in Fig. 33. This system was first used and taught by Prof. Lang von Hanstadt, of the Schemnitz Bergakademie in Austria, as early as 1835,† and was subsequently recommended by Prof. Weisbach in 1859. In this modern system here portrayed, the instrument and targets are of equal height, and are made interchangeable in the 3-legged base by opening the set-screw at the side. In this way the target may be removed, the conical spindle of the instrument set into the socket, and the tangent-screw of the azimuth-axis fitted to work upon the pin shown protruding from the right leg. This system of set-

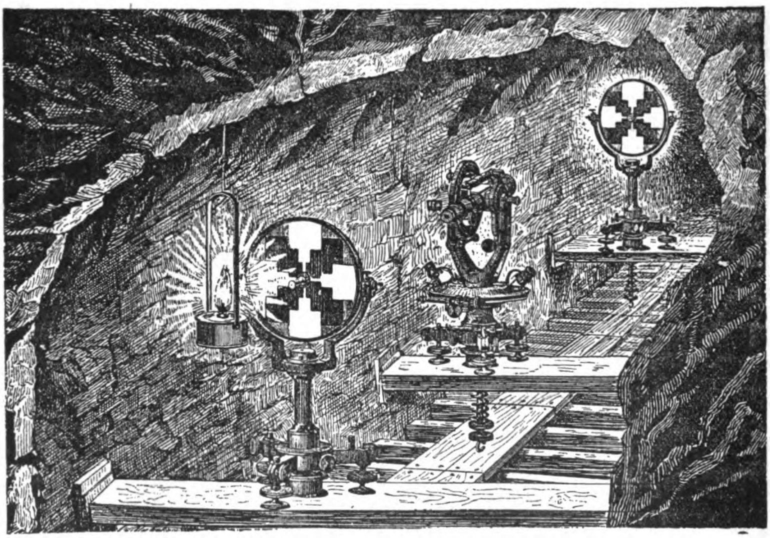
* *Die Geometrischen Instrumente*, C. G. K. Hunäus, Hannover, 1864.

† *Anleitung zur Markscheidekunst*, J. N. L. von Hanstadt, Pesth, 1835.

ting-up is not so complicated, delicate or expensive as the Freiberg brackets, but takes a little more time to secure, and cannot be used in large openings, any more than the other can be used in rock-tunnels where there is no timbering.

The telescope of Junge's goniometer revolved completely in its standards, and could be made to sight objects downward in declivities unusual with most theodolites. If steep upward sights were necessary, the eye-piece prism was used and attached to the ocular by means of a spring-clamp. The tele-

FIG. 33.



Breithaupt's Modern Mine-Theodolite with interchangeable Targets and the *Spreitzen* system of setting-up.

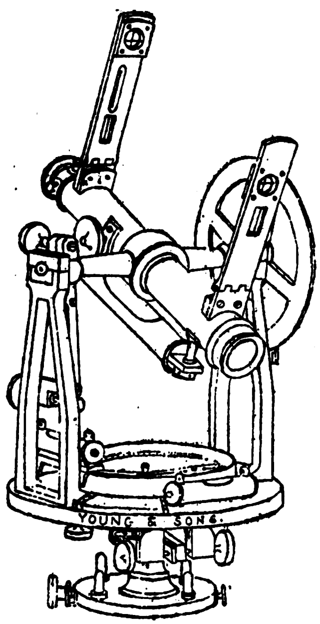
scope was provided with two diopters for ranging it into line, though for universal observation these preceded the telescope and must be looked upon as the forerunners of extended sights.

The origin of sight-vanes must be sought in the very earliest times, and, as applied to mine-surveying, in the first instruments ever used. When they had outgrown their usefulness as principal factors, they were used in conjunction with the telescope, first to assist in directing it upon an object, and later, being lengthened and provided with windows, to make observations in dips that approached verticality. When and by whom they were first used for this purpose the writer is now unable to say; but the instrument shown in Fig. 34 was built by Young at an early date and shipped to Mexico. The tripod upon which it was mounted was one of America's first adjustable-leg forms, and was very heavy and awkward.

Diopters and extended sights had been used for observing very near objects that came within the focus of old-time telescopes; but their later application for vertical sighting gave rise in America, no doubt, to the top-auxiliary telescope.

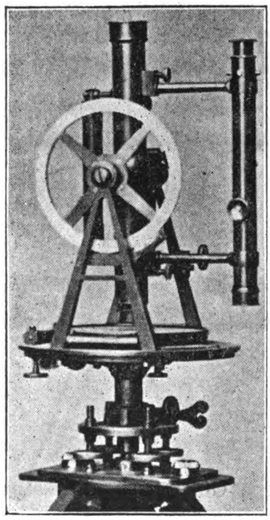
The available evidence concerning the invention and intro-

Fig. 34.



Instrument with Sight-Vanes.

Fig. 35.



Draper's Top-Auxiliary.

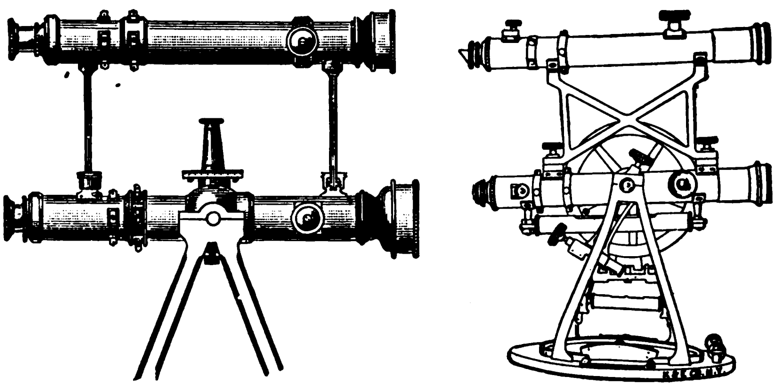
duction of the top-auxiliary telescope is not conclusive, but Knight says that Draper was probably the first to introduce it in 1840. The instrument shown in Fig. 35 is easily identified as Draper's by the peculiar style of tripod-head. The base-plate of the instrument is set upon two threaded spindles projecting from the tripod-head, and held in position by two milled nuts.

Gurley's first top-telescopes (Fig. 36) were attached to the main by coupling-nuts and "steady-pins" which provided for their ready removal and replacement. Until very recent years these have been made by all American makers in styles similar to the first model, with no means of effecting adjustment for parallelism and alignment beyond the guarantee of the maker, which, in the best makes, could not be relied upon as permanent.

So far as the writer knows, no very serious errors of execution have been recorded during the fifty years' use of the non-adjustable auxiliary, though there has always been room for such error in the fact that it was hardly possible to place the instrument a second time in the exact position it had once occupied.

The growing sentiment among American engineers in favor of instrumental construction permitting accurate adjustment led

Fig. 36.



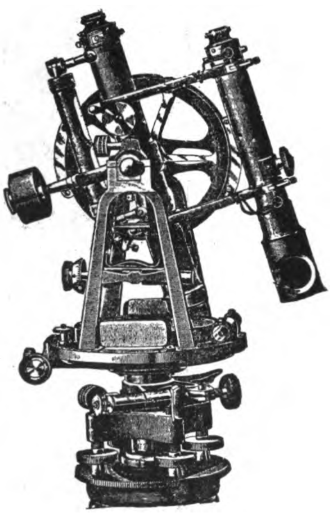
Gurley's Top-Telescope. A German Improvement.

Per Larsson, E.M., then at Vulcan, Mich., to begin in 1882 a reconstruction of the top-telescope by providing at least that it should be capable of most of the adjustments of a level, by placing it in Y's that were permanently fixed to the main telescope. Such an instrument was made for him by Buff & Berger, of Boston, and was then justly considered very complete, inasmuch as the line of collimation of the top-telescope could be adjusted independently by rotation in its Y's. The adjustment for parallelism, however, was too complex an operation to be undertaken outside the factory.

In the later models the Y's were put on top, so as to be partly balanced by the long bubble beneath; but in Mr. Larsson's instrument they were put under the telescope, so as to be out of harm's way, and worked very satisfactorily. The later model shown in Fig. 37 is provided with the gradientor-screw, as applied by Prof. Stampfer, of Vienna, in 1873, to the tangent movement of the horizontal axis of transit-instruments. As employed in the rapid determination of distances it was first used by him in 1839, and mentioned in his work of that year.*

The silvered head, appearing in Figs. 37 and 38, is graduated into 50 parts, and the screw is cut with such a value as to cause the horizontal web of the telescope to move, for each graduation of the head, over a space of .01 foot upon a rod 100 feet from the focal center of the telescope. In mine-instruments this arrangement is very convenient, light and efficient for the establishment of water-courses, contours, etc.

FIG. 37.



Larsson's Top-Telescope.

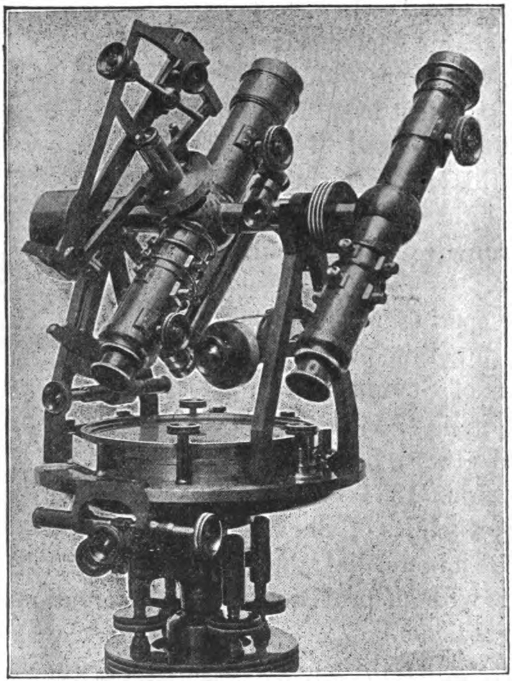
In Europe special instruments are constructed for this purpose; the *Distanzmesser* of Stampfer, the gradiometer of Stanley, and Short's telemeter-level (1889), being notable examples. Since 1894 Casella has applied the principles of Short's telemeter to the miners' dial; but the instrument is without provision for the observation of anything but gentle gradients.

Somewhat earlier, the manner of attaching the side-telescope was also improved. The transverse axis of the main telescope was extended to end in a threaded hub, upon which the side-auxiliary was screwed with a coupling-nut, very similar to the Gurley method of securing the top-telescope, and, we may say, attended with very nearly the same difficulties. After attaching it loosely, and revolving the auxiliary by hand until its horizontal-wire should cut the same point with the main telescope, it was a matter of some perplexity to tighten the hub while it remained in this position, and a matter of speculation

* *Elemente der Vermessungskunde*, C. M. Bauernfeind, München, (1856 to) 1890, pp. 417, 422.

whether it would long remain that way. Fig. 38 shows an admirable feature in what are known as "disappearing stadia." These were invented in 1880 by Hon. Verplanck Colvin, Superintendent of the New York State Survey, to overcome the liability of error in leveling with the wrong hair. He caused Gurley to put the stadia-hairs upon a separate diaphragm, so as to be entirely out of focus when not in use. They are very

FIG. 38.



A Modern Gurley Mine-Transit with Solar Attachment and "Disappearing Stadia."

desirable in all instruments, and particularly so in mine-transits, where so much depends upon correct vertical angles. As early as 1865, B. S. Lyman used glass stadia-rods in the coal-mines of Pennsylvania to avoid chaining through mud.* They might have been used, however, in Europe at a much earlier date by engineers who chose to employ such aids.

In 1778 William Green, a London optician, published an

* *Jour. Frankl. Inst.*, 3d series, vol. lv., 1868, p. 384.

account of the possibilities of "subtense measurement" with either fixed or adjustable micrometer-lines in the focus of the eye-piece. Possibly he got his ideas indirectly from William Gascoign, of Yorkshire, who is said to have devised in 1639 a micrometer for astronomical instruments consisting of two pointers traveling by screw-threads in opposite directions.

No practical use, however, was made of these discoveries until 1824, when Major M. Porro, of the Piedmontese Army Engineers, designed the topographometric instrument with anallactic telescope, which he named the "Cleps." Its first notable application was in the topographical survey of Switzerland in 1836. It is now largely used for military reconnaissances in Germany, being supplied by A. Salmoiraghi, of Milan.

Prof. Baker says: "Stadia-hairs were not introduced in America until after the Civil War, and have not yet come into the general use their merits warrant."*

One other distinctive feature of the Gurley instrument here considered is the solar attachment. This is essentially a Burt solar, but was remodeled by William Schmoltz, of San Francisco, in 1867, and has been mounted since 1874 upon the hub of the main telescope, with trivet-adjustment to secure the verticality of the polar axis. The polar axis-spindle, with hour-circle, is permanently fixed, as shown in Fig. 38, to the main telescope, to which the solar is attached at will, and upon which it revolves, precluding the use of anything but a semicircular vertical arc, which, for the purpose of laying off latitude, is ample.

The original solar compass was invented in 1836 by William A. Burt, of Michigan, as the result of an effort to overcome the annoying defects of the magnetic needle. It was first made for him by Young, and mounted upon a simple ball-and-socket base without tangent-screws. Concerning it Prof. Baker says: "It was a very ingenious instrument, and while, at the time, it deserved the popularity it attained, it now reflects more credit upon the inventor than the one who uses it, as it possesses possibilities of error." But Capt. Talcott, in a letter to Mr. Burt, testified that, in running the boundary-line between Iowa and Minnesota, he could not detect in the line it

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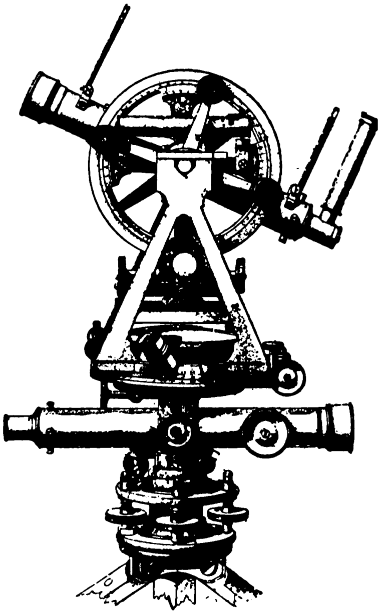
* *Engineers' Surveying Instruments*, Ira O. Baker.

established any variance with the most careful astronomical observations.

Its operation is always more perfect in clear weather; on dark or cloudy days it is impracticable, and when the sun is partly obscured its image is indistinct, leaving room for doubt. In 1878 C. L. Berger proposed a remedy by substituting for the lens-bar a small telescope of low power, but G. N. Saegmuller first made this practical in his excellent invention of 1881, considered on page 729.

FIG. 39.



Hoskold's Miners' Transit-Theodolite.

In the meantime English engineers and mathematical opticians had made such progress as the exigencies demanded and the limitations permitted. In 1857, John Archbutt & Sons, of London, had built for H. D. Hoskold an instrument* (Fig. 39) constructed upon principles prevalent in American types, which are at this day fast superseding the older English models.

In this instrument the upper plates, carrying the standards and compass, were made to project somewhat beyond the horizontal limb, permitting the use of a $4\frac{1}{2}$-inch needle with a 5-inch circle.† The full vertical circle was provided with three vernier arms, and the horizontal graduations were beveled and unprotected; a practice still common in England, but rare in America. The verifying telescope had been in use in the latter half of the last century to insure the stability of astronomical transit instruments, but Hoskold was first to use it with a mine-transit. It had been mounted in small bearings clamped to the

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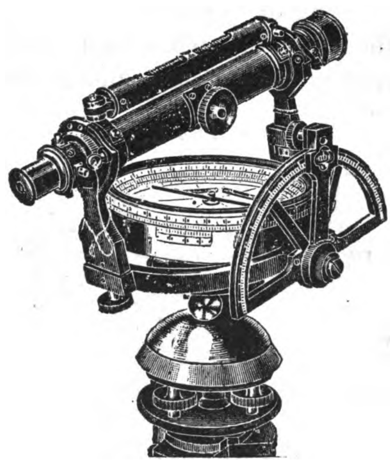
* *Practical Treatise on Mine, Land and Railway Surveying*, H. D. Hoskold, London, 1863; also, *Trans. So. Wales Min. Engrs.*, vol. iv., No. 5, 1865.

† *Prac. Treat. on M., L. and Ry. Surveying*, H. D. Hoskold, London, 1863; also *Trans. So. Wales Mining Engrs.*, vol. iv., No. 5, 1865; also *A Treat. on Mine Sur.*, B. H. Brough, London, 1888.

side of the vertical axis until 1863, when he invented the means of mounting it concentrically, directly under the center of the plates, so that its optical axis should coincide with the zero-line of the horizontal plates. In this way it has been conveniently used for back-sights without stopping at each observation to clamp the zero of the vernier to the zero of the limb. The compound spindles being thus replaced by the verifying telescope, the azimuth axis is inverted between the standards and the vertical axis placed below. An instrument of this kind with two vertical arcs and striding compass was exhibited in the British section at the Columbian Exposition in 1893.

In 1874, two years after the passage of the Mines Act, which regulated, among other things, correct mine-mapping, Stanley, at the suggestion of Mr. W. Preece, mounted a telescope in Y's upon the Hedley dial. The swinging limb still carried the vertical arc, now in an upright position, so as not to interfere with the leveling-screws, and could be inclined to observe angles of depression as great as 55° before the tripod-head interfered. Such angles were determined to the nearest degree only, by a simple index.

FIG. 40.



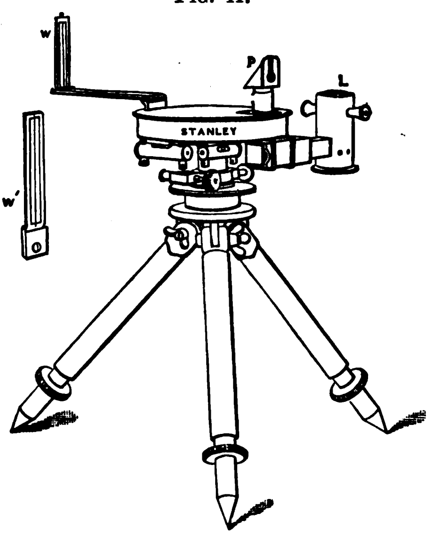
Telescopic Hedley Dial.

The horizontal circles, however, were graduated to read to 3′, and the 4½-inch needle to ¼°. The eye-piece was inverting, and the telescope had a power of 10 diameters. The instrument shown in Fig. 40, which possibly represents the highest modern refinement in English circumferenters, is provided with the Hoffman quick-leveling head, as modified and improved by Prof. J. H. Harden of the University of Pennsylvania in 1879.* It was first invented and patented in 1878 by Daniel Hoffman, of Pottsville, Pa., and was justly considered an improvement over the designs of Pastorelli (1863) and of Doering (1864).

* *Trans.*, vii., 308.

Davis of Derby introduced in 1882 a modification of this improved Hedley dial, in which he made the vertical arc to be replaced by a fixed circular box only 1¾ inches in diameter, with an index-finger traversing the graduated disk. It is necessarily divided very coarsely and made thus compact so as not to interfere with the easy manipulation of the leveling-screws. Its peculiar construction makes it possible to swing the limb in altitude only about 15° each way. Prof. Brough says this is the best instrument for colliery use, and we can only infer that vertical angles must be of little consequence to the English engineer generally. Certain English engineers are also still doubtful about the beneficial use of the telescope in conjunction with the compass for mine-surveying, seeming to agree with Gillespie,* who says "the exactness of the vision of a telescope is rendered nugatory by want of accuracy in the compass and the precision possible in reading the needle," and does not therefore consider it an improvement over the common sights for the ordinary execution of magnetic surveys.

FIG. 41.



Prismatic Compass-Dial.

As late as 1882 Stanley built a prismatic-compass dial (Fig. 41) to conduct surveys in a 30-inch coal-seam. The original prismatic compass was invented by Capt. Henry Cater, about 1814, but this adaptation of it for mine-work is unique. Where space in height is cramped the needle is read from the side. The 5-inch compass has attached to the needle a floating disk of celluloid, upon which the magnetic bearings are read to the nearest ¼° simultaneously with the observation through the sights.

The illumination is effected by prismatic reflection of light

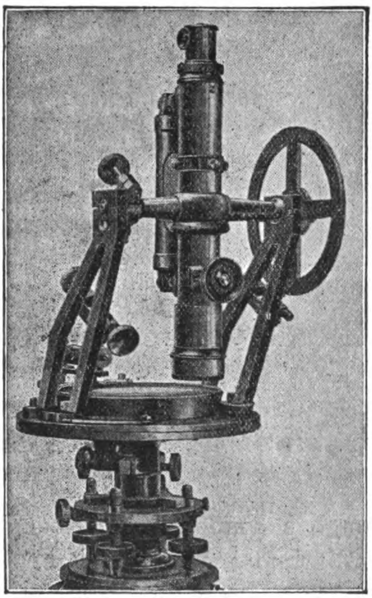
* *Treatise on Land Surveying*, W. M. Gillespie, N. Y., 1856.

from the lamp L, as in the ship's compass. The combined weight of instrument and tripod is 8 pounds. The cylindrical tripod-legs contain screw-threads, which are used for leveling the instrument. This device was patented, but never became popular.

The telescope, no doubt, came into use with the more widespread application of "fast-needle" dialing, as originally employed by Fenwick in England.

The magnetic bearing of the first course alone is observed, and that of all succeeding courses is computed from azimuth survey by use of the vernier-plates. It is then platted by calculated tangents, or by what is considered in England the most reliable of all methods—the use of co-ordinates of latitude and departure deduced from the traverse-tables.* This is a very old practice. In 1791 John Gale published traverse-tables in London, but they had been used from personal manuscript as early as 1635, by Norwood, in the conduct of surveys between York and London.

FIG. 42.



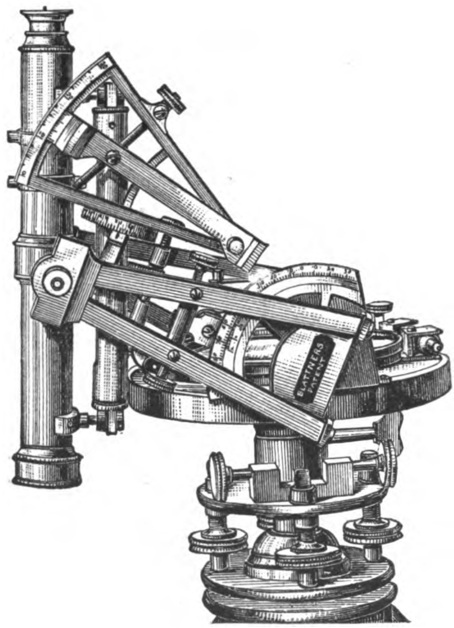
Transit with Inclined Standards.

Returning to the discussion on the Burt solar, it must be observed here that this instrument came into extensive use on Government surveys in the subdivision of public lands. It occasionally took the place of the compass on the ordinary transit; but the revolution of the telescope, and the shadow it cast, interfered somewhat with successful operation. To overcome this difficulty F. R. Seibert, then connected with the U. S. Coast Survey, designed a transit in which the standards were inclined forward, throwing the hub of the telescope just over the edge

* *Mine Surveys*, F. J. Franklands, London, 1882.

of the plates, in a position to leave the solar open without obstruction to the rays of the sun. This instrument was made for him by Young, and was exhibited at the Centennial Exhibition in 1876. For several reasons, however, it was not a success for the purposes intended; but in 1874, at the suggestion of T. S. McNair, of Hazleton, Pa., it was converted into a mining-transit (Fig. 42), which, as such, possessed some interesting features. It was capable of perfect adjustment, and fulfilled in a measure, as did Draper's instrument, the functions of both main and top-telescope. Its construction did not interfere with the direct and perfect reading of horizontal angles,

FIG. 43.



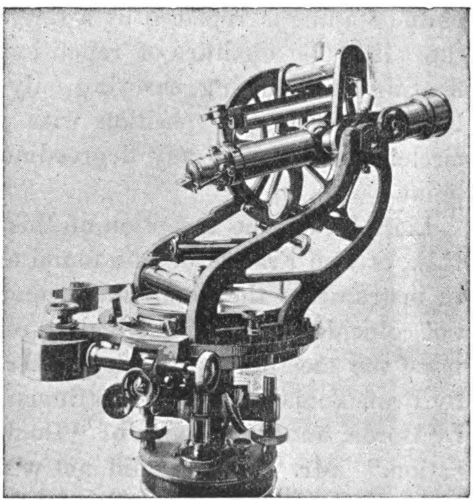
Blattner's "Hinged Standards."

though a counterweight was always required to preserve the equilibrium necessary in the best instrumental construction. The eye-prism is detachable at will. It is inserted between the two lenses of the ocular, forming an image that becomes erect with respect to altitude, but reversed in azimuth. Except by the use of a diagonal eye-piece, a steep angle of elevation can be observed only in a reversed position of the telescope; but its one disadvantage lies in the fact that in the prolongation of an inclined shaft-alignment it cannot be checked by reversed sights. In such cases one must rely solely upon the perfect adjustment of the instrument.

In 1883, Henry Blattner, of St. Louis, Mo., undertook to overcome this objection by introducing what have since been commonly known as Blattner's "hinged standards" (Fig. 43), though they were not hinged at all. "The vertical arc was of an entirely new pattern," he says, "built very strongly, so as to support the standards in any position of inclination by a clamp and opposing tangent-screws." The solar was mounted upon a pin protruding from the standards in such a manner that the latitude could be laid off on the vertical arc and the telescope permitted to move in altitude independently of the solar. In Blattner's first mineral surveyor's transit, of which accounts were published in the *Engineering News*, the telescope was 7½ inches long, provided with adjustable stadia; the needle was 3½ inches long; and both circles were graduated to read minutes.

Blattner's style of vertical arc, with the method of clamping to it the combined weight of the standards and telescope, was not unlike the English model we noticed in Fig. 40, which, however, presents the disadvantage of having no slow tangent-movement.

FIG. 44.



Batterman's Transit.

All my readers will conclude, no doubt, that any instrument in which the center of gravity of the telescope is so far removed from its support, and depending for its stability upon a clamp, is of defective design; and some will concur with Hoskold in the opinion that, in general, "this mode of construction is clumsy, inconvenient and unsightly."

Such opinions to the contrary notwithstanding, we must aver that, while no essentially eccentric type is without faults, that of Young (Fig. 42) possesses the least. It may be called the "American Eccentric," and finds favor in many localities.

The most recent design of this type is that built by the A. Lietz Co., of San Francisco (Fig 44). Concerning it, Mr. O. von Geldren says:

"This transit was designed by C. S. Batterman, E.M., of Aspen, Colo., in 1894. The principles involved are not new, but his application of them is unique; and for the work of transmitting a point to extreme positions in the nadir this instrument has given excellent results. It is properly balanced by a counter-weight, and provided also with a socket on a movable arm, in which a candle may be placed in any convenient position.

The eye-piece prism is also attached to a movable arm by which it is kept always at hand without fear of losing it, and can be laid back against the telescope when not in use. The spring-key between the leveling-screws assures the immovable position of the base-plates to the tripod-coupling which Lietz has recently introduced. In it the usual thread is replaced by three jaws, constructed upon the principles of the wedge, and locks by friction very firmly into grooves in the base-plates made to receive them. No manner of attaching an instrument to the tripod can be more convenient or safe."

Since 1896, instruments of this class have been constructed upon the "cyclotomic" principle, in which the double compound spindle is replaced by a single axis of revolution, while the admirable qualities of repetition are still preserved by a floating exterior ring, carrying only the numbers, which may be clamped in any position with respect to the horizontal circle. In this way any degree-line may be made the zero-point.

Lietz credits the inception of this idea to Luther Wagoner, C.E., of San Francisco, who found errors as great as 3′ in 90° in instruments the compound spindle-centers of which were not coincident.* The method of repetition, in order to determine the measured arc with greater accuracy, was introduced by Prof. Tobias Mayer, of Göttingen, in 1752, and a little later by Borda, under the name of "Double Repetition or Multiplication." Mr. Wagoner did not wish to abolish this practice, but to introduce a new and safer means of accomplishing the same result.

In 1881, G. N. Saegmuller, of Washington, D. C., who con ducts the instrumental establishment of Fauth & Co., introduced

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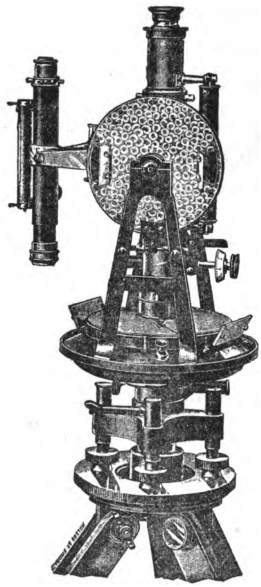
* *Trans. Tech. Soc. of the Pac. Coast*, vol. vii., No. 5.

his telescopic solar attachment (Fig. 45), which Prof. J. B. Johnson says "is accurate beyond any disk-attachment, and represents the correct solution of the solar-attachment problem." The standards, in which the solar telescope may be elevated or depressed, are free to revolve about the polar axis, and are governed by the usual clamp-and-tangent movement. The polar axis is adjusted by trivets at its base-mountings to be at right angles to the line of collimation and transverse axis of the main telescope. When the transit and attachment are in perfect adjustment, its operations are quite precise. The objections to it are mainly the possible errors of the observer in allowing for declination, latitude and refraction; but very careful manipulation will reduce the azimuth of the meridian determined with that of the astronomical North to a few seconds. The original attachment was light in weight and of low telescopic power; but when American mine-surveyors began to employ it in place of the top-telescope its size was considerably increased, and the power of the telescope raised to 18 diameters, as shown in Fig. 45. As used for this double purpose it must be looked upon as the first top-auxiliary, the adjustment of which, for parallelism by means of the base-trivets and for alignment by means of the clamp-and-tangent movement, could be tested and secured by the operator. For vertical sighting it has one inconsiderable fault, to be discussed later, which, in comparison with its other admirable features, cannot be justly said to militate against its successful operation. The mining-transit shown in Fig. 45, having 4-inch circles, graduated to read minutes, and provided with interchangeable eye-pieces to regulate power and light to suit the conditions, must be regarded as one of the best examples of perfect instrumental construction.

FIG. 45.

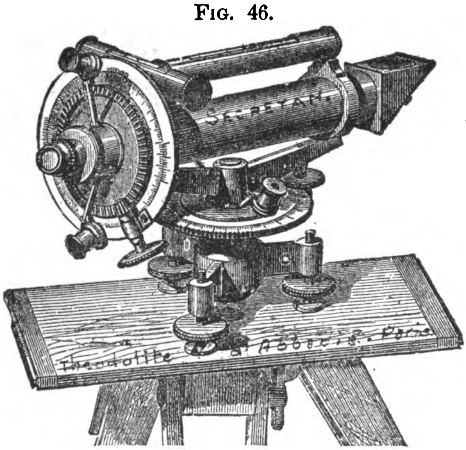


Saegmuller's Telescopic Solar, in Use as a Top-Auxiliary.

In 1885, to meet the ever-prevailing demand for increased efficiency combined with smaller weight, Saegmuller introduced in America the plain detachable object-prism, which was used for a time for vertical sighting, in place of auxiliary telescopes, but was found to be more alluring than satisfactory. When it was simply fitted to the object-glass, like a sun-shade, the 45° mirror it contained reflected rays truly at right angles to the line of sight, but whether or not in absolute verticality was sheer assumption, and the slightest variation from the correct position doubled the deviation of the emergent rays.

This was remedied to some extent by setting a small pillar into the collar of the objective, and so attaching small opposing screws to the prism that they could be made to work upon the pillar. In this way the position of the prism could be regulated very carefully; but to secure for it absolute verticality was an operation that involved more time and trouble than most engineers are willing to take.

Fig. 46.



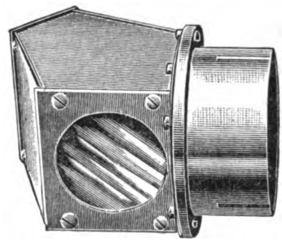
Abbadie's Reflecting Theodolite.

Prof. Steinheil, of Munich, first used, in 1847, for astronomical observations, the object-prism attached to a meridian instrument. Later, M. d'Abbadie, of Paris, employed it, rigidly attached to a small traveler's theodolite (Fig. 46), constructed like a Y-level, mounted upon a circle. The vertical limb of his instrument encircled the telescope at the eye-end. In this way the zenith or nadir position of the prism was determined by bringing the vertical circle to read 0° or 180° upon its vernier.

Before the objective prism came into use, rays were deflected by means of an ordinary mirror, held in the hand, or by attaching to the objective collar a mirror-plate, movable upon a hinge, so as to be set at any angle. In this way Borchers conducted shaft-surveys in 1844 at Clausthal; but the observation of an object at any but a right angle made the calculations complicated.

Last year (1897) Saegmuller brought to perfection the construction of the objective prism. His design is intended to utilize the optical law that *a ray which has been reflected twice in the same plane makes, after its second reflection, an angle with its original direction equal to twice the angle made by the reflecting surfaces with each other.* The double 45° reflecting-prism (Fig. 47), then, will project rays in true verticality when the transit-telescope is placed horizontally, whether the prism be fitted in exact adjustment or not. Therefore the work of this prism in transmitting vertical sights will be as perfect as it is possible to make the adjustment of the telescope to horizontality. As used on American instruments, the objective prism now has but one disadvantage. It is obvious that any necessary movement of the object-glass in focussing destroys the line of sight, and renders variable what should be a fixed eccentricity of collateral sighting. Its most successful operation, therefore, is only with the German or French instruments, which are focussed by movements of the ocular.

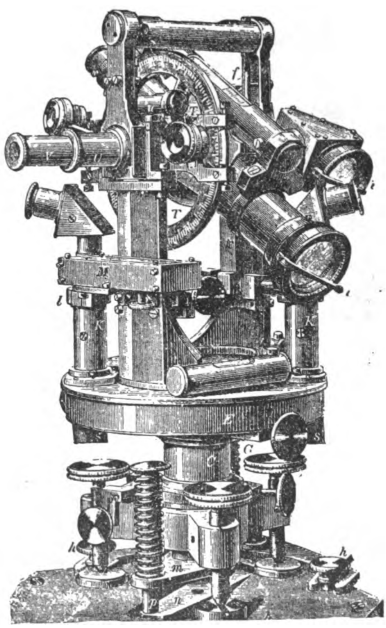
FIG. 47.



Double-reflecting Objective Prism.

The most remarkable of modern applications of the prism to mine-transits abroad is exemplified in the instrument (Fig. 48) introduced by Fric Brothers, of Prague, Bohemia, in 1886.* It is claimed by the makers to be an improvement over all other types, to reduce the errors of eccentricity to a minimum, and to overcome the cumbersome features prevalent in most other German instru

FIG. 48.

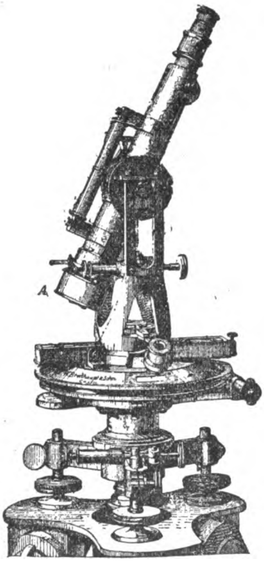


Fric Mine-Theodolite.

* *Zeitschrift für Instrumentenkunde*, Berlin, vi., 221, 1886.

ments. The transverse axis of the main telescope is enlarged and perforated in a manner similar to Hohnbaum's *Grosses Niveau*,* so as to become a secondary telescope for steep sighting. At its outer extremity is rigidly attached a prism, intermediate between the objective and ocular, after the fashion of the "broken telescope" of Reichenbach. It is focussed upon distant objects by a sliding movement of the ocular, as in the mariners' spy-glass, and the barrel is constructed to taper towards the eye-piece according to the scientific principle of the convergence of the rays of light in passing through a lens. The sliding ocular contains the diaphragm and cross-hairs, which are protected from moisture on each side by hermetically sealed thin glass disks; and if by chance any dust-particles should settle upon them, no difficulty is experienced, as the ocular is not focussed upon the plane in which they lie. Spider-webs are hygrometric, being sensibly affected by the humidity of the atmosphere, to the extent of deranging the line of collimation. For this reason Fric suggests that, except for the collection of dust and dew, the occasional German practice of using for the diaphragm a thin glass disk, with delicately etched cross-lines upon its surface, should take the place of spider-webs entirely. The main telescope has a focal length of 17 cm., and is provided with a longitudinal bubble, clamped to its upper surface, that must be removed whenever the telescope is to describe a complete revolution. The horizontal circle is made of thick plate-glass. Its graduations are etched somewhat back from its outer edge, and read by means of the Hensold prismatic glass micrometer with the assistance of reflected light from the prism (*s*) beneath. The needle is placed in a box (*M*) outside the standards, to economize space and weight. It is mounted eccentrically at $\frac{1}{5}$th of

FIG. 49.



Breithaupt's Orientation-Instrument.

* *Die Geometrischen Instrumente*, Hunäus, p. 408.

its length from one end, and balanced by a small counterweight, so as to give the greatest sensitiveness within the available space.

We notice here another evidence of the decline in the use of the magnetic needle, though for the work of orientation a very precise instrument was introduced by Breithaupt in 1887* (Fig. 49). The needle in this case, which is of more than ordinary length and sensitiveness, is designed to take the place of the magnetometer of Borchers (1846), which was suspended by a silken thread before the objective of the telescope and used to determine exactly the magnetic meridian in mines. The most remarkable of such magnetic surveys known to the writer was the extension of the Ernst-August adit-level in the upper Harz,† through a space of 4753 yards, with a final error of only 8 inches in elevation and 1 minute 8 seconds in azimuth. Owing to dense forests between the shafts, their relative positions were deduced from the Ordnance survey in 1876. This is probably the first instance in which any government survey has served as the basis for important underground work.

The orientation-instrument can be provided with a vertical circle to adapt it to a wider range of work, or, as made by Tesdorpf, with a side-auxiliary telescope, counterbalanced by a bracket-lamp. As originally built, however, it was intended only as a supplementary instrument.

The 15-cm. needle is mounted upon a ruby concentrically with the horizontal circle, and the meridian line of the base is in the same plane with the line of collimation. By use of the additional objective-lens (A) the telescope is transformed to a microscope, and in this way used for the very precise viewing of the needle. This makes it a superior instrument to those provided with the usual form of striding-compass, the concentricity of which with the instrument is not always reliable. The striding-compass, as applied to mine-instruments, was first used in Germany in 1837; but its original inventor is not known. Brander describes them as early as 1780, in connection with sun-dials.

In 1889 Buff & Berger introduced it in America with

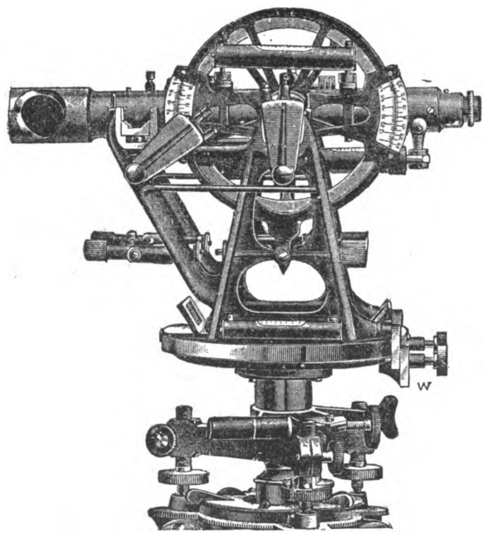
* *Der Bergbau*, No. 24, 1888; also *Cours de Topographie*, A. Habets, Liege, 1895.

† *Berg- und Hüttenm. Zeit.*, li., 293, Aug. 12, 1892.

their duplex-bearing mine-transit (Fig 50), as made for George W. Robinson, of Marysville, Mont. In this instrument vertical sighting could be accomplished, with the main telescope in a position that corresponded to the inclined standards of Young, by removing the telescope, with all its adjuncts, from its normal to its secondary bearings, which were very carefully constructed, being, in fact, cast into one piece with the standards. When in this position, a 4-pound counterpoise was attached to the plates at W.

Later, Keuffel & Esser, of New York, and Fauth & Co., of Washington, each designed instruments of this class, as illus-

FIG. 50.

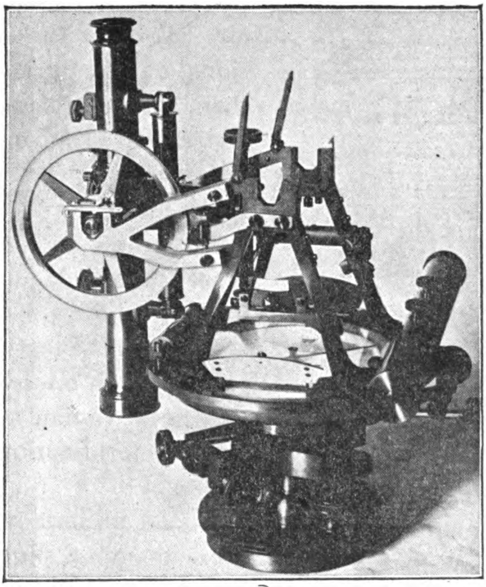


Buff & Berger's Duplex-Bearing Mine-Transit.

trated in Figs. 51 and 52, but have found that their constructions violated the principles which ought to be observed in a perfect transit-instrument. Such conveniences as they afford are hardly commensurate with the risk of getting the delicately-adjusted bearings full of grit underground while making the transposition. "Besides," says Saegmuller, "the instrument was too heavy and too expensive." His instrument weighed 25 pounds complete. The secondary bearings were not permanently fixed to the instrument, but contained in side-arms that were attached, when necessary, by thumb-screws to the upper part of the standards. To this instrument he added his quick-leveling attachment, patented in 1879. It consisted of two wedge-shaped disks, traveling upon each other in a groove, and interposed between the plates and tripod-head.

This, with the quick-leveling heads of Gurley (1878), constructed upon the principles that obtain in the designs of Pastorelli and Hoffman-Harden, and the detachable ball-and-socket quick-leveling head of Buff & Berger (1883), represent the American achievements along this line.

FIG. 51.

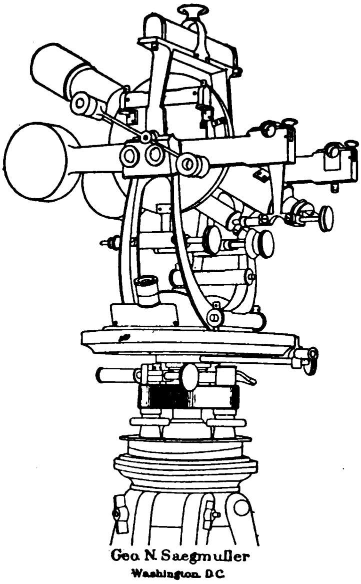


Duplex-Bearing Mine-Transit, Keuffel & Esser.

The concentric model of mine-instrument with the American supplementary telescope must eventually supersede the types of Borchers and Combes abroad; but the popularity of the eccentric instrument in Germany still continues. That recently made by Ludwig Tesdorpf, of Stuttgart (Fig. 53), is one of the few provided with micrometer-microscopes and detachable vertical circle. It has a 12-cm. horizontal circle, reading to 10″, and a 10-cm. vertical circle reading, by vernier, to 1′.

Between the standards is a circular-box bubble for leveling the instrument. The micrometer-microscope is practically the original design of Troughton, in which, briefly, the distance between any degree-line and the index of the limb is carefully measured by a sliding scale that passes through the mutual focus of the objective and the ocular. This is operated by a milled-head screw, of such fineness that one revolution corresponds to 10′ of arc. Each of the sixty subdivisions of the graduated head, then, will represent 10″. The instrument shown in Fig. 53 weighs 6 kg., and its tripod as much more.

FIG. 52.



Duplex-Bearing Mine-Transit, Fauth & Co.

For rapid and accurate subtense measurement some engineers have for a long time been at work on adapting such micrometrical slides to the ocular of the main telescope; but the results of experiments made in the great Indian survey would seem to confine its use still to the determination of the odd seconds in reading horizontal angles.

Prof. Brathuhn has, however, utilized an immovable scale in the diaphragm of the main telescope, on a slightly different principle, that is intended to unite the methods of Dr. Schmidt (p. 34) and the earlier practice of suspending shaft-plumbs in oil and guessing at the probable point of rest.*

The diaphragm he uses is a glass plate upon which the horizontal line is graduated into subdivisions of such value that readings as close as one minute can be estimated. He does not attempt the laborious task of ranging the instrument into exact alignment with the plumb-wires, but sets up at some arbitrary and convenient station, and, by watching the vibrations of each wire upon the scale, determines its angular position

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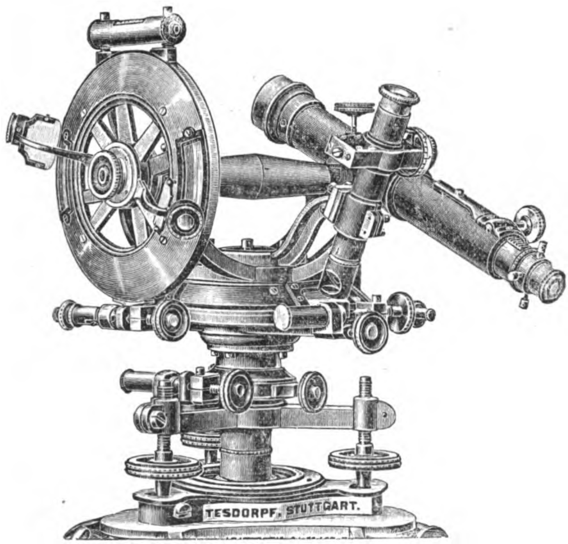
* *Berg- und Hüttenm. Zeitung*, lvi., 395, Nov. 19, 1897.

with reference to the next regularly established station in the survey. The difference of these two readings will give the value of the very acute angle subtended at the instrument from the short base-line between the wires.

One of the most interesting of modern German mine-theodolites is the American pattern of Breithaupt, introduced in 1892 (Fig. 54). It is an improvement upon the generality of American instruments in that the truss-standards (since 1880) have been cast in one piece with the compass-ring; and it possesses also, in the construction of the side-telescope, features well worthy of special comment.

FIG. 53.

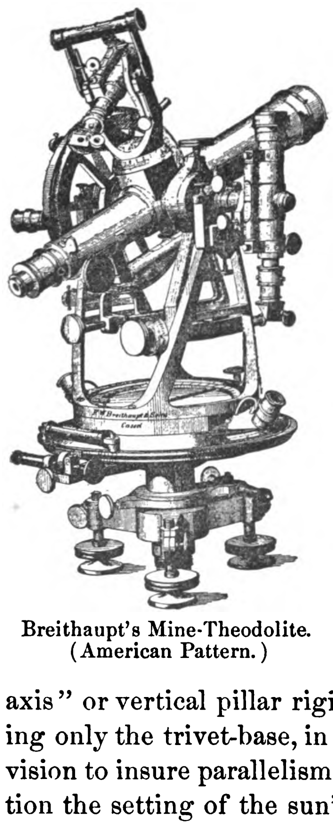


German Eccentric Theodolite.

Its spindle-hub is set into a perforation of the transverse axis in very much the same manner as was customary in the first American model, but has a clamping- and tangent-device that holds it securely, and quickly ranges it into alignment with the main telescope, where its position is verified by a longitudinal bubble. The illumination is accomplished through the transverse axis, as was first practised by Usser, professor of astronomy, at Dublin, in 1790. The 20-cm. horizontal circle is graduated to read by its verniers, or *nonius*, as they are still erroneously called by the Germans, to 10″. Pedro Nuñez, a

Portuguese mathematician, to whom this compliment is paid, published in *De Crepusculis Olyssipone*, 1542, a proposal that upon the plane of the quadrant be described 44 concentric arcs, divided respectively into from 44 to 89 equal parts. The single indicator, then employed, would coincide more or less perfectly with one of the subdivisions. It gave, no doubt, very close readings. For instance, if the index cut the 7th circle at its 43d graduation, the angle was read as $\frac{43}{84}$ of 90°, or 46° 4′ $17\frac{1}{7}$″.

FIG. 54.



Breithaupt's Mine-Theodolite.
(American Pattern.)

The solar on the Breithaupt instrument, while practically the design of Saegmuller, is one introduced by Prof. Dr. Schmidt in 1892, for the use of American students at Freiberg.*

Certain engineers took occasion to point out the possibility that Saegmuller's solar might move in altitude upon its horizontal axis while in use for vertical sighting, and thus destroy the efficiency of the base-trivets. In 1895, Buff & Berger made for George T. Wickes, of Cokedale, Mont., an instrument (Fig. 55) calculated to overcome this objection by making the "polar axis" or vertical pillar rigid with the auxiliary telescope, retaining only the trivet-base, in a new form, with every desirable provision to insure parallelism and alignment. As in this construction the setting of the sun's declination becomes impossible, its uses are restricted to the primary offices of a top-auxiliary telescope; but as such, with its delicate, rapid and effectual means for all necessary adjustments, it represents, no doubt, with Breithaupt's side-auxiliary, all that could be required in such individual devices.

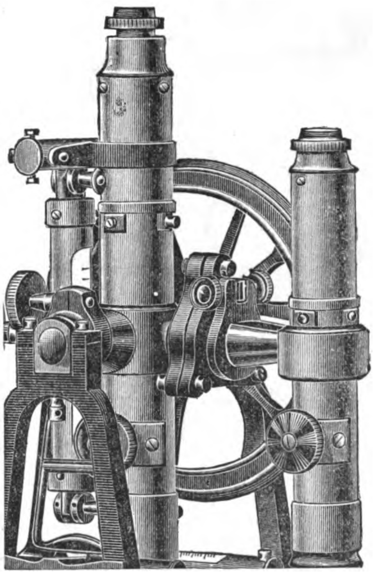
No matter how perfect may be the construction and means of adjustment, however, each of these appliances has, combined

* *Oesterr. Zeit. für Berg- und Hüttenwesen*, No. 21, 1892.

with its advantages, that negative condition known as eccentricity, for which correction must be allowed, varying with the conditions in each case.

In 1896 the writer designed a mine-tachymeter which, as he ventures to assert, by its peculiar yet simple construction, embraces the advantages and eliminates the disadvantages of all other types. Its individuality consists principally in the *interchangeability* of the auxiliary telescope and the means provided to thus transform the instrument from one condition to the other, as shown in Figs. 56 and 57.

FIG. 55.



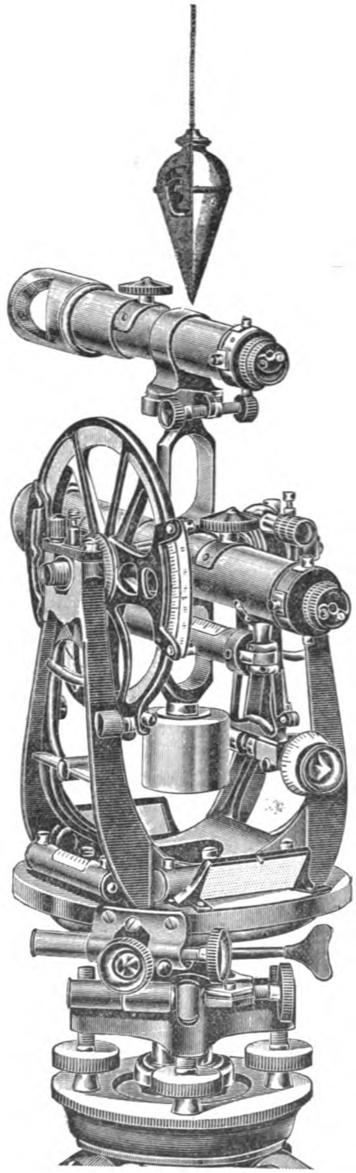
Buff & Berger's Top-Telescope, with Adjusting Trivets.

In this way the double negative quantities become positive in their resultant, so to speak; and we have a mining-transit capable of performing, with more than usual exactness, all the complex functions required in mines, and requiring *absolutely no corrections for eccentricity.*

The auxiliary telescope is so provided with a hub of new design that it may be screwed to the threaded extension of either the transverse axis or the vertical pillars of the main telescope. In this position it is clamped firmly and ranged quickly into alignment with the main telescope by two small opposing screws that work up an arm of the hub. Upon its diaphragm is but one web, so placed that it shall be vertical when on top, and horizontal when at the side. In either position the amount of eccentricity is the same, though perfect operation would not be affected if this varied, since the observation of steep horizontal angles is made only with the auxiliary on top, and of very precipitous vertical angles with the auxiliary at the side.

On this account, any adjustment for parallelism in the optical axes of both telescopes is dispensed with, as its peculiar adaptability will insure perfect results even if the conditions in this particular are imperfect.

Fig. 56.



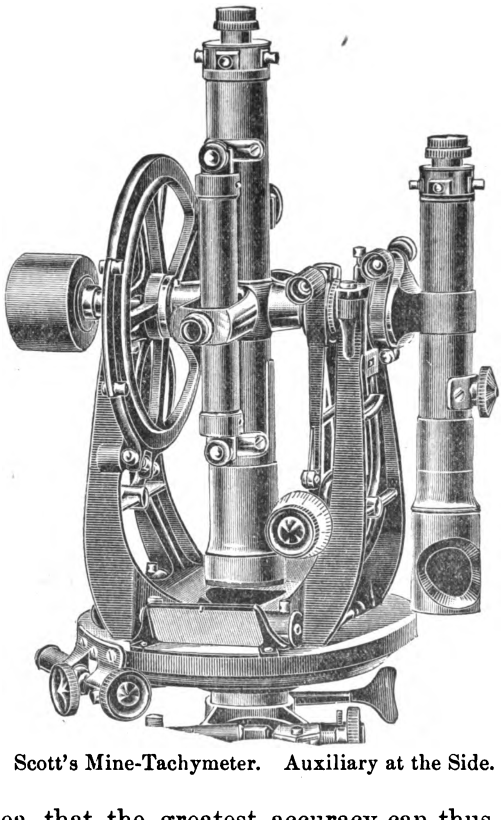
Scott's Mine-Tachymeter. Auxiliary on Top.

Buff & Berger, who made the instrument, have recently added trivets to the base of the upper vertical pillar; but these are unnecessary, and impair the stability of the instrument.

The auxiliary (Fig. 58) has a power of 17 and the main telescope of 24 diameters, being the greatest possible under the restrictions observed with regard to size and light. The amount of light received through the ocular varies as the square of the diameter of the objective; therefore, the larger the aperture in mine-transits the more favorable will be the conditions with respect to light, provided, however, that power be not sacrificed by the use of an ill-proportioned ocular. The ocular of this instrument is inverting, conforming to the general practice of European engineers, who no doubt excel in this respect. As American engineers become better acquainted with their desirable qualities, either the Ramsden, Kelner or Steinheil oculars will be more widely used. They all have the advantage of not only permitting greater light and a larger field, but in a telescope of the same size an objective of greater focal length is permissible, thereby favoring the conditions imposed to secure the best definition. By thus increasing the focal length of the objective, while, by virtue of its construction, that of the inverting ocular is decreased, the magnifying power becomes greater.

Both horizontal and vertical circles are 5 inches in diameter, divided into half degrees, and read to minutes. This, on the authority of many years' practice, and by general consent, is conceded to be most easily read underground, and to be fine enough for mine-work. The novice is generally too much inclined to high telescopic power and extremely fine graduations,

FIG. 57.

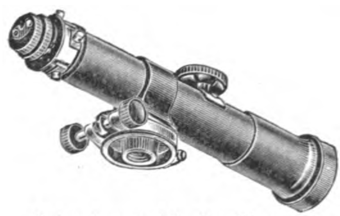


Scott's Mine-Tachymeter. Auxiliary at the Side.

with the idea that the greatest accuracy can thus be attained. But this is a mistake. Beside, the stationary double-lens reading-glasses that become necessary to read such fine circles only provide the means of invariably burning the engineer's face when he attempts to get both his eye and candle near enough to the plates to take a correct reading. The vertical circle is graduated in quadrants, the zero-line running parallel with the line of collimation, and is read by one double vernier, so placed near the eye-end that any angle of elevation or depression may be determined with the telescope in a normal or reversed position. The horizontal graduations read only in one direction, being numbered continuously with one set of figures, from 0° to 360°. This permits the verniers to be single, and provides a uniform method that almost entirely removes any possibility of error in reading, recording, figuring or platting. The verniers are directly under the telescope, so that one need not move to read them, and if the engineer is satisfied that his graduations are correct, he will habitually read but one of these, taking care, however, to repeat every angle at least once; for no mine-surveyor can be certain of his work until he has checked every step by the same or different means.

The U-shaped standards are a new pattern, designed to conform to American practices and methods. Being of one piece they are very rigid, and, as old-time fancies wear out, will doubtless come into general use. They are made of aluminum, and bushed with electrum at the bearings. Their construction does not permit the use of the usual compass-box; but in high-class mine-work the magnetic-needle cannot seriously be said to be essential for any purpose whatever. The history of magnetic surveys is itself the death-warrant of the miners' compass; and in this age of widespread electrical power and lighting (employed with rapidly increasing frequency in mines), the magnetic needle becomes no more reliable in mine-surveys than on the present iron-clad man-of-war.

FIG. 58.

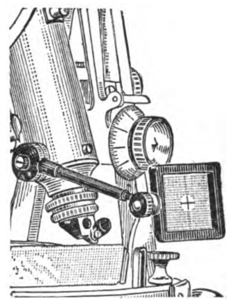


Interchangeable Auxiliary of Mine-Tachymeter.

Mine-surveys are nearly always figured by trigonometrical functions, as referred to the boundary-lines; but if the engineer prefers to use the calculation by latitudes and departures, a good practice is to establish by stellar or solar observation, at one end of the base-line in the surface-triangulation, or, better, at one of the boundary-corners, a true meridian from which every station in the whole system, both underground and on the surface, has an established latitude and departure, and every course an established bearing. After the work of procuring and tabulating these data is once completed, this system is perhaps the most concise in subsequent computation; but the initial time and effort it requires are scarcely repaid by the benefit secured.

For such work, with this tachymeter, the Davis solar screen (Fig. 59) is doubtless best to use. It was invented in 1880 by Prof. J. B. Davis, of the University of Michigan, who, in writing to me, said: "In my opinion, my solar screen requires less calculation than any other, if properly used. Its work is even more precise than the circles of the transit, and requires no special adjustments or mechanical conditions. Some others require those that cannot be tested." If used with an erecting telescope, the full aperture of the objective is utilized; but with an inverting ocular, in order to obtain a clear reflection of the cross-hairs upon the screen, a telescope-cap is provided, so as to reduce the aperture to about ¼-inch.

FIG. 59.



Davis Solar Screen.

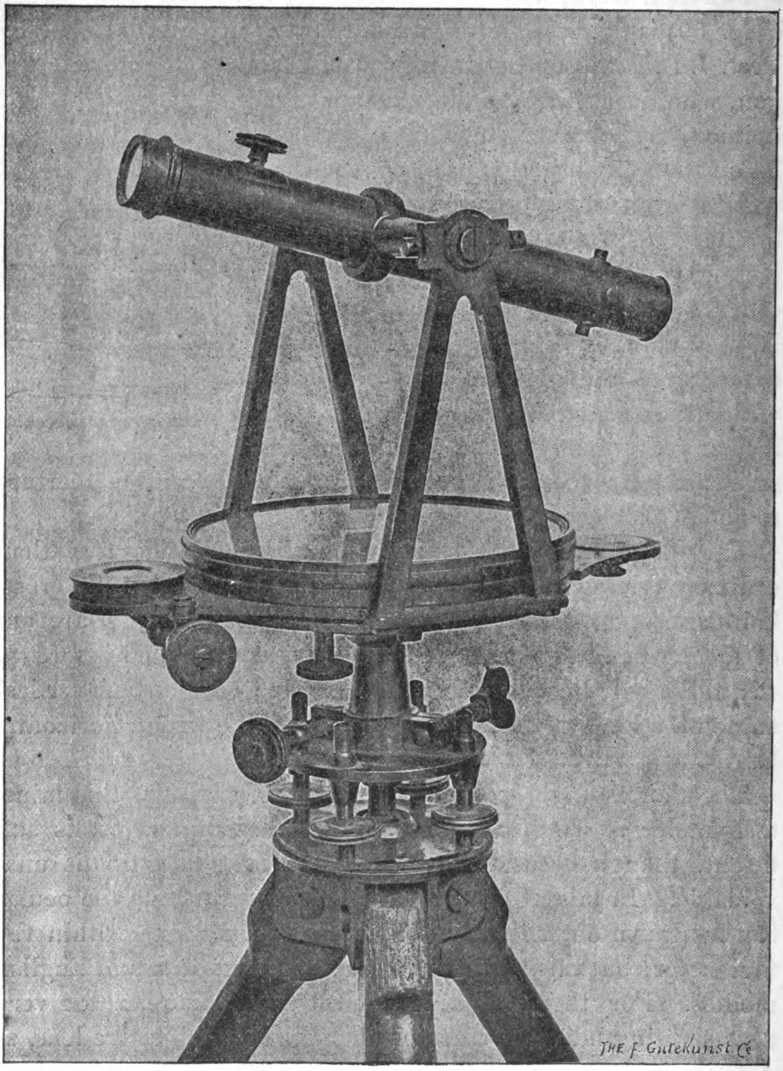
The diaphragm of this instrument is made of more than ordinary thickness. Upon one side are placed the usual cross-hairs and upon the other the fixed stadia-hairs, which are out of focus when not in use. In this way, as explained before (p. 42), there will be no danger of reading an important vertical angle on a long and indistinct sight with the wrong horizontal hair.

The shortest sight possible with the telescope of this mine-tachymeter is 5.5 feet, which for ordinary mine-work is sufficient, though occasionally a shorter sight than this is unavoidable. In most German and French instruments the ocular can be drawn out so far as to permit observations within the first meter; but this plan is impossible in American and English models. For these, then, the only plausible plan for very near sighting must provide for an additional objective lens, as described in connection with Breithaupt's orientation instrument (see A, Fig. 49). Such an arrangement Buff & Berger are now perfecting for this work. It is provided with adjusting-screws at the side, so that the center of the lens may be made to coincide exactly with the optical axis of the telescope.

Otherwise, by the careless addition of an extra objective, the adjustment of the line of collimation may be disturbed.

In designing the mine-tachymeter, it was the writer's object to

FIG. 60.



The First American Transit, built by Young & Son, Philadelphia, 1831.

make it the most complete, convenient, precise and compact instrument yet introduced for mining engineering, and to this end it was his intention to add one other improvement, which up to this time remains but a suggestion; but such engineers or makers as choose to employ it may do so without fear of interference, as the original makers are now seemingly extinct.

In the *Eng. and Min. Journal* of November 7, 1891, is described Cook's patent luminous level tube, which has an inner coating of phosphorescent compound, covered by a coat of water-proof lacquer, by which the bubble is made to appear as distinct against the graduations in the tube in the dark as in the light. As it frequently happens that, because the flicker of surrounding lights seems to absorb all dim rays coming from a long, indistinct sight, the engineer prefers to remain in the dark, the use of such a device would enable him to watch his bubbles while making such observations.

In ordinary setting-up, moreover, it seems likely that the work would be greatly facilitated.

Fig. 60, a picture of the first American transit, referred to on p. 25, may fitly conclude this paper, showing how much progress has been made in the construction of such instruments since that modest beginning, sixty-seven years ago.

The writer invites correspondence upon the topic here discussed, for the purpose of rectifying possible errors and enlarging the historical evidence, which is now of necessity incomplete. The subject has been profusely treated abroad, and ought to receive more consideration on this side of the Atlantic.

DISCUSSION.

SECRETARY'S NOTE.—The foregoing paper aroused so much interest among mining engineers and manufacturers of surveying instruments, that the Institute has already been favored with the following painstaking contributions by way of discussion, addressed either to the author or to the Secretary. The subject is by no means exhausted, nor can it be; for, aside from chronicling the past, doubtless new improvements will still continue to deserve to be recorded. Nevertheless, the present volume must necessarily stop somewhere. The *Transactions*, however, will always be hospitably open to further papers on the subject. Decision as to the propriety, pertinency and value of communications offered rests with the Council of the Institute; but ordinarily those of members would take precedence. Manufacturers' descriptions of their instruments will not be excluded; except that pure advertisements, asserting without defining the merits of special devices, would, of course, be declined.

BENNETT H. BROUGH:* Having devoted many years to a study of the history of mine-surveying, some of the results of which I published partly in a course of lectures† delivered before the Society of Arts in 1892, and partly in a separate work,‡ I consider that the information Mr. Scott has got together to illustrate the gradual evolution of American mine-surveying instruments during the past sixty-seven years forms a valuable contribution to knowledge. There are, however, several statements in the paper that are open to criticism. For example, the author is inaccurate in stating that the use of the compass in mine-surveys is first described by Agricola. As a matter of fact, it is described in the oldest treatise on mining, a work written in German and published anonymously in 1505

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* Formerly Instructor in Mine Surveying, Royal School of Mines; Sec'y Iron and Steel Institute, 28 Victoria Street, London, England. This communication was received January 23, 1899.

† *Cantor Lectures on Mine Surveying*, by B. H. Brough, London, 1892.

‡ *A Treatise on Mine Surveying*, by B. H. Brough, London and Philadelphia; 1st edition, 1888; 7th edition, 1899.

under the title of *Ein wolgeordent uñ nutzlich büchlin wie man Bergwerck suchen und finden soll.* The wood-cut of the miner's compass there published shows the dial divided into twice twelve hours. In the library of the Freiberg Mining Academy there are copies of four editions of this rare and interesting book. Of the edition of 1505 only two or three copies are known.

A compass similar to that found at Neudorf, described in the paper, is exhibited in Florence. It belonged to Galileo.

A study of the history of surveying-instruments shows that in many cases inventions have been anticipated in a curious manner. Thus, the ingenious Rapid Traverser, invented by Captain Henderson in 1892, is, I find, very similar to an instrument invented by Brigadier-General James Douglas, and described by him in 1727, in a work entitled *The Surveyor's Utmost Desire Fulfilled, or the Art of Planometry, Longimetry and Altimetry, brought to its greatest Perfection by the Help of the Ungraduated Instrument, called the Infallible* (London: Printed for John Osborne and Thomas Longman at the Ship in Paternoster-row, MDCCXXVII.). The instrument is thus described:

"It only consists of two Pieces, viz., A and B, whereof A is a square Copper Plate, with two moving visual Rulers turning round upon the central Screw Nail D, passing through the Middle of the Plate A. It is furnished at each Corner with a thin Piece of Brass, which may be taken off and on at pleasure, each being pierced to receive headless Pins, which are soldred fast to the Plate; the four Screws are to make their Plates hold fast the Paper when properly folded at the Corners of the Instrument. To fit the Instrument for Use, first cover the Plate A with a double Sheet of clean Paper. Then B, your Ball and Socket, is to be joined by putting the Screw Nail thereof through the central Hole of the Plate A, gently piercing the Paper; which done, apply the two visual Rulers, and screw them fast with the middle Screw Nail so that the said Rulers move easily about the centre: and thus is your *Infallible* prepared for Use."

To those unacquainted with the delicate magnetic instruments used in Sweden for discovering iron-ores, the author's description of Thalen's magnetometer and Tiberg's inclination-balance as being almost identical will be misleading. These instruments, which should hardly be classed with ordinary mine-surveying instruments, were described in a paper on exploring for iron-ore with the magnetic needle, which I communicated to the Iron and Steel Institute in 1887, and were admirably illustrated in the important monograph read at the Stockholm meeting of that Society in 1898 by Professor G. Nordenström. For some years past a combination of the two instruments has been found most suitable for magnetic explorations.

Surely Mr. Scott is mistaken in ascribing the introduction of the instrument shown in Fig. 14 to W. and S. Jones in 1796. I have in my possession a graphometer of precisely similar design, made at Brunswick in 1630; and graphometers of even earlier date are exhibited in the collection of astrolabes in the South Kensington Museum. The instrument appears to have been invented by Jan Pieterszoon Dou, of Leyden, in 1612, and described by him in 1620. These graphometers, being made prior to the invention of the vernier in 1631,* are of interest in being furnished with the *nonius*, or variously divided auxiliary quadrants, invented by Pedro Nuñez in 1542.

Referring to Mr. Scott's statement that a diaphragm and cross-hairs in the focus of surveying-instruments were first used in 1669, I may point out that Professor E. Hammer has shown that this was first done about the year 1640, in England, by William Gascoigne, who fell, in 1644, at the age of twenty-four, in the battle of Marston Moor. He used hair and thread for this purpose thirty years before Picard and Malvasia. In the middle of the last century glass and mica plates, with engraved lines, were first used in place of cross-hairs. They were described by Brander in 1772, and were used by Breithaupt in 1780. Spiders' webs were not used until 1775.

Credit for the first application of the tacheometric principle in surveying is given by the author to William Green, who was awarded a premium for its invention by the Society of Arts in 1778. This view I adopted in a paper on tacheometry, communicated to the Institution of Civil Engineers in 1888. It has, however, recently been shown by Mr. J. L. Van Ornum, in a scholarly memoir published by the University of Wisconsin, that, although in 1778 the Danish Academy of Sciences awarded a prize to G. F. Brander for a similar device, which he had applied to his plane-table six years before, its real discoverer was James Watt, who used it in 1771 for measuring distances in the surveys for the Tarbert and Crinan canals. In James Patrick Muirhead's life of James Watt is found a state-

* The vernier was invented by Capt. Pierre Vernier, a native of Burgundy, serving the King of Spain in the Netherlands. The Germans seem to have used the Teutonic form "Werner." See Bauernfeind's *Elemente der Vermessungskunde*, 7th ed., Munich, 1889, p. 124.—R. W. R.

ment by Watt himself that he constructed the instrument in 1770, and that in 1772 he showed it to Smeaton.

It is interesting to compare the perfect method of measuring lengths by means of the American steel tapes, referred to by the author, with that formerly employed. In an old German work on surveying by Jacob Koebel, published at Frankfort in 1570, the unit of length is described somewhat as follows: "A rood should, by the right and lawful way, and in accordance with scientific usage, be made thus: Sixteen men, short and tall, one after the other, as they come out of church, should place each a shoe in one line; and if you take a length of exactly 16 of these shoes, that length shall be a true rood." This description is accompanied by a quaint illustration showing the process being put in operation.*

MR. SCOTT: Mr. Newton had sent me an electrotype of Henderson's Rapid Traverser to accompany the text in my article which relates to it, but it was confiscated by our Government officials because the importation of small articles of merchandise through the mails has been unjustly prohibited by the Universal Postal Union Convention.

I cannot let Mr. Brough's description of the "Infallible" go by without citing one other of the progenitors of Capt. Henderson's Traverser, to which Adams has made casual reference in his *Essays*, the first edition of which was published in 1791. He says:

> "Mr. Searle contrived a plain table, whose size (which renders it convenient, while it multiplies every error) is only five inches square, and consists of two parts, the table and the frame; the frame, as usual, to tighten the paper observed upon. In the center of the table is a screw, on which the index sight turns; this screw is tightened after taking an observation."

I did not wish to convey the impression that Jones' circumferentor (Fig. 14) was unquestionably the first of its kind in England, unless what Mr. Newton had ventured to say concerning it would tend to establish that fact. Possibly even Mr. Newton may be incorrect, for an old English work† has this interesting paragraph:

* *Geometrey von Künstlichem Feldmessen.* A copy of this rare book in the Astor Library, New York, is dated 1593. The edition of 1570, cited by Mr. Brough, is in the British Museum.—R. W. R.

† *Geodesia, or the Art of Surveying,* John Love, London, 1744, p. 59.

"This last instrument depends wholly upon the Needle for taking of angles, which often proves erroneous; the Needle yearly of itself varying from the true North, if there be no Iron Mines in the Earth, or other Accident to draw it aside, which in mountainous Lands are often found: It is therefore the best Way for the Surveyor, where he possibly can, to take his Angles without the help of the Needle, as is before shewed by the Semicircle. But in all Lands it cannot be done, but we must sometimes make use of the Needle, without exceeding great trouble, as in the thick woods of *Jamaica*, *Carolina*, &c. It is good therefore to have an Instrument with which an Angle in the Field may be taken either with or without the Needle, as is the Semicircle, than which I know no better Instrument for the Surveyor's Use yet made publick."

The semicircle Love describes had fixed and movable sights, though divided very coarsely; for in the preface of his work he says:

"I have taken Example from Mr. Howell to make the table of *Sines* and *Tangents* but to every fifth minute, that being nigh enough in all Sence and Reason for the Surveyor's Use; for there is no man, with the best instrument that was ever made, can take an angle in the Field nigher, if so nigh, as to five Minutes."

I have recently secured a copy of Prof. Van Ornum's paper on "Topographical Surveys,"* and am glad to ascribe to Watt the honor that seems justly due him in having been first to use subtense measurement in the construction-work on the Scottish canals. I had found a record of this fact,† but without dates or further detail.

From this Bulletin I wish also to supplement my remarks on the plane-table, and reproduce here the description and cut of the original instrument (mentioned on p. 12), for the benefit of the many who have not had the pleasure of reading the paper. Prof. Van Ornum says, in part:

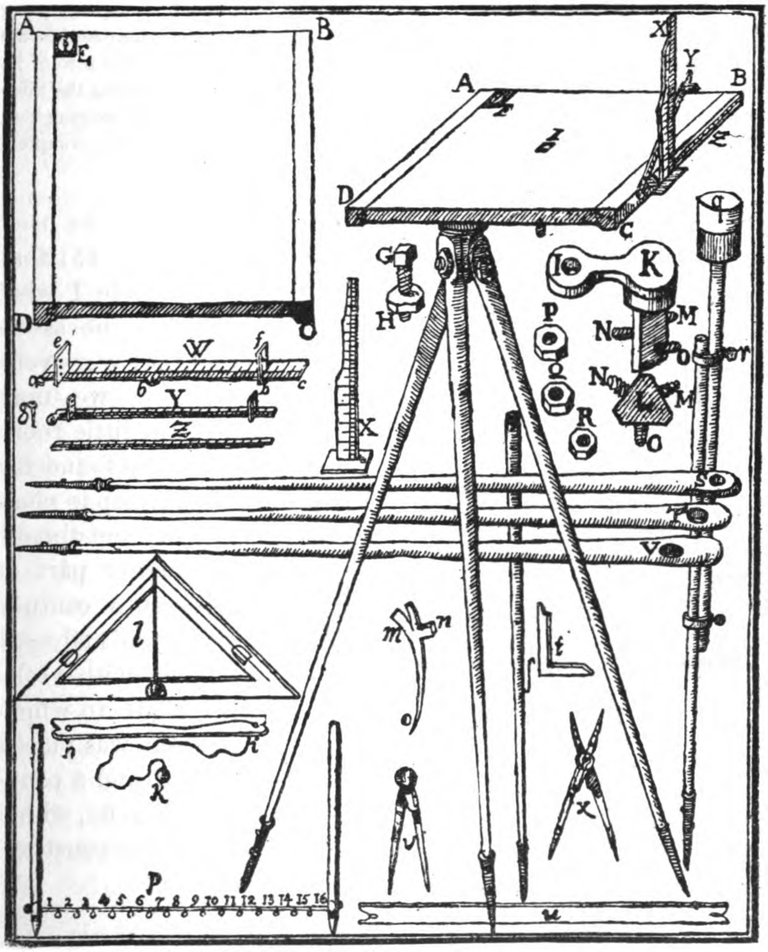
"To Johann Prætorius, the renowned mathematician, professor and savant, prolific in writings and inventor of many mathematical instruments, is definitely credited the invention of the plane table in 1590. To enable the engineer to understand the famous Prætorian Mensula, and to appreciate its peculiarities and principles of construction, Prof. Carl Dziatzko, of the University of Göttingen, Germany, has sent the accompanying cut (Fig. 61) and description, which were taken from M. Daniel Schwenter's *Geometria Practica*, Nürnberg, 1667. A B C D is a plane board about 15 inches square and 1 inch thick, having two cleats on the edges to prevent it from warping. In the corner is a compass, E, in a square box, having a sliding lid, so that it can be opened and shut at pleasure. A spirit-level (not shown) is necessary. G is a wooden screw, the bottom threaded, and the top

* *Bulletin of the University of Wisconsin, Engineering Series*, vol. 1, No. 10, Dec., 1896, pp. 331–369.

† *Inventors and Discoverers in Science and Useful Arts*, John Timbs, F.S.A., N. Y., 1860, p. 287.

having a square head. There is a nut, H, at the bottom. In the center of the board is a square hole, into which the wooden screw G is glued. K I is a hardwood piece, with a round hole at I, through which the screw, G H, passes. To K a triangular piece, L, is nailed. On three sides of this piece three wooden screws, M, N, O, are glued, and three nuts, P, Q, R, made for them. Three pieces, S, T, V, 5 to 5½ feet long, are made to fit these screws, M, N, O, thus forming the tri-

Fig. 61.



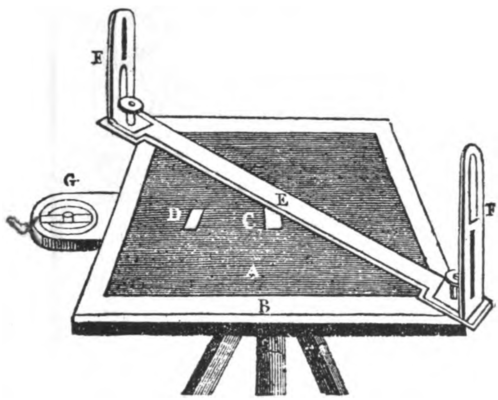
The Prætorian Mensula.

pod. A graduated brass scale, W, 14 inches long by 1 inch wide, forms what is called the chief scale. A semicircular piece of brass, *a*, is left at one end, and a hole made in it on the edge of the rule so that a fine needle can be passed through it. Six inches from this a similar piece, *b*, is left. Two sights, *e* and *f*, are made. The sight *e* has three fine holes perpendicular to the edge of the scale and in a plane with it. The sight *f* has a hole cut in it, and a fine wire or thread stretched

across it in the plane of and perpendicular to the edge of the scale. These sights are made so that they can be turned up or down. Three other brass rules, X, Y, Z, similarly graduated, are called the side rules. The first rule, Z, is $\frac{2}{5}$ of an inch wide and 1 foot long, and is fastened rigidly to the cleat B C, so that the edge of it is in the middle of the cleat. The second rule, Y, is similar to Z, but has, besides, a semicircular piece of brass fastened to one end, with a hole in it. A screw, *g*, fits in this hole and the rule is fastened to the cleat B C, so that it coincides with the rule Z. This rule turns about the screw *g*, and has two sights, the same as the chief rule. The third rule, X, is 9 inches long and is soldered to a square piece of brass, so that when it is fastened to the table it will be perpendicular to the rule Z. The point where the top edge of Z crosses this rule is taken as the zero of its scale. A rule, *n i*, with the plumb-bob *k* attached, is used for centering the table over a point in the field. A target, *q*, *r*, *s*; triangle, *l*; square, *t*; measuring rod, *p*; hammer, *m*, *n*, *o*; compass, *v*; proportional dividers, *x*; and rule, *u*, complete the secondary equipment."

Such instruments as this were doubtless the first to be used in the Swedish mines; and where I have said (p. 13) that they were rude I wish to substitute the assertion that they were very complete, if we may judge by the little room there has been found for improvement up to comparatively recent times.

FIG. 62.



Plane Table Described by Simms.

In the latter part of the eighteenth century Mr. Beighton had used a plane-table with a telescopic alidade, in which the telescope was placed at one end and a counter-weight at the other. The instrument shown in Fig. 62, which is taken from a standard English work,* represents the construction in general use about 1840. The author says:

"It is a board, A, about 16 inches square, having its upper edges rabbeted to receive a box-wood frame, B, which being accurately fitted can be placed on the board in any position with either face upwards. This frame is intended both to stretch and retain the drawing-paper upon the board, which it does by being simply pressed down into its place upon the paper, which for the purpose must be cut a little larger than the board. One face of the frame is divided into 360° from

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* *A Treatise on Mathematical Instruments*, F. W. Simms, F.R.A.S., London, 1834–1844.

the center, C, fixed in the middle of the board, and these are subdivided each way as minutely as the size of the table will admit. The object of these graduations is to make the plane table supply the place of the theodolite, and an instrument formerly in use called a semicircle.

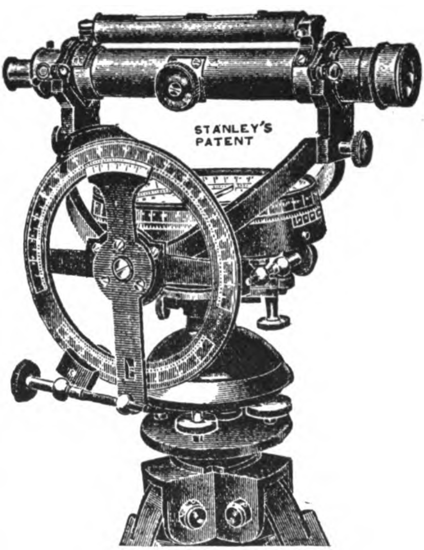
"There is sometimes a second center-piece, D, fixed on the table at about one-quarter of its width, from one of the sides and exactly half its length in the other direction.

"To the under side is attached a center-support with ball-and-socket or parallel plate-screws, by which it can be placed upon a staff-head, and made to sit horizontal by means of a circular spirit-level."

The author says, further, that the box-wood frame and its graduations could be dispensed with entirely, and that the expedition with which certain field-work may be performed by a person who is expert in its use is its chief recommendation.

W. F. Stanley* (communication to author): I wish to acknowledge with thanks a copy of your article, and to express my pleasure with the extent of your research. In the preparation of my work I spent some months along these lines, but only partially succeeded; therefore, I know the trouble. What you have said concerning Fig. 40 I believe to be indisputable facts, but I beg leave now to submit a description of an instrument (Fig. 63) which I completed in the latter part of last year (1898), just as your paper was going to press. It is the first dial of the Hedley style, I believe, which may be used for sighting in true verticality. The Hedley ring did not permit this; but, by remodeling into a sort of cradle, this difficulty is avoided. The vertical limb is now a complete circle, and graduated to read on the upper half from 0° to 90°, in minutes of arc, each way. In the lower arm of its vernier is

Fig. 63.



Stanley's Latest Improved Hedley-Dial.

* Math. Instrument Maker, 4 and 5 Gt. Turnstile, London, England.

an index, which is used to indicate the correction in hypothenuse and base, as marked on the lower half of the circle.

The horizontal limb is graduated outside, as shown, and reads to minutes by double opposite verniers, placed so as to be coincident with the line of sight.

The diaphragm of the telescope is provided with platino-iridium points for subtense measurement, as described in my work,* p. 128. This alloy has about the hardness of spring-tempered steel, and is, as far as known, perfectly non-corrosive in air or moisture. We have found that this point-reading is more exact than with the web, as irradiation, due to the edge-reading of the web, is entirely avoided.

The growing sentiment in England is greatly in favor of 3 leveling-screws, but I do not think mine-surveying so exact as surface, and the strain put upon the axis by the use of 4 leveling-screws is unimportant, and otherwise much minimized by the springiness of the Hoffman-Harden tripod head. The great difficulty with our engineers here is to get head-room in the shallow workings of our coal-mines, and it was for this reason that I designed the prismatic dial you have illustrated in Fig. 41.

On account of its apparent height your mine tachymeter would not be received favorably in this country. The dial here described has been built as low as the conditions will permit, and seems to answer in many mines, though, as I say, there are obvious reasons why it should be still lower. Its total height, including the 3¼-inch tripod head, is 10 inches, and it weighs 8½ pounds.

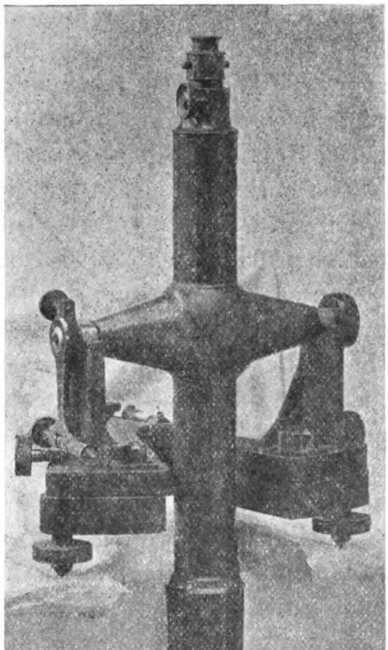
Mr. Scott: The height of my instrument is not so great as it would seem by a casual inspection of Fig. 56. The standards are purposely made a little higher than is usual, so that, with a full aperture of the telescope, it can be made to observe objects in dips up to about 55°, and as great as 63° with about one-quarter of the diameter of the objective above the plates. They are, however, no higher than is necessary to effect conveniently the complete revolution of the 9½-inch main telescope and the partial revolution with the 5½-inch auxiliary telescope

* *Surveying and Leveling Instruments*, W. F. Stanley, London, 2d ed., 1895.

attached. When the interchangeable auxiliary is placed on top, the total height from the tripod-head in the 5-inch model is 14 inches, and the total weight 12 pounds, or 5.5 kilogrammes.

C. L. Berger & Sons* (communication to author): After much difficulty and delay we have been enabled to secure a photograph of the nadir instrument (Fig. 64), to which you have referred on p. 701. It was designed by our Mr. C. L. Berger to carry the alignment of the Dorchester Bay sewer very accurately down through the westernmost of the three shafts sunk upon it in driving its entire length of 6090 feet. The lower part of the cast-iron stand rests upon three supports, the two forward being contrived to act as leveling-screws, the rear one being merely a stationary swivel-point upon which the upper part is made to move slightly in azimuth by means of the opposing tangent-screws shown acting against two small pillars near the base of the Y-standards.

Fig. 64.



Nadir Instrument, Built for Crafts in 1877.

When the desired position is thus attained, the base is clamped by means of the set-screws or nuts shown in the forward part on each side. The adjusting block, usually set into the bearing of the horizontal axis, was dispensed with in this case, as the adjustment could be secured by means of the leveling-screws and a delicate striding-level provided for that purpose.

The telescope had a 2-inch aperture, a focal length of about

* Math. Instrument Makers, Successors to Buff & Berger, 9 Province Court, Boston, Mass.

20 inches, and a power of about 40 diameters. As in all telescopes of this length and size, the focusing arrangement is placed at the ocular, where it is always within easy reach.

Mr. Stearns, in the paper to which you have referred, correctly said: "As the use of a vertical cross-wire would have caused confusion on account of its looking so much like the string, two wires crossing each other, and making a small angle with the vertical, were used instead."

The entire weight of this instrument is about 50 pounds.

F. W. BREITHAUPT & SOHN* (communication to author): We have studied very carefully the copy of your work which you sent us. We regret that we have no drawing of the first complete telescopic mine-theodolite made by us in 1832 for the Imperial Brazilian Mining Association of London.

The horizontal circle, however, was 5 inches in diameter, divided into $\frac{1}{2}°$ and read by verniers to 1 minute of arc, and the ocular provided with a prism for steep upward sighting.

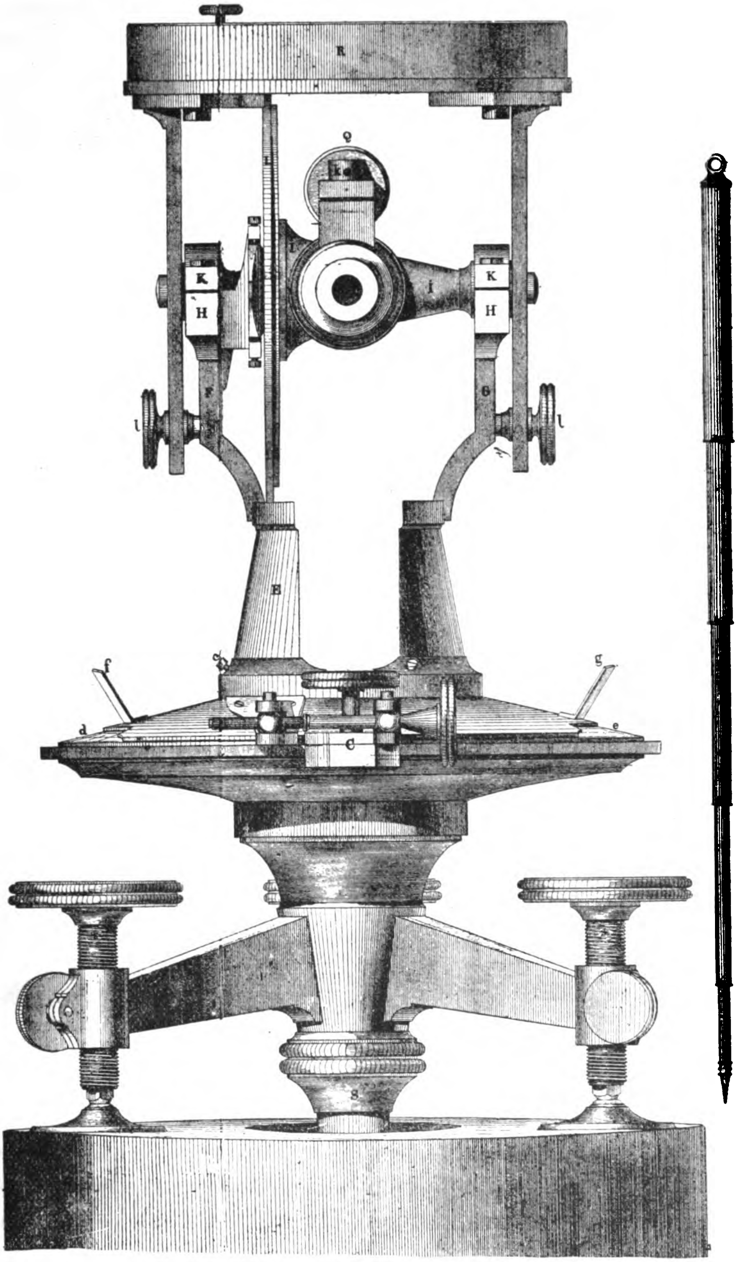
We send you a copy of the fourth volume of our *Magazin*, published in 1860, in which you will find illustrated a mine-theodolite (Fig. 65), the first of its kind in Germany, which we made for the Mine-Surveyor-General of Saarbrücken in 1836, and which Bergingenieur Praediger, in the same year, used in that celebrated survey of 2000 meters in the Ensdorfer tunnel at the Kronprinz coal-mines, near Saarlouis.

It will interest your readers to notice the apparatus provided to measure the height of the instrument above the station over which it is set.

It was made of five small tubes, one sliding within the other, so as to be convenient to carry about and quickly attached to the hook of the bar that passes down through the head of the tripod. In this position the bottom of the first tube was always 30 inches below the horizontal axis; the next, when pulled out its full length, 40; the next, 50, etc.; and, finally, the odd inches indicated on the last draw. We call attention also to the way in which the plummet was balanced by a counter-weight—a method that does not compare very favorably with the reel-plummets used in your country to-day. The tripods had exten-

* Math. Instrument Makers, Established 1760, Cassel, Germany.

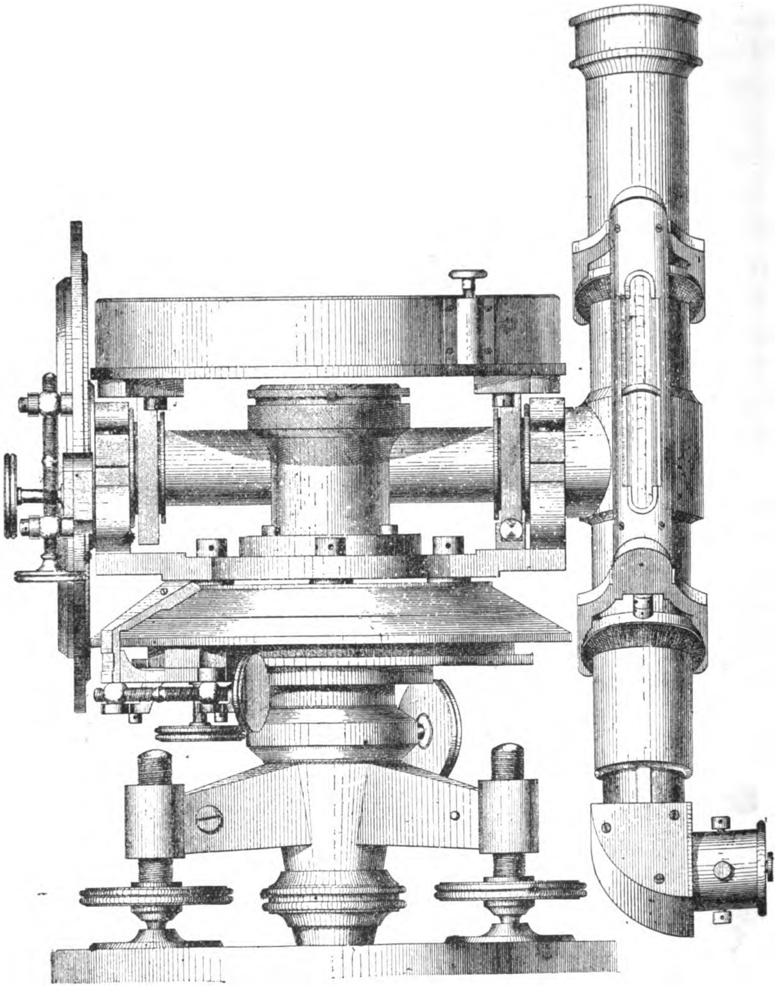
Fig. 65.



Praediger's Original Instrument of 1836.

sible legs, and the signal targets were so designed that their centers should correspond with the axis of the instrument in height.

FIG. 66.



Breithaupt's First Eccentric Mine-Theodolite.

In the same magazine is also illustrated the eccentric theodolite (Fig. 66) in its first form, as it appeared in 1834. Among the advantages claimed for it then may be enumerated:

1. It may be used to sight an object in any elevation or depression with the single exception where the object is exactly

vertical above or below the center of the instrument, and this difficulty can be obviated by a little shifting of the object or the set-up point. As a little disadvantage one could mention, the object must be sighted in two different positions of the telescope, unless a trigonometrical calculation is made to account for the eccentricity of the telescope; but this operation is not only convenient but absolutely necessary to compensate for the little imperfections in instrumental construction. All vertical angles are read without correction.

2. The far easier adjustment of the instrument.

3. Diminishing the height of the telescope's axis, which is only 2 inches above the horizontal plates.

4. Greater length of telescopic axis between its supports and larger diameter of vertical circle.

5. The construction is such that the bubble tube on the telescope can also be placed to stride the axis for its more accurate adjustment.

For convenience, the telescope had a prismatic ocular, and was provided with a reflector to measure altitudes of the sun, for which purpose this theodolite is well adapted. It is also convenient in sighting the polar star to establish the true meridian. The striding-compass and circular box-bubble are both on top of the instrument, and very easy to observe.

We cannot give any authentic information as to who first used this instrument, but in any event it is quite wrong that Borchers had used it as early as 1835, as you record it on p. 27. He was not employed at Clausthal until 1841.* At that time he found there, in the Royal Mining Academy, a theodolite of our make, which was not intended, or properly designed, for mine-surveying. With it, however, he conducted a mine-survey, the results of which were so satisfactory that he was led in March, 1842, to order a theodolite, which we delivered in May, 1844. We regret that we have no presentable illustration; but concerning it, we will say that the vertical circle was divided into $\frac{1}{2}°$ and read by opposite verniers to minutes. The horizontal circle was 6 inches in diameter, divided into $\frac{1}{3}°$ on silver and read by verniers to 30″. The vernier openings in the covering of the limb were provided with glass plates to

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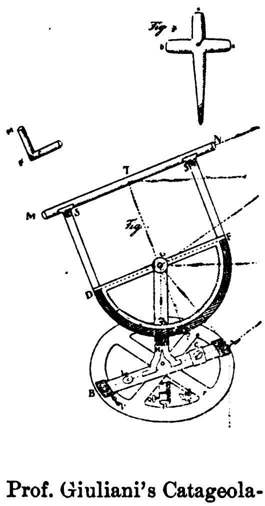
* See *Der Bergwerksfreund*, vol. xiv., p. 419.

protect them from dust, etc., the invention of which device must be credited to our house in 1835. The telescope was 13 inches long, was reversible upon its horizontal axis through the standards, and provided with a bubble-tube that could be turned to the line of sight. There was also a striding-compass, but the special feature was the reflector arrangement fixed to the objective, to which you have referred on p. 52 of your work. This reflecting mirror moved in a small graduated arc, upon which it could be clamped in any convenient or desirable position, and the exact value of the deflection-angle read by a small vernier provided for the purpose.

Borchers had this concentric instrument in commission until 1856. On June 10, 1850, the great Ernst-August tunnel was begun, and the first holing was made in 1856. Then, on account of the work to be done in inclined shafts, Borchers had an eccentric theodolite made by Meyerstein, very much as you have shown on p. 26.

PROF. DR. MAX SCHMIDT* (communication to author): As your work deals only incidentally with the catageolabium of Giuliani, I shall be glad to supplement it at your solicitation with the best description it has been possible for me to prepare in the short time I have had at my disposal for this purpose.

FIG. 67.



Prof. Giuliani's Catageolabium, 1798.

On p. 79, Section 91 of his work, Giuliani says:

> "If I were a mine-surveyor I would use an instrument shown in Fig. 2, Plate V. (here reproduced in Fig. 67), which corresponds in its principal parts with Brander's *Scheibeninstrument.* I will call it *Catageolabium*,† as it serves for subterranean measurement."

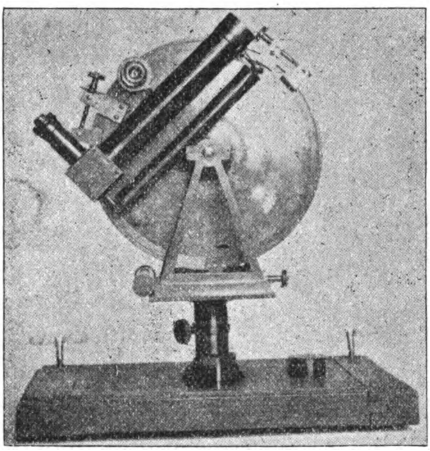
Here follows his description, from which it appears that the circle had a diameter of 14 or 15 inches and was divided into 24 hours of 60 minutes each. It had two verniers, by which the hour-minutes were divided

* *Vorstand des Geodetischen Instituts der Königl. Technischen Hochschule*, München, Germany.

† Constructed from the Greek words κατά, downward through, γῆ, earth, and λαβεῖν, to take or to measure.—SCOTT.

into 15 parts. On the alidade there was a small circular box-bubble and compass. The vertical arc was of 6-inch radius, and provided with one vernier, by which each degree of arc could be read to 2 minutes. Upon this vertical arc was a tube supported by two pillars of such length "that the tube can see beyond the plate in very precipitous angles" (this is, therefore, certainly the first top-telescope); "but the discomfort experienced with these precipitous angles by being obliged to hold the head so far back or so far forward over the plate in order to get the eye to the tube is avoided by unscrewing the front part of the tube and substituting another small tube bent at a

FIG. 68.



One of the Oldest-known Broken-Telescopes.

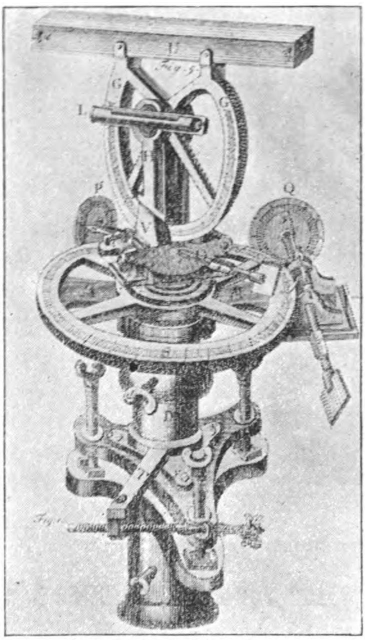
right angle and provided with a 45° reflector." (This is the first broken-telescope that I know of.)

Another very old broken-telescope is shown in the accompanying illustration (Fig. 68). It is one made by an unknown mechanic, though from the metal work and workmanship I should say that it came from the shop of Hoeschel—the son-in-law of Brander—somewhere between the years 1800 and 1810. The objective is achromatic and of Fraunhofer's design. The instrument consists of only a vertical circle, a broken-telescope and a telescope-bubble of Brander's pattern. It is now in the possession of the geodetic department of the Royal Technical Academy *Hochschule*) of Munich.

Another of the earliest types of these instruments which I have in my collection was probably made by Utzschneider & Fraunhofer, but in what year I do not know. The striding-bubble it now possesses has been added recently, as well as the micrometer-screws and verniers of the vertical circle. But the telescope, the horizontal circle, the tripod base and the arms which support the reading-glasses remain unchanged.

I send also another illustration (Fig. 69) of the *Scheibeninstrument* of Hoeschel as modified by Oberbergrath von Voith in Amberg, and described in his work.* The illustration shows a theodolite of Hoeschel as it was duplicated in 1792, for the Bavarian Academy of Science, for a land-survey. To adapt this theodolite for mine-surveys, von Voith (in 1805) replaced the telescope with a diopter-tube, while the micrometer-screws for the measurement of angles remained unchanged.

Fig. 69.



Von Voith's Theodolite.

This instrument was also provided with a single vernier at one end of an alidade, or arm, at the opposite end of which was the clamp and tangent-screw. For mine-surveying there were provided signal-lamps, in which the rectangular window was marked with a cross. Brander's bubble-tube (which was hinged at one end and provided with double-adjusting nuts at the other) occurs again on the vertical arc. To set up the instrument in the mine, v. Voith used the Hungarian surveying-buck.

Komarzewski's instrument is described and illustrated in the *Journal des Mines, No.* 48, *Fructidor, An XI* (1803). *Rapport fait*

* *Vorschläge zur Vervollkommnung der Markscheiderinstrumente,* Ignaz v. Voith, Landshut, 1805.

à l'Institut National des Sciences et des Arts sur un Graphomètre souterrain destiné à remplacer la boussole dans les mines, as well as in the little work entitled *Mémoire sur un Graphomètre souterrain* (*à Paris chez Charles Pongens*), which says that the instrument is constructed upon the same principles as the theodolite, and consists of a circular disk, which is placed firmly and in a horizontal position by means of a level with a cylindrical air-space.

But the illustration is nothing else but the *Eisenscheibe*, as it is portrayed in von Oppel, and as it was improved by Studer in Freiberg, for the measurement of vertical as well as horizontal angles, " under the instructions of Krumpel," in 1792.* Komarzewski made surveys in the mines of Freiberg with this instrument between 1795 and 1801.

Borchers, while a mining engineer in Clausthal, wrote† that in France mine-surveys were made about 1835 with a theodolite with eccentric telescope. Reference may be made also to an article by Prof. Combes, *Annales des Mines*, Series 3, *Tome* ix., 1836, and to the separate edition, published in the same year, and entitled *Sur les levés de plans souterrains*, etc.

The theodolite as a mining-instrument was described and illustrated in the work of von Hanstadt in 1835; but in the *Bergwerksfreund*, vol. 14, p. 392 (1851), the Royal Prussian mine surveyor of Saarbrücken says that the use of the theodolite had been established in the mines there since 1817. The official records of that district show with certainty that Praediger used a theodolite there in 1835. Two theodolites of this kind, ordered from Breithaupt by the Royal Prussian Ministry of the Interior, were described by Praediger in the *Bergwerksfreund* in 1836.

In the work of Gensanne‡ is described the *Recipiangle ou Graphomètre*, which, according to the illustration, consists of a half-circle with one set of fixed and one set of movable sights, so that it is nothing else but an astrolabium. Again, the work of Duhamel§ describes a method entitled *Lever de plan d'une Mine avec le Graphomètre*, etc.

* *Freiberger gemeinnützige Nachrichten*, 1803, p. 189.

† *Bergwerksfreund*, vol. xiv., No. 40, 1851.

‡ *Géométrie Souterraine*, M. de Gensanne, Paris, 1770; Montpellier, 1776.

§ *Géométrie Souterraine*, J. P. F. G. Duhamel, Paris, 1787, p. 179.

The solar apparatus shown in Fig. 54 was first made in Germany by Hildebrand of Freiberg, on an order of Bergingenieur Keller, who was then in America, but with improvements suggested by me.*

Mr. Scott: Dr. Schmidt may be correct in ranking Giuliani's instrument as the first of broken-telescopes, but I must differ with him in the assertion that in it is to be found the first *top*-telescope; for while the sighting tube occupies the same relative position it is in no sense an auxiliary device, or what the Germans call *Hülfsapparat.* There is a distinction between an eccentric main telescope and an eccentric auxiliary telescope, and in this comparison it does not matter whether the eccentricity occurs at the side or above the center of the instrument. The sighting-tube of Giuliani's instrument is no more to be considered a *top*-telescope than that shown in Fig. 66 is to be considered a *side*-telescope. I could also question the statement, but not with the same degree of assurance, that the sighting apparatus in the *Catageolabium* is a broken-telescope at all. It seems to be a simple application of a prism to the eye-piece. In the common acceptation of the term, as I understand it, a broken-telescope is one in which the prism is placed between the ocular and the objective, as I have it in Fig. 68. There seems to be a prevailing opinion that the invention of the broken-telescope belongs to Reichenbach. T. Ertel & Son, his successors, in writing to me, doubtless with reference to the instrument mentioned by Prof. Schmidt (p. 84) as "another of the earliest types," say:

> "Since our present manager came to the direction of our business he has been able to discover only one of Reichenbach's instruments, which we sold to the Royal Technological Academy. As nearly as could be judged by its appearance it must have been made some time in the first twenty years of this century, but we are not certain that this was the first of its kind."

Illustrations of the *Eisenscheiben* of von Oppel, to which Dr. Schmidt has referred, I reproduce here (Figs. 70 and 71) from my copy of this justly celebrated old work.† On pp. 207–212 he seems to say, in part:

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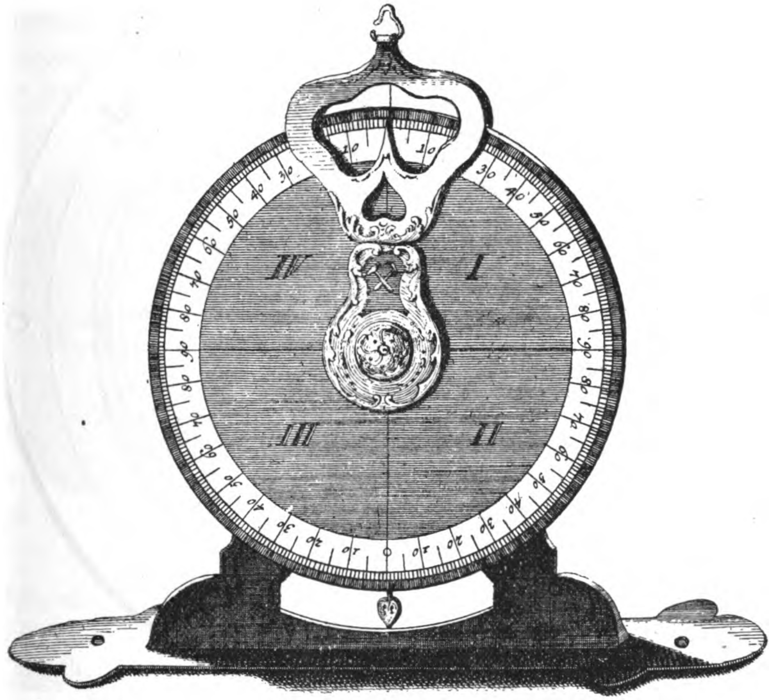
* *Zeitschr. für Instrumentenkunde,* vol. viii., p. 188.

† *Anleitung zur Markscheidekunst,* F. W. von Oppel, Oberberghauptmann in Dresden, 1749.

"I divide the *Eisenscheiben* into two principal kinds, those that give the angle in the common degree of the circle and those which express it in hours, etc. The first kind (Fig. 70), which is graduated into 360°, I propose to make as follows: Take a circular brass plate and divide it into four quadrants, each of which is marked with a Roman numeral, as is shown, for distinction. Each quadrant is divided into degrees and numbered each way from the principal zero-line, which is engraved upon the back of the plate as well as upon its face. The index-arm must now be pivoted at the center in perfect concentricity with the plate, and at its outer extremity provided with a ring or hook, to which the measuring chain may be conveniently attached. Then make a stand, the base of which can be screwed to a desired station, and mount the plate upon it by two hinges, so that it

FIG. 70.

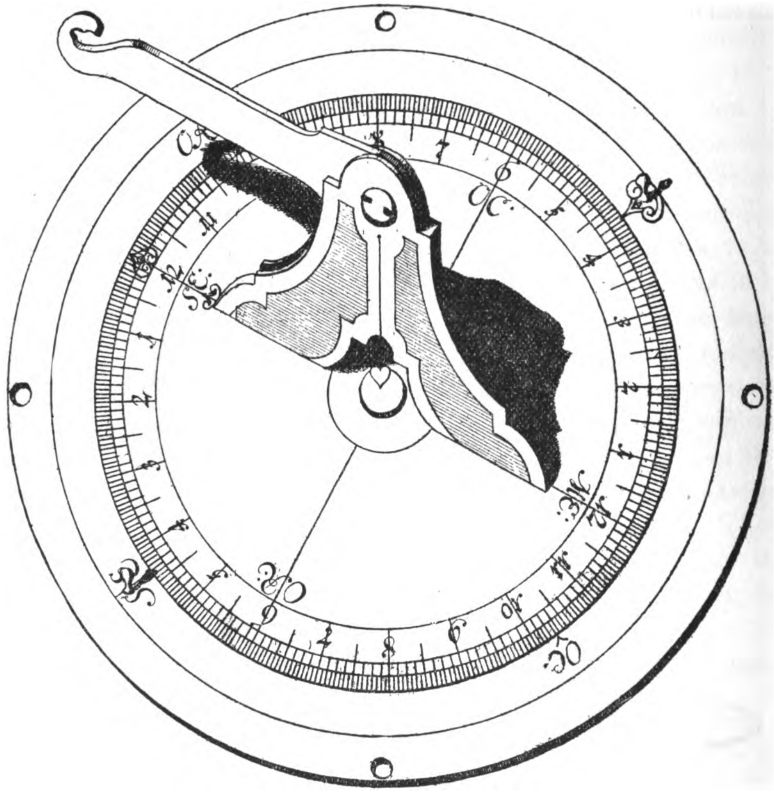


Von Oppel's Eisenscheibe, Style No. 1.

can revolve, if necessary, to a horizontal position upon the 90°-line. If the small plummet line, which is attached to the center of the upper part of the base, always coincides with the meridian-line that is engraved upon the back, the base will be perfectly horizontal.

"The *Eisenscheibe*, which is divided into hours (Fig. 71) and the subdivisions thereof, I recommend as being just as convenient for use. In a solid brass circular plate, which is hollowed out for the purpose, is inserted a smaller graduated disk, as well as a ring surrounding it, each of which may be revolved about a common center at will without disturbing the position of the other. In the graduated circle the cardinal points (Meridies, Septentrio, Occidens and Oriens) are marked in reversed position as in the compass, and upon the 12th-hour line is securely fastened a strong brass plate, standing perpendicularly upon it, and holding a brass indicator-arm provided with a hook at its outer end, to which the brass measuring-chain may be attached. The intermediate ring is divided simply into quadrants, and upon its meridian-line are two small blue steel pins to aid in moving it upon a back-sight, where it is clamped by means of small brass pins from beneath. Through the outer plate are bored a few holes, so that the instrument can be securely screwed to any station-point. On each side of the vertical plate are suspended small plummets, which determine the horizontality of the setting."

FIG. 71.



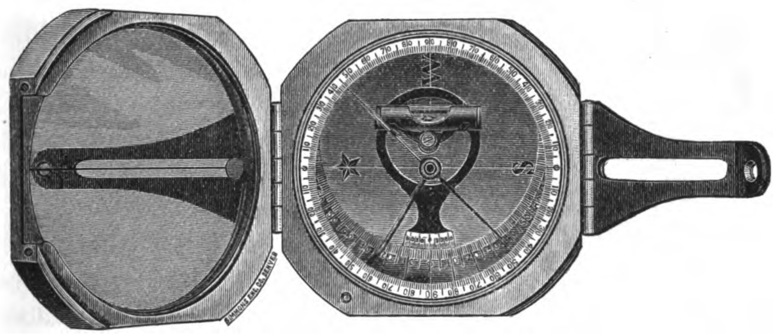
Von Oppel's Eisenscheibe, Style No. 2.

D. W. BRUNTON, Denver, Colo. (communication to the Secretary): I have read with care Mr. Scott's most interesting paper, and regret that I have not time to discuss at length some of the many questions it suggests.

In Aspen, Leadville, and Red Cliff, Colo., and generally in western mining camps where contact ore-bodies occur, and strip or vertical veins are almost unknown, the favorite (and, to my mind, by all odds the most convenient) instrument is

Buff and Berger's new high-standard mountain and reconnoissance transit, with a 4-inch horizontal limb, weighing 6 pounds. In this instrument the tangent-screws are placed at one side, away from the line of sight, and the edge of the horizontal arc is notched as deeply as possible without cutting through the metal. This arrangement, combined with the greater elevation of the standards, permits angles of either elevation or depression up to about 70° to be read with the ordinary telescope. This is as far as it is ever necessary to go in this region, except on shaft-work, which is always done by plumbing. The great practical objection to instruments with top or side auxiliary telescopes is not that they cannot be brought into adjustment, but that, being elaborate and expensive, they must be carefully

FIG. 72.



Plan of Brunton's Pocket-Transit Opened for Taking Courses or Horizontal Angles.

kept, and therefore are frequently in the office, perhaps several miles away, when occasion for their immediate use arises.

At the request of the Secretary, I take pleasure in contributing to this discussion an account of my pocket mine-transit,* manufactured by William Ainsworth & Son, Denver, Colo., and already in use in every country from Australia to Alaska. It is employed in the work of the United States Geological Survey, and the surveys of most of the States and of Canada. Instruction in the use of it is a part of the engineering course at the Lawrence Scientific School, Harvard University, the School of Mines, Columbia University, and a number of the western mining schools. The chief merits of this instrument consist in

* Patented September 18, 1894.

its extreme portability and the extraordinary rapidity with which reasonably accurate surveying can be performed by its use.

Many years ago I began experimenting with the purpose of devising a combination-instrument which would perform all the necessary survey-work required for current daily mining practice and commercial and legal mine-examinations. After constructing six or eight different forms, I hit upon the design now finally adopted, and made arrangements for its manufacture with the house above named. The development and introduction of this instrument has been with me a labor of love, and not an enterprise looking to commercial profit; and the same is, to a considerable degree, true of the manufacturers, who use the utmost care in the production of the instrument, and push its sale largely as an indirect advertisement of their chief business, namely, the manufacture of instruments of precision and high-class balances, in which latter line they have already surpassed nearly all competitors, and achieved the command of the American market.

Fig. 73.

Correct Position in Taking Courses or Horizontal Angles not more than 45° above or 15° below the Observer.

The dimensions of this pocket-transit are $2\frac{3}{4}$ by $2\frac{3}{4}$ by $\frac{15}{16}$ inches, and the weight (in aluminum case) is 8 ounces. In other words, it is strictly a pocket-instrument, and is, in fact, carried in the pocket like an ordinary compass, which it does not exceed in bulk. Yet it does the work of a sighting-compass, a clinometer, a prismatic compass, and an Abney or Locke level, measuring horizontal and vertical angles, dips, etc., with a high degree of accuracy.

I will not enter into detail here as to the manner of its use for all these purposes. The manufacturers will furnish on demand a circular covering these particulars, and a few general remarks will be sufficient in this place.

Fig. 72 is a plan of the transit when opened for taking courses or horizontal angles. It shows a spirit-level, which should be set, for this operation, at right-angles to the line of sight.

Fig. 73 shows the proper method of *holding* the instrument in taking courses and horizontal angles.

The instrument is correctly sighted on the object when the eye, looking into the mirror which lines the lid, sees the black center-line bisecting both the opening in the front sight and the object sighted at; after which, the reading of the needle is comparatively easy if the proper precautions as to position and leveling have been observed. The most important of these is, that the instrument should not be turned in the hands, as is customary with an ordinary compass, but the hands should be held rigidly against the body, which should serve as a tripod for the instrument, and changes of direction should be made by twisting the body to right or left, preserving the level position as indicated by the bubble.

For inclined sights and for taking dips, the bubble-tube (which is easily revolved, by means of a crank on the back of the instrument, with the middle finger of the right hand, while the thumb and fore-finger grasp the instrument) furnishes an accurate reading by means of the vernier attached to it (Fig. 72) and revolving with it.

A little practice will enable the engineer to perform with this small pocket-transit work of great variety and surprising accuracy at very little cost of time. In many cases, such a small and portable instrument will be to the engineer a most agreeable change from the numerous old-fashioned contrivances which it supplants.

H. D. HOSKOLD, Buenos Aires, Argentine Republic, S. A.* (communication to the Secretary): The writer is not aware that any record exists indicating the period when angular and linear measurements were first introduced and practiced as a science, and the form of the instruments employed as auxiliaries in useful astronomical observations and engineering operations for scientific and economic purposes. Still, as previously stated,† he believes that the first instruments were exceedingly rude in construction, and probably consisted for the most part of two

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* Director of the National Department of Mines and Geology and Inspector General of Mines of the Argentine Republic. This communication was received May 5, 1899.

† *Trans. Am. Soc. Civ. E.*, vol. xxx., p. 137, 1893.

movable cross-bars of wood or metal fixed on the top of a rod, the opposite end of which was thrust into the ground for use; or some such contrivance may have been placed on a square board in the form of a plane-table. The angles observed and formed by the radial bars may also have been determined in linear measure by applying a simple straight-line divided scale of equal parts, similar in principle to that which was applied to the cross-staff of navigators in 1514,* or by the divided sides of a quadrilateral figure or geometrical square described upon a board.

Nevertheless, in the Chaldean records, recently discovered, mention is made of an *iron wheel* (or circle) constructed some 4000 or 4500 B.C.; but nothing is said about its use. It is important to note that the late Mr. George Smith, of the British Museum, discovered, prior to 1870, in the ruins of the tile-brick library in the Palace of Sennacherib (704 B.C.), a large fragment of a circular Assyrian astrolabe, the circumference being originally divided into 12 equal parts, corresponding to the signs of the zodiac and months of the year. It had, also, an inner circle, and in each division the principal or prominent stars are found. This instrument is at least 2604 years old, and probably the oldest on record.

The ancient astronomers (date unknown) employed copper circles of large diameter placed in the meridian, as also at right angles to that line;† but we have no evidence how they were divided. Astronomical and other observations were practiced, it is said, in Egypt 3000 B.C.; as they were also in China 2700 B.C., if Chinese history is worthy of credence. A Chinese emperor, Hwang-ti, is said to have invented the cycle of 60 years, 2600 B.C.‡ He has also been credited with the invention of various astronomical instruments, including one for observing the four cardinal points, which is generally considered to have been a magnetic compass;§ but it was more probably a circumferentor. It is recorded that early Buddhist astronomy possessed instruments made of brass; but their inferiority and mode of use caused them to give place to larger ones, enormous

* *Life of the Navigator John Davis* (1578), p. 145, 1889.

† J. S. Bailly, *Histoire de l'Astronomie Ancienne*, 2d ed., 1781, p. 13.

‡ Davis, *History of China*, vol. i., p. 219, 1857.

§ J. S. Bailly, *op. cit.*, p. 121.

instruments built up of masonry, the divided portion, or arc of the circle, being of marble. With these instruments, angles were measured to single minutes. In 1729 such an instrument existed in Delhi, and a degree upon its divided limb was measured equal to $2\frac{5}{6}$ inches. Claudius Ptolemy, in the second century, possessed similar instruments, as also the astrolabe, with four circles placed in different planes, which had been invented, some 300 years before, by Hipparchus, the greatest discoverer in mathematics, astronomy, geography, etc., of ancient times.

From what has been brought forward, it cannot be fairly argued that the ancients may not have possessed portable circular instruments for rough land-observations long prior to the times of Hipparchus, Ptolemy or Sennacherib. Unfortunately, however, the infamous and ever-to-be-lamented destruction of the Alexandrian libraries, an incalculable loss to the world for all time, has placed it out of our power to determine the particular form, nature and size of the instruments used during the earlier ages. The sculptured and painted figures recently discovered upon the walls of a copper-mine at Wady Magerah, which was worked under the reign of the Egyptian King Senefura, 4000 B.C., and also the map of an Egyptian gold-mine from 1400 to 1600 B.C., afford strong inferential evidence that mine-surveying was known and practiced at a very early period of the world's history. From that period to the time of Hero and Euclid—also improvers of instruments and the science of surveying—little of importance is known relative to such matters; neither have particular details come down to us regarding the instruments and mode of surveying adopted during the earlier Greek and Roman mining period. Even the great Roman engineer, Antoninus, does not appear to have employed any angular instrument in determining the direction of the various lines of roads measured by him in the nations conquered by the Romans. It is highly probable that mine-surveying was forgotten more or less, or hid in obscurity for several centuries, as a forbidden art, or suspicious dark practice.

Tradition affirms that the first mode of performing surveys in mines in England involved the use of a low, three-legged stool, like a small plane-table, a chalked string, some kind of measure, and a book for entries. It seems that the plane-table was fixed at the end of the first bend in the underground road, and the string, held in the direction of the road leading back to the shaft, was then raised a little by the forefinger and thumb, and let fall suddenly, producing upon the table a chalk-line, a portion of which was erased to leave room for succeeding lines. The string was then stretched in a forward direction and treated as before, the measure of the lines being entered in a book, as also the number of the chalk-lines. At the second bend in the road the last preceding forward line was brought into the direction of the last piece of road measured, and the string stretched in a forward direction. Thus a kind of rough traverse-plotting was carried on underground. Undoubtedly, however, that plan of surveying must have been limited to a few lines. It is also probable that such surveys were made with the purpose of repeating them at the surface; and, if so, the direction of the first line in the underground working must have been determined by suspending two lines down the shafts, which, in those early times, were very shallow. When the writer was a boy he heard an old miner of eighty-four make this statement, and the old man had heard it from his grandfather. Whether this plan of surveying is older than Agricola, 1546; Digges, 1571; or Houghton, 1681, cannot be determined; but it is highly probable that it preceded the latter, and continued to be employed after he wrote his work on *Surveying of Mines*. This mode of the three-legged stool may also have given rise to the old-fashioned land-surveying plane-table.

It is on record that the "good ship Plenty" sailed from Hull in 1338, directed by the mariner's or sailing (magnetic) needle; so that a rough magnetic compass could have been employed in England for mining and other surveys previous to the time when Agricola wrote; but there does not seem to be any actual proof that such was the case during the long interval which elapsed until the time of Houghton.

Quadrants and plane circular astrolabes, the one divided into 90° and half of the other sometimes to 180°, for measuring the elevation of the sun and stars at sea and on land, existed at an early period in the East, in Spain, and in England. The former had plain sights attached to one side, with a plumb-line to mark the angle. The circular instruments had plain sights attached to a radial bar, revolving around the circumference in the same manner as in Digges's *theodelitus*. Such quadrants and astrolabes were sometimes suspended by a ring in the vertical plane of the object to be observed. Two such instruments as those described, of small diameter, are represented upon the second original Borgian Map of the World, by Diego Ribero, Seville, 1529, which map is preserved in good condition in the museum of the Propaganda at Rome. The instruments referred to are divided to single degrees, and, in that respect, are superior to the *theodelitus* of Digges; the parts of a degree were estimated. An exceedingly curious ancient magnetic compass, with five divided circles, is also engraved upon that map. The instruments of Ribero were of a common type, used long before and after his time, and they present sufficient evidence to prove that these were the models from which the compass of Agricola, 1546, and Digges, 1571, and others were derived. The astrolabe, in fact, in its simplest form was a plane circle (in contradistinction to that with four circles in different planes, sometimes divided half-way round, and sometimes entirely so), and, consequently, must have been used for land-surveying exactly in the manner described by Digges. At the International Geographical Congress, London, 1896, the authorities of the British Museum exhibited a number of astrolabes—the earliest being one made in Toledo, Spain, in 1067. There were also one made in Valencia in 1086—evidently derived from Moorish or Arabian sources—and one made in Cairo, 1240, as well as one made of brass, in England, in 1260, and one formerly belonging to Sir Francis Drake, 1570, besides various others of the fourteenth century and succeeding dates.

With the exception of the omission of some types of surveying instruments, Mr. Scott has fairly represented in his paper the progress made in various countries in the construction of instruments for the object under discussion. In the copy of Digges's second edition, 1791, in the possession of the writer, Chapter 27, there is a diagram of his 2-foot surveying circle—*theodelitus*—a copy of which was sent to Mr. Scott. We cannot suppose, however, that a circle of so large a diameter was commonly used in mines; still, it could have been so employed. Nothing would be gained by following Mr. Scott in detail, because he has done his work so well.

It would appear, however, that little improvement was made in land- and underground-surveying instruments up to the time when Ramsden completed, about 1760, the grand invention which he applied in practice during the period from 1784 to 1799. Others followed, some time prior to 1788, in Germany, and also probably in France about 1790. As far back as 1804, Fenwick, a celebrated surveyor and colliery viewer of Durham, England, proposed the plan of a "fast needle," as he termed the *circumferentor* or rough theodolite-limb, constructed in his time. Still, he had to depend upon the magnetic needle to obtain the bearing of some selected line in the survey. Fenwick's book contains a complete system of magnetic-compass or dial surveying, and, so far as that system is concerned, it has not been, nor will it ever be, superseded.

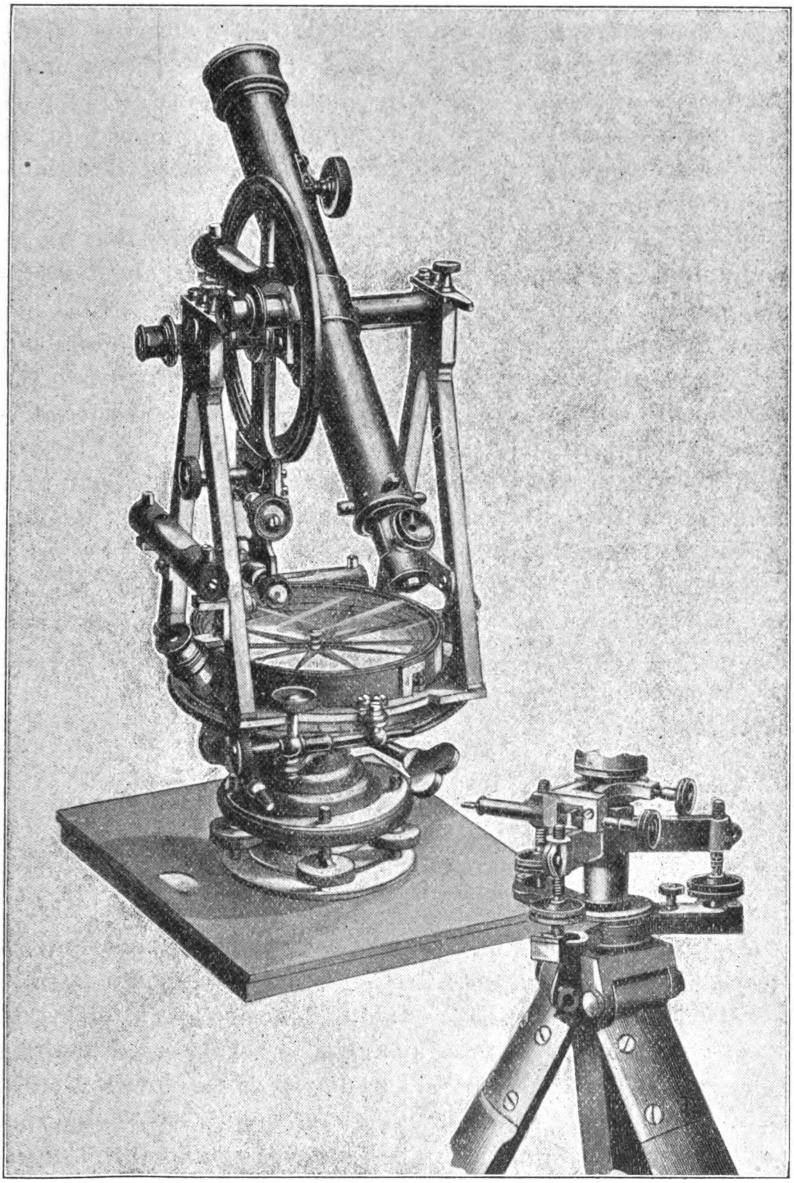
Various opinions had been emitted from Fenwick's time up to 1842, when Butler Williams,* a prominent English civil engineer, suggested the necessity of improving the theodolite and adapting it more generally to mine-surveys. He also wrote a very concise and exceedingly useful chapter upon underground surveying, suggesting the use of three tripods, as also a system of plotting underground surveys by co-ordinates. Combes and D'Aubuisson had formerly attempted to introduce some such plan; still, such was the opposition and obtuseness of that period, that the miners' dial in some form or another was, and still is, continued in use for mine-surveying. Various authorities have stated that the writer was the first in England to publish, in 1863, a general system of mine-surveying by the sole use of the theodolite. That work advocated plotting underground surveys by the co-ordinate system, and for this and other useful purposes a complete set of traverse-tables formed part of the work alluded to.†

Although no account of the miners' transit-theodolite (Fig. 74) was published earlier than 1863, still the writer believes that he had it in use prior to 1858. By means of a long diagonal eye-piece, the instrument was intended to be used for connecting underground workings to the surface by direct sighting up a shaft, and fixing an illuminated wire in the same direc-

* *Practical Geodesy*, B. Williams, C. E., pp. 207, 219, 1842.

† *Practical Treatise on Mining, Land and Railway Surveying and Engineering*, London, 1863.

FIG. 74.



HOSKOLD'S MINERS' TRANSIT THEODOLITE.

In the right-hand lower corner is shown the method of mounting upon three leveling-screws.

tion as the first drift underground. In deep and wet shafts this plan was impracticable; but in shallow dry pits, when the operation was performed on dark nights, fair success was obtained. For deep pits, the writer found that two chains made in a particular form of steel wire of different sizes, to support the weight suspended down a shaft for determining the direction of the first line in the underground survey, were completely satisfactory.

The theodolite, Fig. 75, was designed soon after that represented by Fig. 74; but it was not constructed until about 1862–63, and an account of it was published in 1865.* However, some defects had been introduced in the construction, and being pressed for time, the writer did not attend further to the matter until 1889, when Troughton & Simms made some alteration in the instrument, making it as represented in Plates I. and II. of the writer's paper, published in 1893.† That firm also constructed a new instrument of the same class as that under consideration, introducing some improvements represented in Fig. 75, which was exhibited in the Argentine Mining and Metallurgical Section at the Chicago Exhibition in 1893. The jury on scientific instruments gave the highest award for the instrument, finding the chief points of excellence in it to be as follows:

"1. It is an instrument of new appliances.

"2. Peculiarity, beauty and novelty of construction.

"3. Adapted to facilitate surveying operations with greater accuracy and in less time than is usual with surveying instruments.

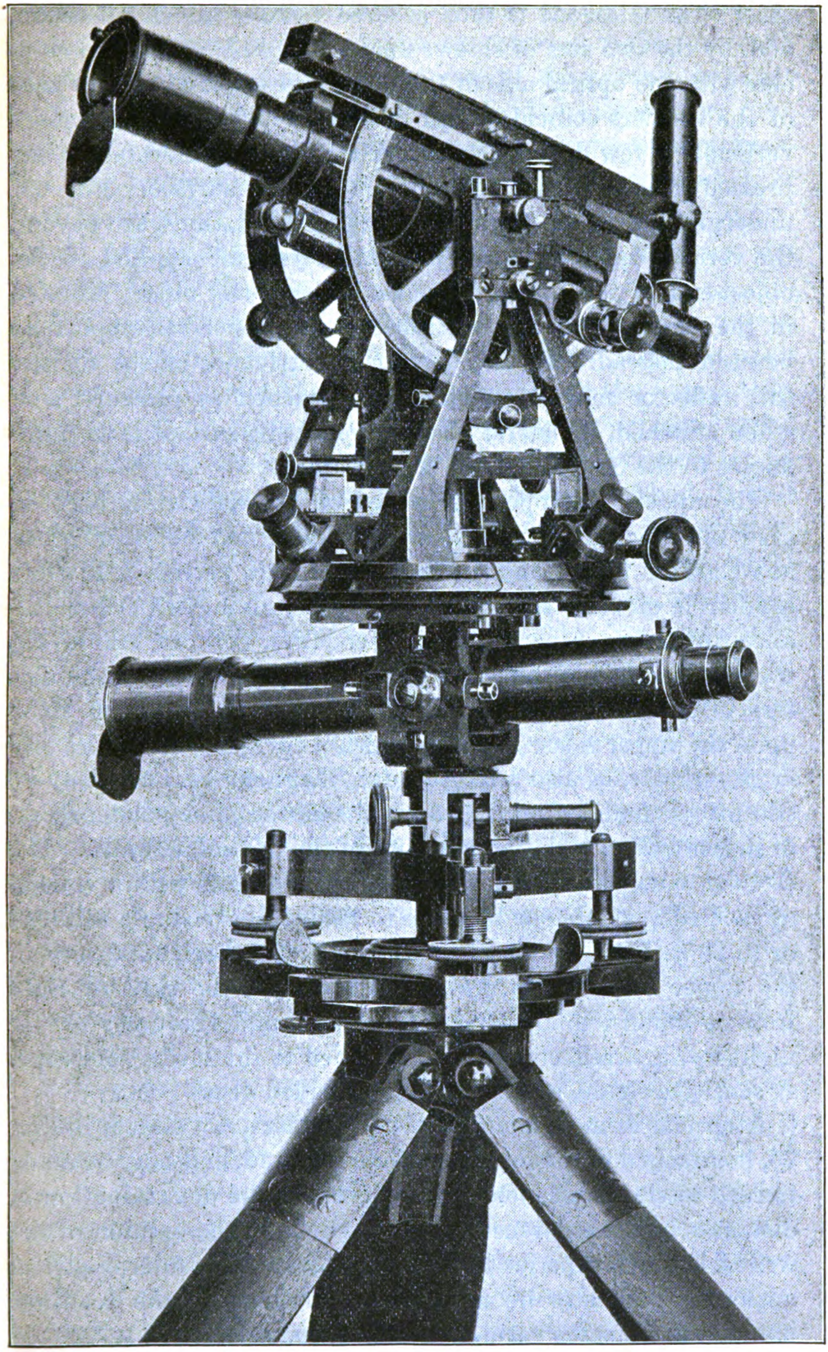
"4. It is a general labor and time saver."

As may be seen in Fig. 75, one of the principal improvements consists in the adaptation of a second, or, as we should term it, lower telescope, arranged to move upon a short horizontal axis, the telescope occupying an elongated or oval-shaped opening made in the center of the enlarged part of the lower vertical axis. Each end of the short horizontal axis is suspended in a collar between four adjusting screws, which pass through the termination of a short horizontal cylinder, the collar of which is firmly screwed or cast to the outside of the lower vertical

* *Trans. S. Wales Mining Engineers*, vol. iv., No. 5, 1865.

† *Trans. Am. Soc. Civ. E.*, vol. xxx., pp. 135–154, 1893.

FIG. 75.



HOSKOLD'S ENGINEERS' THEODOLITE.

axis. The telescope is thus secured against lateral vibration, and, by the two sets of screws named, may be adjusted to coincide with the optical axis of the upper telescope when the zero of the verniers coincides with 360°, 90° and 180°. It moves vertically a few degrees, sufficient for sighting elevated or depressed objects within its range, upon the surface. For use underground, when elevated or depressed stations are beyond the vertical range of the telescope, a reflector applied to the object-end of the lower telescope reflects any object situated in the perpendicular or vertical; or the upper telescope may be used instead. By an ingenious contrivance of the maker, this reflector may be attached or detached at pleasure, and, when attached, its lateral plane or reflecting-surface is at right-angles to the optical axis of the telescope.

The upper telescope is mounted on Y's sufficiently high to give the amount of vertical angle which may be required in any class of mine; and its horizontal axis carries a divided semicircle on each side of the telescope, giving a perfect balance to the upper parts of the theodolite, without employing useless dead counterpoise weights. A groove about three-quarters of an inch in width and four inches in length is fixed upon the upper telescope, into which a corresponding part of a large circular, as also a long-trough, magnetic compass may be slid for use underground or upon the surface, independently of, or in connection with, the readings of the theodolite-limb. The circular compass carries a long sensitive needle with a vernier at each end, which may be made to read either to single minutes or to 20 seconds, as may be required. The horizontal axis of the upper telescope is perforated to admit the rays of light from a lantern to illuminate the hairs underground; or, for night-work, a reflector is also attached to the lower telescope. A sensitive stride, or axis-level is provided also.

A special form of micrometrical eye-piece, not shown in Fig. 75, is attached to the telescope when required, and may be made to read to single seconds. Its chief use is the determination of distances by the sub-tense system,* which, in the opinion of the writer, is much superior to the stadia plan. This micrometrical apparatus may also be used as an auxiliary to the readings obtainable from the verniers of the theodolite.

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* *Trans. Am. Soc. Civ. E.*, vol. xxx., pp. 147, 148.

The simple but efficient arrangement of two telescopes in the instrument under notice enables an observer to dispense with the usual practice of making the zero of the verniers coincide with 360°, 180°, etc., or zero of the divided circle, every time any angle has to be measured in traverse or circuitous surveying, thus reducing the time and labor at least to one-half of that required by the use of other classes of surveying-instruments, and, at the same time, securing greater accuracy and certainty in the final results.

The *modus operandi* is simply to set the instrument over a station, properly level it, and direct the lower telescope upon the back-station, and the upper telescope upon the fore-station, neglecting the vernier readings during the operation; then a single reading determines the amount of the observed angle between the optical axes of the two telescopes, which is also that between the two stations. If the observer has not sufficient confidence in his manipulation, or suspects that some slight displacement of the instrument or slipping of the screws has occurred during the interval of the observation, he may decide the question instantaneously by applying the eye to each telescope in quick succession, when, if no error has been introduced, the vertical hairs of each telescope will continue to strike through each station-mark. If, on the contrary, any slipping of the parts of the instrument has resulted, it is instantly corrected by applying the eye first to the lower telescope, bisecting with the body tangent-screw, and then to the upper one, performing the same operation with the upper tangent-screw. Or, if the error was only due to an imperfect observation made with the upper telescope, the last operation will suffice for the correction. However, with proper care, no such vitiating error should occur.

It is apparent that with the use of a theodolite having only one telescope, no such instantaneous check-proof can be obtained at each station, at least without reversing the telescope from the fore- to the back-station, or *vice versa*, and then examining the vernier-zero in order to determine if it coincides with the zero of the divided circle as at first fixed. Each of the known modes of measuring horizontal angles in traverse or circuitous surveying requires two separate readings before an angle can be determined. This would be the case when the vernier-zero is made to coincide with 360° at only the first angle, and when at each succeeding station each preceding angle or fore-reading is made to become the back-reading alternately. For the engineer is never certain that some slight displacement has not occurred during the transit from one station to another, due to jarring or the slipping of screws, verniers and divided circle, contraction or expansion of parts; or it may be that the operator has unconsciously touched the tangent-screw of the vernier and divided circle, etc., rendering a constant examination of the vernier-readings an absolute necessity for both back- and fore-readings, comparing them with the book-entries, all of which means a waste of time and extra mental and manual labor. To insure absolute freedom from error, when the vernier-zero is employed for all the back-observations, it is necessary to observe the supplementary angle, or, at least, repeat the angle, either of which would involve four separate operations and readings.

On the contrary, even when the supplementary angle is taken by the theodolite under consideration, Fig. 75, only two separate readings are required. For example, suppose that the angle is 178° 35′ 15″, and the supplementary equals 181° 24′ 45″, then 178° 35′ 15″ + 181° 24′ 45″ = 360°, as it ought to be, if the instrument is in perfect adjustment and the manipulation is correct. Any difference from an entire circle would show the amount of error—plus or minus. A small amount of error, amounting to from 15″ to 20″, will sometimes exist, when instruments are inferior, and is difficult to eliminate. It will, therefore, be manifest that the lower telescope is capable of rendering incalculable service.

This instrument may also be made to take the place of a transit-theodolite for a variety of operations, especially in producing transit lines. For example, when it is necessary to produce any given line—a frequent operation in a certain class of surveys—it is done by first placing the telescopes to look in opposite directions, making the zeros of the three verniers of the horizontal circle coincide nicely. The lower telescope is then directed to the back-station; and the optical axis or vertical wire in the upper telescope points out the direction of the transit line. The verniers being double, there are nine distinct readings by which to effect the coincidence before producing the line; and as the verniers read to fifteen seconds, the probable error, plus or minus, would be $\frac{15}{9} = 1.66$ seconds. It is doubtful whether a line could be prolonged by a transit-theodolite within this limit of error.

Where townships or extensive areas of land are required to be set out in blocks, this instrument would prove invaluable, for the reason that the two telescopes may be set at right-angles at the commencement of a day's work, and the corresponding work set out with the greatest facility and accuracy. It may, however, be convenient to examine the vernier-readings as the work proceeds.

In the wide arms carrying the reading-microscopes, and just behind each of them, a hole is drilled, and on the top of each hole a reflecting prism is screwed, having a horizontal motion, so that each of them may be turned until a ray of light is caught and reflected upon the verniers, which are thus effectually illuminated, so that it is not necessary to bring the light of a candle or lamp inconveniently near the head when the angles are read.

When the instrument is used on the surface, the long or trough magnetic compass is slipped into a corresponding groove to receive it under the horizontal divided circle, or on the top of the upper telescope.

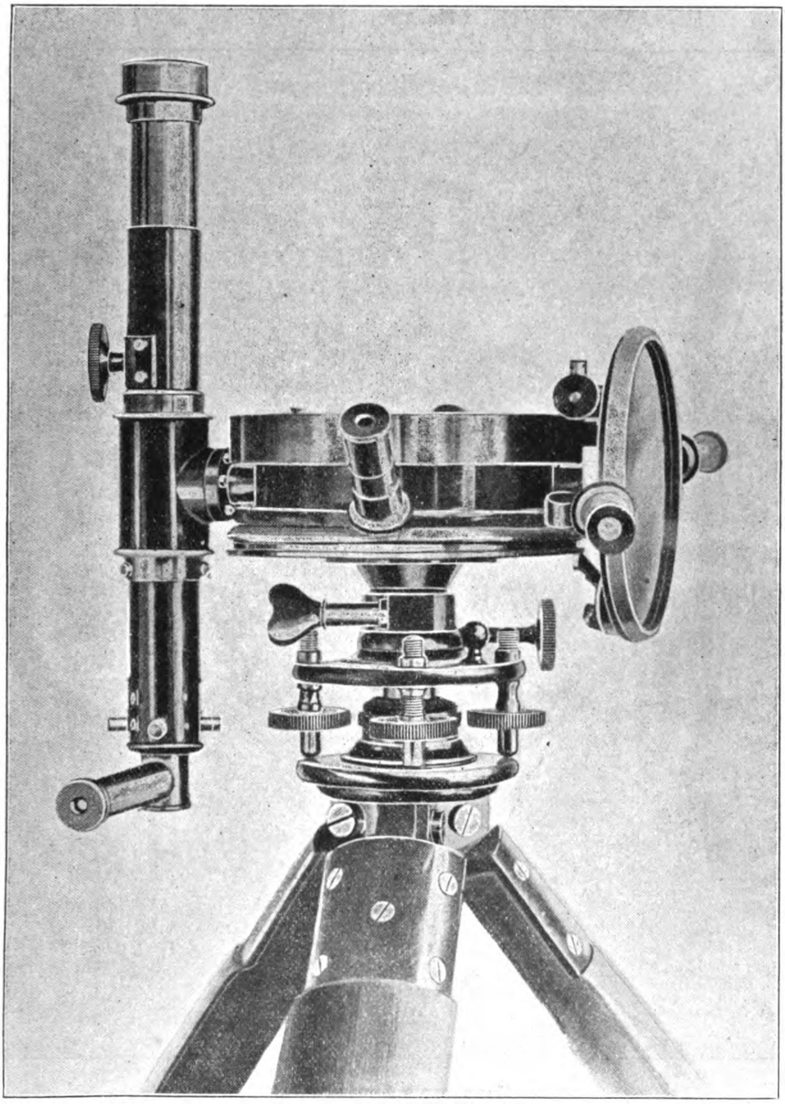
By preference, a triangular leveling- and centering-frame of light weight, with three leveling-screws, is attached to the theodolite, Fig. 75. The conical heads of these screws are locked by a slipping plate into a similar triangular frame, which is screwed to the top of the tripod-stand. This leveling-frame carries two other thin movable plates, and vertical pins working in elongated slot-holes, and a circular clamping-ring. By means of this beautiful apparatus, invented by Troughton & Simms, the instrument has a free motion in all directions, carrying the plumb-line and bob with it, and can thus be easily and accurately centered over a fine mark made in the station.

Another theodolite of this class is now in course of construction by Troughton & Simms, and more closely corresponds to this description than the one represented by Fig. 75, which was hastily constructed to be exhibited at the Chicago Exhibition. It will have every modern improvement that the application of mathematical principles, mechanical art, and good workmanship can command, or exact surveying require. All the parts, except the bearings, axis and screws, etc., are made of composite aluminum metal; consequently, weight should not now be considered an objection to the general use of the theodolite for mine-surveying. Unfortunately, however, this kind of opposition to necessary progress will still continue in various quarters. It would be a false affectation of modesty not to note that American and other authorities have decided that this type of instrument is the best English theodolite yet introduced for general underground and surface-surveying.

On page 28 of Mr. Scott's paper reference is made to another quite distinct class of mine-surveying instruments, *i.e.*, the type known as theodolites with eccentric telescopes working round the circumference of the divided circle, instead of over its center. The French appreciated this plan, and it also prevails in Germany to a considerable extent. The great objection to French instruments of this class is the dead counterpoise-weights that they are obliged to apply at one side of the instrument, in order to balance the telescope, vertical circle and level placed on the opposite side. Combes introduced a similar and more portable instrument of this type for mine-surveying in 1836. Mr. Scott has represented it in Fig. 23 of his paper, as also the double target for sighting; but it is the opinion of the writer that this instrument was not much favored out of France. Casella also introduced in 1869, for the use of travelers, a very small instrument of this kind, superior in some respects, but inferior in others, to that of Combes. It is well balanced, but, in order to effect this, he has mounted a horizontal axis over and across the diameter of the magnetic compass, with a level on the top of the axis and at right-angles to it. This axis carries a telescope on one side and a vertical circle on the other. The obstruction due to the horizontal axis and level renders the instrument of no value as far as the magnetic compass is concerned.

The type represented by Fig. 76 in elevation and Fig. 77 in plan, and denominated *angleometer*, is of the same class as that of Combes and Casella, but superior in construction to either. It was designed by the writer some years prior to 1870, and consists of a divided horizontal circle, vernier-circle and double vertical axis, mounted upon a four-screw leveling-base, as is common in theodolites. The horizontal axis carries a telescope at one side of the horizontal vernier-circle, and a vertical circle

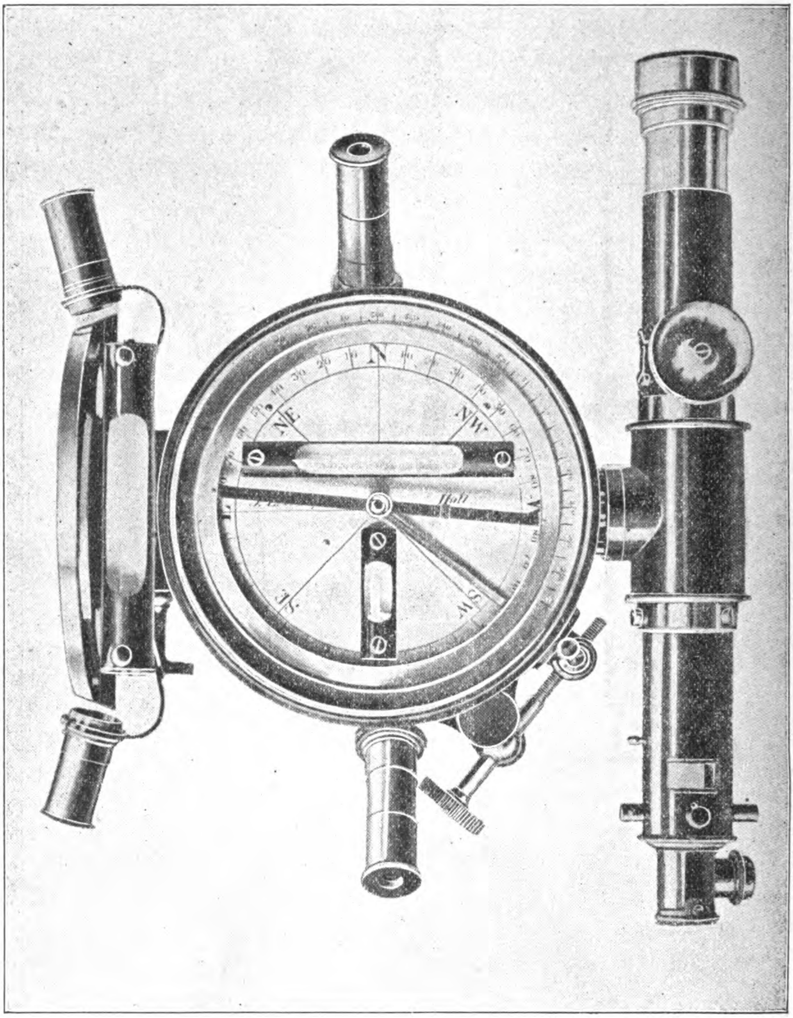
FIG. 76.



HOSKOLD'S ANGLEOMETER.

with sensitive level, attached to the verniers at the opposite side. The horizontal axis is mounted on very low bearings, a little higher than the diameter of the axis, and screwed to the upper side of the vernier-circle. The magnetic compass is placed over the horizontal axis, and almost in contact with it; the outer ring or circular portion of the compass-box is continued

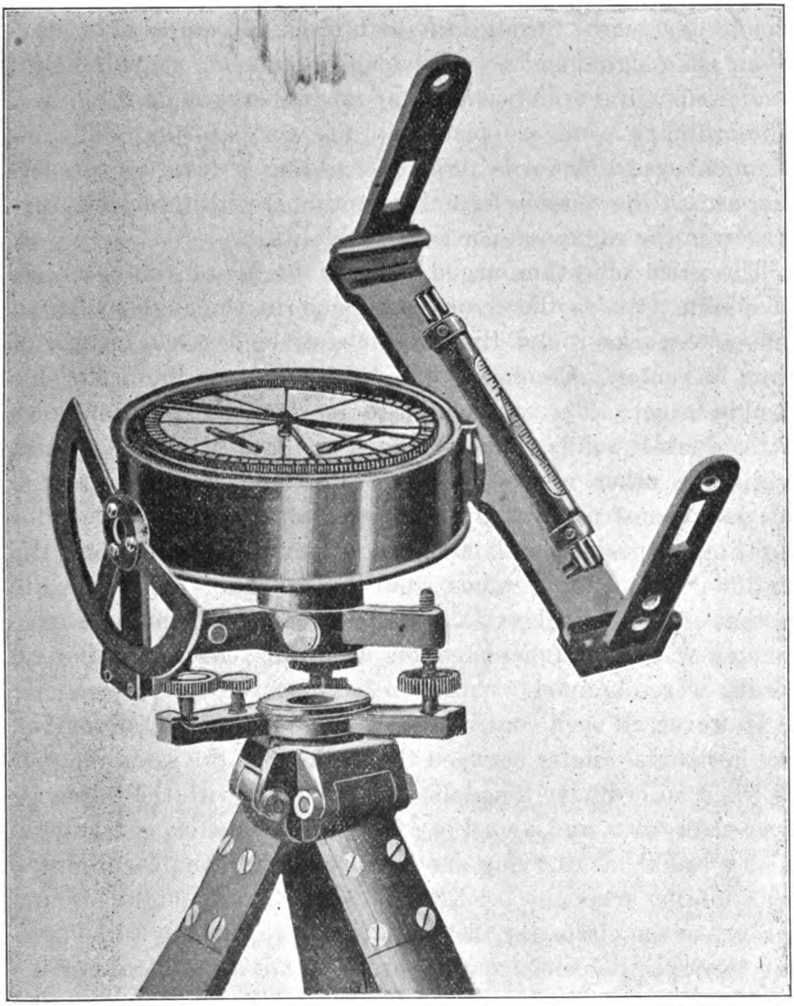
FIG. 77.



HOSKOLD'S ANGLEOMETER.

down to meet in contact with the vernier-circle or plate, so that the axis and its bearings are hidden from view. The magnetic needle carries a very light and delicate circle, as in a prismatic compass, with vernier-readings; but verniers reading to 20 seconds are preferable to the circle. The particular construction of this instrument insures a perfect balance of the parts, and leaves the face of the magnetic compass free for fine magnetic observations. This instrument is the most useful of its

FIG. 78.



HOSKOLD'S SURVEYING COMPASS.

type, especially in low and confined roads in mines, as also for connecting the first line in an underground survey to the surface by direct telescopic sight down a shaft. It is also well adapted for the observation of stars near the zenith for latitude- and time-determinations. It was a patented instrument, and received the highest award in the Scientific Instrument Section of the London Exhibition in 1872.

A very plain and useful magnetic compass, Fig. 78, was also exhibited at the same time. It is similar in construction to the angleometer, without the theodolite divided circle. The horizontal axis works through the bottom of the compass-box, carrying plain sights and a sensitive spirit-level on one side and a semicircle with verniers and clamp tangent-screws on the other. The ordinary levels are placed in the compass-box. The instrument was afterwards altered by adding a level to the vernier-arm of the semicircle, and mounting it with three leveling-screws in the same manner as a theodolite.

The great objection urged against the use of the eccentric theodolite type is the error occasioned in the angles when a telescope works round the limb of a divided circle instead of from its center. Combes avoided this error by the use of his double target. The writer used for surface-work station-poles with double points, one of which marked the station-point while the other was sighted to. For underground work, a specially constructed lamp and apparatus was employed for sighting-purposes, the lamp being removed as far from the station-point as the distance from the center of the theodolite to that of the optical axis of the telescope. When the angleometer was used in connection with this contrivance, good results were obtained.

However, all such contrivances may be avoided by observing the horizontal angles between the stations in the same manner as when an ordinary theodolite is employed, with the telescope over the center, and by using a circular protractor, constructed with a radial bar carrying another bar at right angles, mounted with folding arms and pricker-points to move round the circumference of the circle, the distance from the center to a line passing through the pricker-points being equal, on the scale of the plotting, to that from the center of the angleometer to the optical axis of the telescope.

It would occupy too much space to attempt to describe the construction and merits or demerits of all the forms of instruments which have been proposed to be employed in mine-surveying from time to time, because they are as various as the capricious and impracticable ideas of those who attempted to introduce them. Of the instruments represented by Mr. Scott's paper, pp. 35 to 61, Figs. 45 and 55 appear to the writer to be the least cumbrous and most useful. At the same time we must agree that Figs. 56 and 57 possess the merit of substantial construction, and doubtless will supersede many of those previously in use in North America. The form exhibited in Fig. 57 appears to be preferable, for the reason that the writer has been unable to satisfy himself that the second telescope attached to Fig. 56 is absolutely free from lateral vibration. This, however, is a point which Mr. Scott may be able to clear up. One of the principal features in most North American surveying-instruments is the addition of a second or auxiliary telescope in one form or another, intended for the purpose of making a connection of underground workings, one with another, by sighting down steep inclines to the perpendicular, and also with the surface by sighting down a shaft; but some of the modes of attachment of the auxiliary telescope are exceedingly unsightly, cumbrously heavy, and are also uncertain in action.

So far as the writer knows, the first recorded attempt, in England, to perform the very important operation of producing a surface-line in any given direction underground by sighting down a shaft is to be found in a book by C. Bourns, now very scarce.* It was performed when the Box Tunnel was constructed by the Great Western Railway Company, England. Bourns says:

"The shafts were so deep (some of them from 300 to 400 feet), that it was found the plumb-lines would not answer the purpose on account of oscillations caused by currents of air or otherwise; the following method was therefore resorted to, viz., shafts 20 feet in diameter were sunk, in the line; the center-line at these shafts was fixed by a theodolite, or a transit-instrument, as the case might be. The mode of accomplishing this will be understood on reference to the figure [Fig. 79].† The instrument being first set in the line, on the surface, at A or B, and a point fixed in the bottom of the tunnel by means of the vertical arc; and then another point found in a similar manner from the other side; a short length of line was thus obtained, which was carefully produced both ways to meet other portions worked from the adjacent shafts. These points, and the line through them, were tested at every length, before the brick-work was put in.

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* *The Principles and Practice of Engineering and Other Surveying*, C. Bourns, 3d edition, pp. 249, 250, London, 1843.

† Copied from the original.

When a shaft is so deep that the range of the arc of a theodolite is insufficient to enable an observer to see to the bottom of a tunnel, a transit-instrument must be made use of instead."

Such is the description given by Bourns in the work previously referred to. It is highly probable that the transit-instrument to which he refers was similar to, or at least some slight modification of, Fig. 80, which is copied from F. W. Simms's* figure of an instrument made by Troughton.

The portable meridian transit named had a telescope 20 inches in length, with a diagonal eye-piece for observation in

FIG. 79.

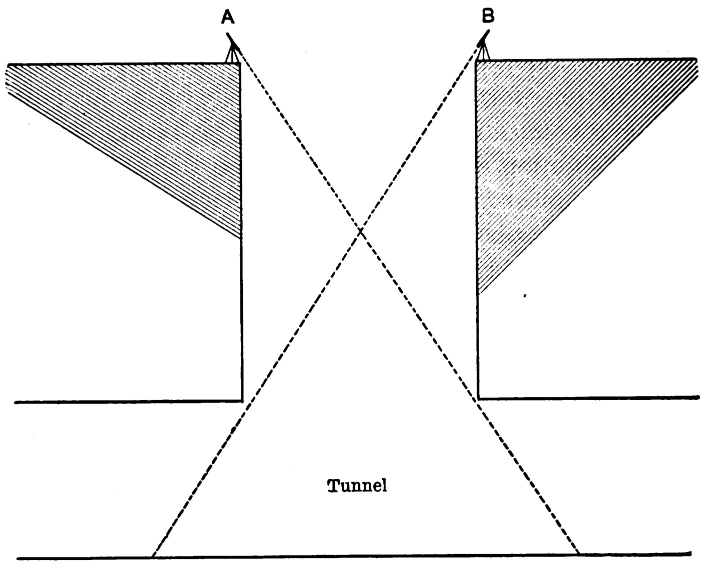


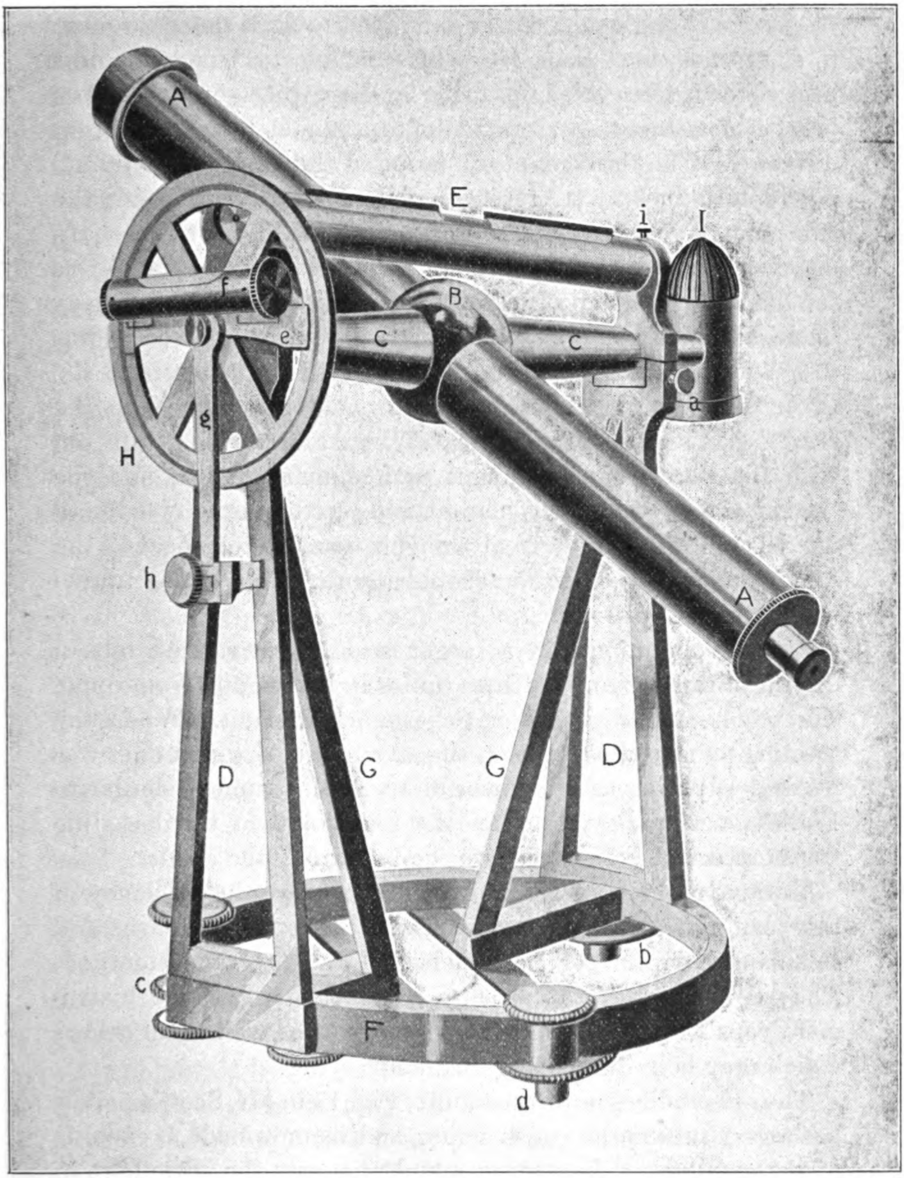
DIAGRAM ILLUSTRATING BOURNS'S METHOD.

the zenith and nadir. The circular ring base, upon which the upper parts of the instrument rested, offered great facilities for nadir-observations. However, considerable time was expended in bringing the optical axis of the telescope to the vertical plane of the line, which had to be produced down a shaft into a tunnel. The heavy and massive base now attached to this class of instrument renders it of less service for nadir-observations than the old pattern.

Mr. Beanlands, however, perfected the system of connecting

* *A Treatise on the Principal Mathematical Instruments Employed in Surveying, Leveling and Astronomy*, F. W. Simms, Ass't at the R. Observatory, Greenwich, p. 62, 1836.

Fig. 80.



PORTABLE TRANSIT INSTRUMENT
TROUGHTON

surface-lines with underground workings, and *vice versa*, and applied it to mine-surveying in 1856 with great success.*

* *Trans. North of England Inst. Mining Engineers*, vol. iv., pp. 267–273, 1856.

Many years since, when the writer occupied himself largely in mine-surveying with various kinds of instruments, the telescope of his angleometer was employed to fix a short base-line in shafts not more than 10 feet in diameter. The two points thus set out were used to drive a short piece of tunnel to a point where the longer portion of the tunnel took a different direction. The third point or station at the bend in the tunnel was determined by stretching a fine copper wire through the two points previously determined at the bottom of the shaft, and from this third station the principal part of the tunnel was set out, the direction of which depended upon a long survey made at different levels. One of the tunnels referred to was over 300 yards in length, and when the workings met from the two sides no appreciable difference could be detected in the axial direction or in the levels. When a survey is conducted with the necessary instruments and amount of care, and the system of co-ordinate calculation and plotting is adopted, and the base of the survey is no longer than that indicated, the same amount of precision should result, though the tunnel were ten times as long.

Similar operations, on a larger scale, were carried out in driving a railway-tunnel, three miles in length and from opposite points, under the river Severn, in England. When the meeting-points were gained, the axial line of the tunnel was perfect. In this case a powerful transit-instrument similar to Fig. 80 was employed to fix the two points of the base-line transferred from the surface to the bottom of the shafts.

Various other cases might be cited to prove the efficiency of this plan of making connections, which, thanks to Bourns and Beanlands, will never be superseded by any other method. The only difficulty is to procure a sufficiently portable instrument capable of performing this operation, as well as all others which may be required in general surveying.

The old cradle-type of theodolite, Fig. 17 in Mr. Scott's paper, has a very substantial construction, and, as now made, is capable of performing excellent results, and possesses the advantage of resisting a good deal of rough work before becoming impaired. If an extra pair of Y's, longer than those at present employed, were made to attach and detach at pleasure, the telescope could be thrown forward sufficiently to enable an observer to sight down a shaft. When a young man, the writer did excellent work with this class of instrument, which was then thought to be a grand acquisition. For general underground work a 5-in. magnetic compass was specially made to attach and detach, by means of screws, at the top of the telescope of this type of theodolite; and by this mode many curious and erratic differences were discovered in the direction of the lines as determined by the theodolite-limb and the magnetic needle. The magnetic needle was read by means of a strong microscope, all objects of iron or steel being removed to a distance during the time occupied in the magnetic observations.

The difficulty experienced by Mr. Scott and others in reading theodolites more finely divided than to single minutes is principally due to the result of the divisions being placed on the flat or horizontal upper face of the circle instead of upon a conical or beveled-edge form, as is generally adopted in England, where the divisions upon flat circles have been abandoned for many years past.

The writer does not agree with Mr. Scott in the opinion that "the novice is generally too much inclined to high telescopic power and fine graduations, with the idea that greater accuracy can thus be attained," etc. It is evident that if Mr. Scott could be certain of reading the observed angle in all cases to a minute of arc precisely, and could be positive that nothing remained which could be determined by a more finely-divided vernier, then his assertion might hold good, and could be boldly urged; but considering that frequently it is difficult to determine with absolute precision which of any three minute-divisions, close to one another, is the one most nearly in coincidence with a division upon the divided circle, it is manifest that, in the majority of cases, there must exist a small angular quantity which a vernier divided to read to a single minute of arc will not indicate, and which must remain undetermined. This small angular quantity will fall between one and fifty-nine seconds in the minute-division preceding or succeeding to that supposed to coincide with a division on the divided circle. This error or discrepancy in one course of a traverse survey swings the whole subsequent portion of the survey round by an equal angular amount; and consequently results in a more prominent error in long surveys than in short ones.

To illustrate this principle: Supposing that the observed angle is 164° 31′ 0″, and the supplementary angle 195° 28′ 0″, then 164° 31′ + 195° 28′ equals 359° 59′ 0″, or one minute in defect; but this difference of one minute would not have been known without taking the supplementary angle. On the contrary, employing a 20-second vernier, we find the first angle to be 164° 31′ 40″, and the supplementary angle, 195° 28′ 0″; and 164° 31′ 40″ + 195° 28′ = 359° 59′ 40″, which is only 20 seconds from the truth, showing clearly that this class of vernier-theodolite is at least twice as accurate as that with a minute-vernier. Naturally a 15-second vernier would give closer results. For example, let the first angle observed be 164° 31′ 40″, and the supplementary angle to be 195° 28′ 15″, then 164° 31′ 40″ + 195° 25′ 15″ = 359° 59′ 55″, or only 5 seconds from forming an entire circle. The use of a minute-vernier could not give such a close approximation to the truth. We find that in all high-class surveying the most accurately divided instruments, with fine readings and corresponding optical power, are adopted. We cannot afford to become inattentive to well-established principles and practice, nor can it be permitted to descend in the scale of progression and agree that a five- or ten-minute vernier is as good as one divided to single minutes; for in that case we should go on degenerating until we accepted Ribero's division to a single degree, or Digges's to a two-degree division.

It is true, there is a medium course, and an instrument adapted to one class of work may not be the best for a different class of work. It is necessary, therefore, to determine the fineness of the divisions of a theodolite-circle and vernier according to the nature of the work and the degree of accuracy sought to be attained. An error of one minute would be serious on very long lines, if any important work depended upon the survey, such, for example, as a long tunnel driven from opposite ends, or the fixing of boundary-lines at a remote point between two or more rich mines; especially if the region to be surveyed were not an open one, free from such obstacles as would prevent checking by trigonometrical observations. During more than half a century of experience with various kinds of instruments, the writer has never experienced inconvenience in reading theodolites of 4 in. in diameter, divided to read to 20 seconds of arc, and to-day he finds no difficulty in reading a 5-second vernier attached to a transit-theodolite of 8 in. diameter, which he sometimes employs for simple trigonometrical and astronomical observations. However, a good deal depends upon habit. The best-sized theodolite for general underground and surface work is from 5½ to 6 in. in diameter, reading to either 15 or 20 seconds, and this gives ample space between the divisions for facile reading with strong microscopes. Such surveying-instruments are now preferred in nearly all parts of the world. To avoid scratching, as far as is possible, the best metal to divide upon is platinum, and with gold verniers a more facile means of reading is afforded.

Mr. Scott passes lightly over the sub-tense system of determining distances, probably for the reason that his single-minute theodolite would not command the process. Nevertheless, in the opinion of the writer, as previously observed, this is a most accurate and facile system, as has been proved on the great Indian surveys. The writer has pointed out what kind of apparatus is required in connection with a theodolite for performing it. The micrometer-microscope attached to the eyepiece of the theodolite of the writer, now in construction and similar to Fig. 75, is all that is necessary. Such a simple auxiliary may be applied to any theodolite, and may be constructed to measure to one second of arc or less.

If it is required to measure, by the instrument shown in Fig. 75, an angle smaller than 15 seconds, the micrometer attached to the eye-end of the telescope is employed in the following manner: Suppose that the vertical hair intersects a station-mark, and the reading is believed to vary, plus or minus, from exactly 15, 30 or 45 seconds. The vernier-circle is turned backwards until the verniers mark the nearest of these numbers. The vertical hair should then appear out of contact with the station-mark; and the small distance from the permanent vertical hair in the telescope to the station-mark is measured with the micrometer. Let this measure be 11.6 seconds, and the previously measured angle 174° 10′ 30″, then the entire angle would be 174° 10′ 41″.6. For instruments of small size this is a more convenient plan than that of attaching long and powerful micrometrical microscopes to read the horizontal circle instead of verniers; because such an arrangement renders the instrument more costly, cumbrous, bulky, and liable to get out of order.

The following is an example of the Tanner mode of determining distances:

Measured angle, 3° 10′ 31″.4; sub-tense base, 30 meters.

Then *log.* of the base of 30 meters, ...	1.4771213
And *log. co-secant* of 3° 10′ 31″.4, ...	11.2565632
Log. of the distance required, ...	2.7336845
Distance required, ...	541.60725

The average of several measurements of the angle should be employed. When the distant point is in an elevated place, the length of the line to be determined would be that of the hypothenuse of a vertical right-angled triangle, and should be reduced to the horizontal by the ordinary rule.

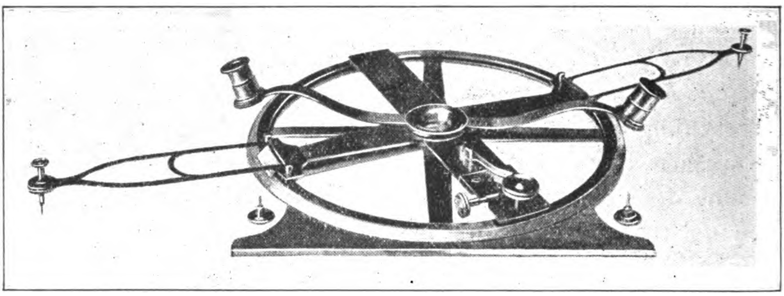
Cook & Sons, of York, introduced some years since a new model of surveying-instrument of the transit-type, the standards or Y's of which, and the vernier circle, are cast in a single piece, insuring great stability and freedom from vibration. The lower circle has a square outer edge, similar to a thin cylinder, and the divisions are marked upon the upper portion of the square edge, so that the vernier, being also square-edged, fits so nicely that the division line between vernier and circle is almost imperceptible. The vertical circle is divided in a similar form. The divisions are read either by direct sight through horizontal microscopes or by perpendicular sight through prismatic microscopes. The instrument of this class, formerly used by the writer, had very low Y's, without transit-movement, and was found to be a very efficient instrument.

The writer cannot agree with Mr. Scott's opinion upon Everest's theodolite, which is a very elegant, useful and light instrument. No one knew better than Everest what was required for filling-in surveys in a hot climate like that of India. The instrument is constructed to-day with divisions upon a beveled-edge circle, and has other improvements; and when the country to be surveyed is not very mountainous, as in England and in a large part of the Argentine Republic and other surrounding republics, this instrument is, and could be further, used with great advantage, especially when the lines are long and the engineer becomes fatigued from excessive heat in passing from station to station. Under such circumstances, any one would endeavor to avoid the extra weight unavoidable in heavy transit-theodolites. However, circumstances must decide what instrument is best adapted to a certain place and class of work.

As all practical engineers know, all underground surveys should, if possible, be conducted in a circuitous traverse form, always seeking to finish at the point of commencement; the corrections of all the angles may then be determined before leaving the mine, or at least before plotting the work. The sum of the internal angles, treated by the well-known rule, will exhibit any error which may exist, plus or minus. If none such can be found, and the plotting will not agree, then the error must be sought for in the measure of the lines and not in the angles. Long before 1863, the writer advocated that the first underground line—continued—should be made a common base to which all the underground and surface-surveys should be referred; that is to say, this line should be laid down as a common meridian prolonged throughout the plan, from which line all the angles observed underground and on the surface should be plotted. In that year he published this system, demonstrating its great utility and superiority, and showing that no accumulation of error could exist, as is too frequently the case when the co-ordinate system of plotting is not adopted. This plan only requires that all the observed horizontal angles should be reduced in such a manner that they are in a proper condition to be set off or plotted from this first line, assumed as a common meridian for the whole. Moreover, as this is the line which should be produced upon the surface by the process already noted, it is the fittest to be selected for this object. However, with proper care the same reduced horizontal angles referred to may be plotted from this base-line by a single setting of a circular protractor and similar good results obtained. All that is required, in addition, is a long and accurately-made metal parallel ruler of sufficient weight to run parallel upon a board 20 feet long, without deviation, to transport the angles to the plotting-points or artificial stations on the paper.

A protractor similar to Fig. 81, which was constructed for the writer many years since by Messrs. Troughton & Simms, is well adapted for this class of work. It is 10 inches in diameter, divided upon a silver beveled edge, and reads by two verniers to ten seconds. The folding arms are mounted at each end by a screw carrying fine pencil-points for marking off angles, instead of using steel points. The readings of the circle are aided by two strong microscopes, revolving in arms round the circle. When the protractor is fixed, it is kept in position by very fine needle-points screwed into the sides of the instrument and taking hold of the paper; or two weights may be applied. The beveled edge of the circle offers greater facility in reading than when the divisions are placed upon a horizontal or flat surface. There is also cast at one side of the circle a bracketed projecting piece of brass with a beveled edge forming a line a little longer than the diameter of the circle, and set parallel to

FIG. 81.



HOSKOLD'S CIRCULAR PROTRACTOR.

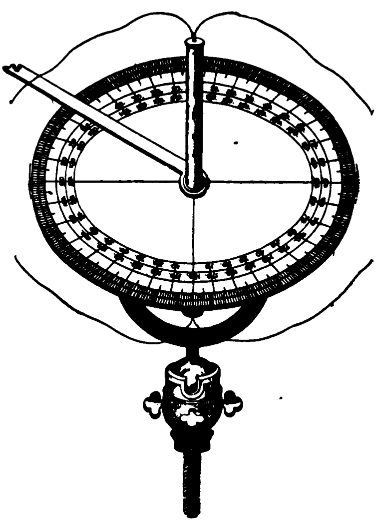
a line passing through the 360° and 180° divisions. This useful appendage enables the draughtsman to slide the instrument along a steel straight-edge, previously placed against the meridian line, with the view of plotting some of the angles from more than one position or station, when they are very numerous, and the pencil-dots representing them come too close together. The instrument has a clamp and tangent-screws, with a spring attached.

If either of the modes of working indicated in the foregoing remarks were always employed, using the theodolite to observe the angles, independent of magnetic bearings, no need could exist for the true or magnetic meridian; but as some people will always have a fancy for the use of the magnetic compass, its corresponding meridian, as also the true meridian, may be determined and laid down upon mining plans, at least as an ornament, and to satisfy curiosity or other exigencies.

The writer desires that this contribution shall be taken as an independent paper upon mine-surveying and instruments, as well as representing his part of the discussion of Mr. Scott's paper, which, in his opinion, is a very creditable, useful and important production.

MR. SCOTT: I think that I shall voice the sentiments of the Institute at large when I take this occasion to thank Gen. Hoskold for his very elaborate and scholarly contribution to the topic I was trying to cover in a few pages. His description of the old manner of conducting underground surveys by the graphic method of snapping chalk-lines on the top of a 3-legged stool is very interesting. No doubt this was the practice, as he explains, before Houghton wrote his fifty-nine articles on the "Laws and Customs of the Wapentake Lead-Mines;" but is it not more reasonable to suppose that it found its rise in the systems of plane-table surveying that were in vogue nearly a hundred years before?

FIG. 82.



Voigtel's Mining Astrolabe.

I am of the firm belief that the science of mine-surveying in all its forms, as well as all the instruments devised to facilitate the art, were in nearly every case derived from some method previously pursued in field, geodetic or astronomical surveying. Thus, as he has recorded here, the astrolabes exhibited by the British Museum date back to the 11th century; while the oldest instrument of this class that I know of as being employed in mine-surveying is one described by Voigtel in the first edition of his work (1686) as something new—of such recent manufacture, in fact, that he was unable to include it in its proper place in the 14th chapter of the work, which treats of the use of two or more *Scheiben* in conducting surveys in iron-mines. Voigtel says:

> "It is a newly-invented instrument, by use of which the operations in iron-mines are conducted still more accurately than by any of the methods previously described. It is divided into 360 degrees. Through its center is a hollow tube, as high as the diameter of the plate, extending, one-half above and one-half below, at right-angles to the plate, tapering somewhat toward its extremities. Through the tube two waxed threads are drawn and tied at the ends, one set extending forward, the other backward; and into these loops the measuring-cord or chain is hooked when at work. About the tube revolves an index-arm, extending somewhat beyond the plate, so that when the cords are pulled taut in operation, it can reach them, and the horizontal angle can be read as indicated, even if the courses are elevated or depressed as much as 45°. Then there is a base with a wooden screw, so that the instrument can be set up on any timbering in which an auger has previously bored a hole. The base has a movable ball-and-socket joint with four screws (as shown in Fig. 83), so that the instrument can be properly secured for horizontality by means of a bubble-tube—too well known to require special illustration or description."

Mr. Hoskold's verifying or lower telescope, set so as to be always coincident with the zero of the vernier, is apparently a very ingenious contrivance, and of great convenience in taking back-sights; but why does he not adopt Mr. Wagoner's cyclotomic circles with it, so that the azimuth axis (which must now of necessity be inverted between the standards) may be dispensed with, thereby making his theodolite a *transit* instrument? While the matter is now before us I would advance the proposition that this cyclotomic principle is the only correct one yet devised for nadir-instruments in which the vernier-circles are to be preserved; for the perforation in the simple vertical axis may be large enough for all practical purposes without perceptibly increasing the size of the base. The A. Lietz Co., 422 Sacramento Street, San Francisco, Cal., will be glad to furnish full information concerning the means whereby a repetition-theodolite may be constructed upon a single axis of revolution.

I cannot permit myself to enter into a prolonged discussion upon the relative merits for mining work of minute-graduations as compared with those of finer divisions. On this point nearly every engineer has an individual opinion very difficult to influence one way or the other. The reason I advocate minute-graduations is because the possible error of the angular measurements is substantially as small as that of the linear ones.

A 100-foot steel tape divided into 10ths and 100ths of a foot is, I believe, most generally used by American engineers for the measurement of underground courses. In a 5-inch circle, graduated to read minutes, the maximum error will probably not exceed 30 sec., whose corresponding lineal error in an average course of from 50 to 100 feet can scarcely be detected on a tape of the above description. Many American engineers have been, and, I believe, are still using a chain underground;* but there is no sense in too highly refining the instrument while the means of measurement are in so many cases quite rude.

It seems strange that Mr. Hoskold should declare himself favorably inclined toward Figs. 45 and 55, and object to my interchangeable auxiliary, when placed on top of the main telescope under conditions almost identical with the others mentioned. There is no form of detachable top-telescope conceivable to me in which the possibilities of lateral vibration are so completely removed. The vertical pillar, to which the auxiliary is firmly screwed and clamped, is cast in one piece with the telescope-hub, just as are the horizontal axes, and there is no more possibility of vibration in one than in the other. Figs. 45 and 55 are, as I have said, in my opinion, excellent types; but neither, I believe, is so simple in construction, nor can either be used at the side if occasion should require it. There is no room, certainly, for a distinction between Figs. 56 and 57; for they are the same instrument, and the construction and method of application, as well as the means of adjustment, are precisely similar.

As to Everest's theodolite, all I have said about it is on p. 697 of my paper, and amounts to nothing more than a simple statement that the instrument "practically became obsolete twenty years ago." Beyond what this statement might be deemed to imply, I expressed no "opinion" whatever.

JAS. B. COOPER† (communication to the author): If Mr. Hoskold is correct in saying that the first instruments used for surveying consisted of two movable cross-bars of wood or

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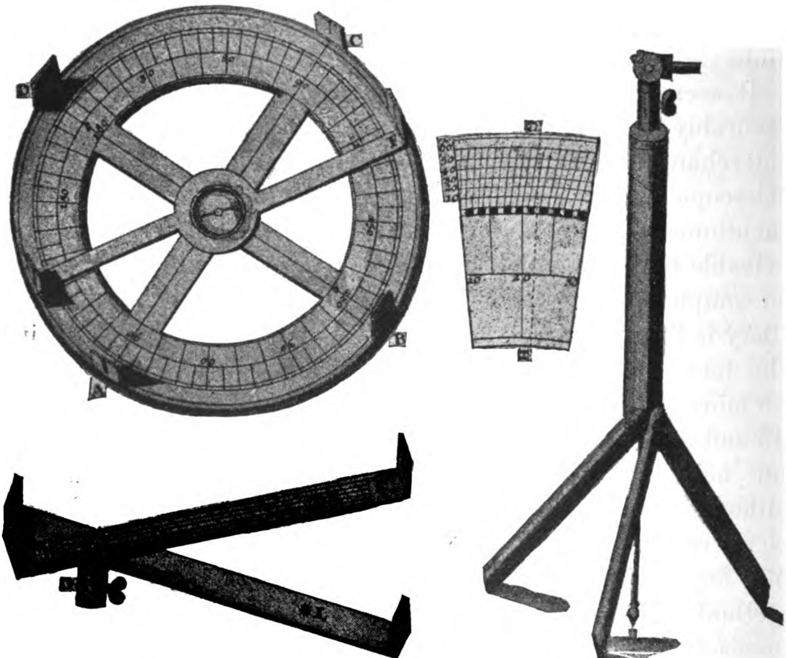
* *Report on Mining Methods, etc., in the Anthracite Coal-Fields,* H. M. Chance, Harrisburg, Pa., 1883, p. 371.

† Supt. Calumet and Hecla Smelting-Works, South Lake Linden, Mich.

metal, fixed to the top of a rod, then we have here in Fig. 83 a survival of the most ancient method ever used.

All the figures given in this cut (though rearranged to suit the present need) are taken from Tab. XI. of the *Mathematischer Atlas* by Tobias Mayer, Philomath, Augsburg, 1744. The lower figure represents the cross-staff as described by him. It consisted of two plain brass rules pivoted upon each other

FIG. 83.



Astrolabium and Cross-Staff from Mayer's Math. Atlas, 1744.

near one end, as shown, and provided with simple sights at each extremity. From the center, N, were marked off very accurately the points M and L, so that they should be equidistant from the center. In whatever relative position, then, the rules might be placed, N M and N L would always be equal and mark the sides of an isosceles triangle whose base, L M, would naturally vary in proportion to the size of the angle measured through the sights. When the sights had been fixed very carefully on their respective objects, a pair of compasses was employed to measure the distance L M, which was at once determined in terms corresponding to the other sides upon the scale I K, after which the angle M N L was calculated.

This instrument was mounted upon the tripod shown, the construction of which, as Mayer says, is too well known to demand special description.

This tripod was likewise used with the *Astrolabium*, which he also introduces, and was so constructed that the spindle at the head could be tipped to a horizontal position for the measurement of vertical angles. He says:

"For the measurement of angles in the field and for the laying out of the same we use the astrolabium. It is usually made of brass, though sometimes also of wood, and has a diameter of from 8 to 12 inches, divided into 360 deg., and by use of the diagonal scale, G, to 10 or even 5 min. of arc. At each quadrant are placed the diopters A, B, C, and D, and from the center revolves the rule E F, at the ends of which are also placed two diopters somewhat higher than the others. The observations are read to 10 minutes of arc, with the 20° diagonal scale; by which it will appear that the line G H, for instance, marks the angular value of 22° 20′."

This is a method of reading angles not mentioned by Mr. Scott; but I am undecided as to whether it has an individuality all its own, or is only a modification of the *nonius* he has described on pp. 59, 60.*

W. S. HUNGERFORD, Jersey City, N. J. (communication to the Secretary): In connection with the very able and complete paper of Mr. Scott on "The Evolution of Mine-Surveying Instruments," a short description of the instruments and method employed by the writer, some fifteen years ago, at the iron-mines of Low Moor, Va., of which he was superintendent, may be of interest.

In the mines referred to there were several main track-levels approximately parallel and about 100 feet apart vertically, and at varying horizontal distances, according to the dip of the vein, which was from 50° to 75°. Between these levels there

* SECRETARY'S NOTE.—The diagonal scale (or method of transversals, as it is sometimes called), is said by Thos. Digges (*Alæ seu Scalæ Mathematicæ, Capitulum Nonum, Londini*, 1573), to have been invented by Richard Chanzler, an English artist famous for his skill in the construction of mathematical instruments, and to have been long well known in England. See Robert Grant's *History of Physical Astronomy*, London, 1852, p. 442. For these facts I am indebted to Mr. B. S. Lyman, of Philadelphia, Pa.—R. W. R.

were frequent upraises, and these again connected by frequent levels and workings of great irregularity and often difficult of access, but all of which it was desirable to keep promptly surveyed and plotted. The entrances of the main track-levels were either on the open side-hill or connected by a vertical hoisting-shaft. The main levels were all connected carefully with a transit-and-level survey with frequent permanent marks; these levels, ending at the hoisting-shaft, being oriented by means of two plumb-wires, as described in Borchers's *Markscheidekunst*, p. 143. The accuracy of this orienting was tested upon the opening of the first upraise to the next higher level and found, in a traverse of about a mile, to close within 4 inches. The transit surveys were carefully calculated by latitudes and departures, referred to an astronomically determined meridian, and plotted in three projections.

The transit used was an 11-cm. instrument made by Aug. Lingke, of Freiberg, Germany, in 1877. The horizontal circle was graduated from 0° to 360° and read by two verniers to single minutes, as was also the vertical circle. A fixed reading-glass and a reflector were used for each vernier. With properly adjusted reflectors there should be no difficulty in getting the light on the verniers without burning the face. The vernier-readings could easily be estimated to 30 seconds, and by repeating the angles and taking the mean readings an accuracy of 15 seconds was attainable. By using rather high standards an angle of depression of 52° was secured; but beyond this no provision was made for observing very steep angles. The transit had no magnetic needle, and the telescope was inverting. The writer would add his endorsement to all that Mr. Scott has said in favor of this form of telescope. The usual objection that the inverting of the object is likely to cause confusion is, in the experience of the writer, entirely unfounded.

The intermediate upraises, levels and workings were surveyed by means of the cord, steel tape, hanging-compass and clinometer, of course using every available opportunity to check the work by connecting to the more accurately determined points of the transit-survey. The inclined distances were reduced to the horizontal and vertical by means of the trigonometer and the hanging-compass. The compass was designed to stride the transit at pleasure, as also to be used interchangeably in a brass protractor-plate for plotting, care being taken that the drawing-table, stands, etc., contained no iron nails, screws or bolts. There was no local magnetic attraction in the mines; but in a few instances, where rails or other iron material influenced the needle, perfectly satisfactory results could be obtained by a slight variation of the method and by taking the magnetic bearing at each end of the cord. This method was found abundantly accurate for filling in between the transit-surveys; it was expeditious and entirely mechanical, and could be used in places where a transit could hardly be taken. In fact the assistant, a bright young man taken from the mining force, was soon able to make and plot these compass-surveys, and give the necessary directions for upraises, etc., without any aid from the writer. If it was desired to connect a point in one level with a point in another level by an upraise, the magnetic bearing between the two points could be taken directly from the horizontal projection, and from the known horizontal and vertical distances the angle of inclination of the upraise could be drawn on paper, and a triangular piece of board could be cut to correspond and given to the mine-foreman, who had only to keep one side level, and the other on a straight edge, to get the required inclination.

In this connection a simple device of the writer for controlling the grade of a level under construction may be worthy of mention. The average miner, working in a level, has very little idea of grade, except as he sees the water run; and although the average grade may be very accurately controlled by the chain and leveling-instrument, there may occur very annoying variations between the visits of the engineer, particularly if the work is rapid. One must change these at much expense, or leave a permanent defect in a track over which many thousand tons of material may have to be moved. The grade of the level having been determined upon, a wedge-shaped straight-edge is prepared of convenient length, say 12 feet, wider at one end than the other by the amount of the grade in its length. Thus, if the grade is 1 in 400, and the straight-edge 12 feet long and 6 inches wide at one end, it would be 6.36 inches wide at the other end. The miner has simply to drive wooden leveling-pegs about 12 feet apart, leveling the top of the straight-edge with a spirit-level, with which he is provided, and driving the front peg down or cutting it off at the proper height. The miner has no linear measurements to take, as the exact distance apart of the leveling-pegs has no influence upon the grade. It was surprising to find how uniform a grade was thus obtained, and how slight a correction was required by the later instrumental surveys.

MR. SCOTT: Mr. Hungerford admits that the greatest angle of depression possible with his instrument was 52°. By force of circumstances, then, he was required to employ the *Gradbogen* in connection with it, to determine dips as great as 75°—as an expedient, I should say, rather than a convenience.

I am convinced that in the use of fixed reading-glasses there is no danger of losing them; that they are always in focus, that one hand, which would otherwise be engaged, is left free, and that a considerably higher power is possible, while the field still remains flat though somewhat diminished in size. Strictly speaking, fixed reading-glasses with a properly adjusted reflector, mounted behind them upon the radial arm of the socket, are a European innovation; and while my previous remarks were based upon an unsuccessful experience, it may be that with the great majority of American engineers I shall some day learn to adopt them. If Americans were generally more eager to adopt some of the more cumbersome and tedious of the German appliances and methods there would be no occasion for a diversity of opinion as to the correct method of illuminating and reading the verniers.

Herr Max Harrwitz has sent me from Berlin a description of Jahr's theodolite,* in which we have an instance of the extremes that are resorted to by the profound and ingenious Germans to effect a desired end. Suspended to the *Stengelhaken* (*a*, Fig. 84) is a small wooden box in which the electric current is produced in two ½-ampere accumulators that are set into hard-rubber cells. From this source two leading wires (*L*), positive and negative, are led each to one of two metal rings (*d* and *e*) that are separated by a little strap and countersunk into a hard-rubber plate (*c*). The connections of the leading wires

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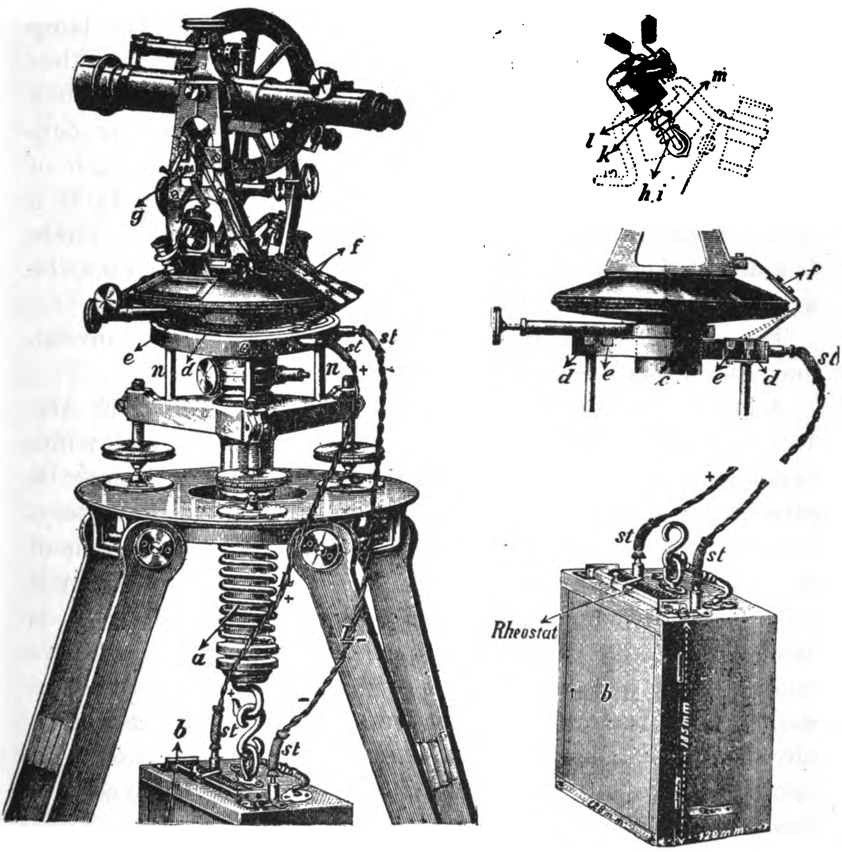
* Given in *Der Mechaniker*, vol. vi., No. 18. Sept., 1898 (from *Zeitschr. für Vermessungswesen*).

with the accumulator poles are made through casings at *st.* The hard-rubber plate is attached by three screws (*n*) to the base of the theodolite, and is perfectly concentric with the axis of the instrument. Upon the metal rings revolve, as desired, two contact springs (*f*) which are rigidly attached to the upper part of the theodolite, and by means of wires are connected with the

FIG. 84.



Illuminating Apparatus of Mine-Surveyor-General Jahr, of Breslau, Germany.

switch (*g*) and the lamps (*h* and *i*). By the switch either of the lamps can be turned on as required. The portable box (*b*), including accumulators and fixtures, weighs about 2.75 kg., or a little over 6 pounds. On the upper side of the box is a rheostat to regulate the current. Both incandescent lamps may be fed from 8 to 10 hours continuously, so that if one required two minutes to read both verniers, one charging of the accumulators would be sufficient for from 240 to 300 readings.

Of late several American engineers have been using small portable electric lamps, of the dry storage-battery type, with great advantage and convenience. The one used with much satisfaction by the writer is made by the American Endoscopic Co., of Providence, R. I. It weighs only 0.6 kg., and has a small, 8-candle power incandescent bulb with silvered parabolic reflector, that will burn continuously for 8 hours. The lamp has two batteries, one of which may be in use while the other is getting charged. A small switch at the side of the box turns the light on or off as desired, the current being continuous and the illumination brilliant. The entire length of the box is 6 inches, and, having a cross-section of only 1½ by 3 inches, it can be very conveniently carried in the pocket. There is a detachable bulb at the end of a flexible cord, which may be arranged so as to leave both hands entirely free.

The chief merit of this lamp consists in the great convenience of its small size compared with its efficiency.

Another portable electric lamp is made by Elmer E. McIntyre, of Pittsburgh, Pa., and has a small bulb and white enameled reflector mounted on a stick-pin, so that it may be attached to the hat or any part of the clothing. The battery-case is strapped around the waist, and weighs 1.4 kg. It is of 4 c. p., and is designed to burn 10 hours, though in reality it falls decidedly short of that. To recharge the battery, it is removed from the case and the positive and negative poles are connected, by means of a specially provided intermediate socket, to an incandescent lamp on any 110-volt direct-current circuit. The amount of voltage and amperage that the larger lamps consume afterwards passes into, or through, the coils of the battery.

By the use of such portable electric lamps, the dimness of flickering candle-lights, the dripping of grease and the crude features of all other methods of illumination are forever done away with, except for those who will persist in magnetic surveys and the necessary bulky copper oil-lamps. But in these cases may we not say, in general, that the method of illumination is in consistent keeping with this awkward system of surveying?

J. E. JOHNSON, Longdale, Va. (communication to the Secretary): The paper of Mr. Scott has evidently been prepared with much care, and displays such a comprehensive knowledge of the subject that one has a feeling of trepidation at criticising any part of it. Nevertheless, I am compelled to take issue with one paragraph, namely, the second on page 25, which is as follows:

> "In recent years the hanging-compass has been redesigned by Queen & Co., of Philadelphia, and is said to be still indispensable to certain surveyors in Virginia and Pennsylvania. The excuse for employing the hanging-compass in cramped and tortuous channels to-day, however, seems absurd; for the transit can be made to do the most reliable work, even when removed from the tripod, anywhere that a man can take it."

This paragraph indicates a misconception as to what is possible and what is commercially practicable; in other words, *what pays.* It also seems to indicate that the words "cramped and tortuous" might have decidedly different meanings in different mining regions.

There is no doubt that, given unlimited time and unlimited expenditure for general and local appliances and support, a transit-survey can be made of any hole that a man can crawl through; but there is also no doubt that, with a hanging-compass outfit, when running on short lines between definitely-located points, work which is substantially accurate and entirely within the needs of ordinary commercial engineering can, in many cases, be done in as many minutes as the transit-survey would require hours. To explain the circumstances under which this is true within the writer's own knowledge, it will be necessary to give a brief *résumé* of the paper to which Mr. Scott alludes, in a footnote, as having been published in *The Engineering and Mining Journal*, August 1, 1891, taken from *Transactions of the American Institute of Mining Engineers.** The paper was written by Mr. Guy R. Johnson, then engineer for the Longdale Iron Company, of this place, now General Manager of the Embreville Iron Company, of Tennessee, and the mines described by him were those of the former company.

The mines, like others in the Oriskany or brown ore-deposits in this State, have for their objective a stratum, rather than a

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* *Trans.*, xx., 96.

vein, of ore taking the place of the Oriskany sandstone, and lying immediately under the black slate [Rogers' No. VIII.]. The exact nature of the stratum as to thickness, dip, continuity, etc., varies in each case with the mountain in which the particular mine is located. Locally, the ore-stratum is vertical or even dipping *toward* the mountain at its southwest end, and gradually twists, like a huge "warped surface" or a helix of very high pitch, as it goes northeast, lying at an average inclination of about 35° at its extremity in that direction. The stratum is entered at intervals of 120 feet vertically by tunnels through the slate, which of course follow the ore after they reach it, generally keeping the bottom inner corner of the tunnel just along the foot-wall. The irregularities in places are extreme, the tunnel being in a number of places at right-angles to its proper general direction, and in a few, pointing the opposite way.

The main tunnels are connected at intervals of approximately 120 feet horizontally by a pair of upcasts—one called, locally, the "chute," the other the "man-way." Along with the main heading, after the ore is reached, is driven another about 20 feet above it, called the "air-way." Subsequently other levels are driven, all at intervals of 20 feet vertically, making, of course, five between each pair of main levels. It is impossible to describe the operation properly without some reference to time and the consecutive order of the operations, and it should be said that the mine is worked down in successive levels, each main entry being driven when there is still several years' ore in sight in the one above. The main entry and air-way are carried on together, as stated, and as fast as they reach the proper points for the upcasts, these are started and cut through to the main entry next above for ventilation, etc. The levels above the air-way are driven approximately in the order of their heights above the main entry, so that it may be a year or two after the main entry passes a given chute before the "100-foot level" reaches it. After a given section has been developed in this way to its extremities, the 20-foot pillars are "split," and then "robbed," beginning at the top, of course, and working down.

In surveying the mine a transit-line is first run with some care in the main entry, putting nails in the ties, instead of the collars or "caps," as the ties are very much less likely to move or break; and in using wire nails instead of tacks it is remarkable how seldom points are lost, even after the lapse of many months, or even two or three years. The passing of all chutes and man-ways is noted on the transit-survey.

Starting at these points, a string-survey is taken through them, taking the bearing, inclination and length on the string. The passing of all the levels is carefully noted, and the distance of the string above the bottom of the level at the point taken as the intersection is noted also. Subsequently the compass is removed from the gimbals, fitted with standard-sights, and mounted upon a small tripod with a ball-joint connection. The levels above the main entry are then run out, sighting from the compass forwards and backwards at lamps held in the center of the level, thus taking both a "back sight" and a "fore sight," as with a transit, but only setting up at alternate stations. This saves one-half of the number of "set-ups," and avoids the error of not setting the compass vertically over the point last sighted at, an error liable to occur when only taking foresights. The points noted as the intersections when making the string-survey are located on the tripod-compass-survey of the levels by eye, and notes of their location taken.

This will doubtless seem to many mining engineers a barbarous method, and from the point of view of absolute accuracy undoubtedly it is, as compared with making a transit-survey of the whole mine—chutes, secondary levels and all; but the remarkable thing about it is the accuracy which may be obtained in this way. It should be noted that the length of each individual string-survey is only from 120 to, at most, 250 feet, and that when the upcasts are cut through to the main entry next above, the upper end of the survey can be connected with a known point on the transit-survey of that entry.

By the aid of a trigonometer, or mechanical traverse-table, the horizontal and vertical lengths of the inclined sights are obtained and plotted; first as a "plan," or map, reduced to a horizontal plane, and from this and the vertical components of the sights an elevation is constructed; also cross-sections, when necessary. It should have been said also that a line of levels is run into the main entries, and the elevation of the top of the rail is taken at all chutes, to form the basis for the elevations derived from the respective string-surveys.

Moreover, with regard to the barbarous practice of locating the intersections of the upcasts and secondary levels at the same point in space by eye, I would say that never more than a thousand feet per year of the mine are opened up in the way described; that, as the survey is brought up to date every year, there are comparatively few new upcasts and a correspondingly small number of intersections to carry in one's head during the period elapsing between making the string-survey of the upcasts and the compass-survey of the secondary levels; and that, owing to the rapidity with which the work can be done in this way, this period is very short—not over a few days. It is needless to remark that one's memory would not be equal to the task for the period required if a transit were used.

It is also to be noted that the iniquity of using this method is largely counterbalanced by the fact that a variation of a few inches, or even a couple of feet, with the compass will simply result in displacing the line parallel to itself by that amount; whereas with a transit, on lines of the same length, averaging, perhaps, 20 feet, the same error, swinging the entire remaining portion of the line through a corresponding angle, would make the results so obtained worse than useless. Again, there is a fair chance with the compass that the errors will balance one another, but practically none with the transit.

As a matter of actual experience, surveys so made plot on paper with a degree of accuracy that is almost surprising, the intersections, as noted on the two surveys in which they occur, coinciding so closely as frequently to be almost within the errors of plotting. For the purposes for which the survey and map are designed—that is, to show the progress and shape of the mine, to give directions for cutting new passage-ways of moderate length when necessary, and to show the mine as it practically is—this system of surveying is as useful and satisfactory as it would undoubtedly be preposterous if applied for the location of points to hit exactly with vertical bore-holes, or for similar absolutely accurate work.

It would undoubtedly be possible, as observed in the beginning, to carry a transit-survey through these mines or any others; but the difficulties of the process would be immense. The chutes and man-ways are "cribbed up," when it is necessary to timber them, 3½ feet square inside. They follow the flexures of the foot-wall of the ore in one direction, and sometimes, unfortunately, the equation of personal error of the miner or foreman in the other, and occasionally even both at once; so that the bends are sometimes very short, especially in the vertical plane. Frequently, of course, these bends occur when the chute is nearly or quite vertical, and the difficulties of getting satisfactory readings with compass and clinometer are very great; and a survey of accurately-fixed points with a mining-transit, capable of use throughout the entire vertical plane, dismounted from its tripod (the only way it could be taken through or set up), would be a matter of an indefinite amount of preparation for each sight, and unlimited time and expense. In the matter of time, it is necessary to note that the chutes are, normally, more or less filled with ore, and must be specially emptied, with inconvenience and loss of time, in order to be surveyed at all.

Something over a year ago it became desirable to connect two main entries by a transit-line, and so a man-way was cut with especial care to keep it straight and have the inclination sufficiently uniform to be within the vertical range of a standard transit (without other attachment than those appertaining to the ordinary horizontal and vertical circles); but in spite of these precautions, and the simplicity of the problem presented in surveying the opening, the time consumed in the operation was an earnest of what it would be to do the same thing in steeper and more tortuous places.

In view of these facts, I must beg Mr. Scott to believe that there is a field, small in size and importance as compared with the Lake Superior region, perhaps, in which the hanging-compass has a respectable, if not exalted, sphere of activity and usefulness still left to it, and in which, for the purposes of what may fairly be called commercial engineering, it is far better than any form of transit ever yet designed or ever likely to be.

JULIUS KELLERSCHON* (communication to the author): Being assured, by the contributions from Messrs. Hungerford and Johnson, that in various parts of America the old German method of cord-surveying is still used to apparent advantage for certain kinds of work, I take this opportunity to submit

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what I believe to be the first English translation of the text in Prof. von Miller-Hauenfels's work* that relates to the rules of which Mr. Scott has spoken on page 9.

It is not quite just to ascribe to Prof. Hauenfels the entire credit Mr. Scott has given him; for investigations in a scientific and systematic manner had been conducted some time before the beginning of this century, as will appear below. But the Leoben professor, no doubt, was the first to get complete information on the subject in comprehensive form for the use of the student and practitioner. He closes his remarks, however, with an observation to the effect that the varying tension on the cord, its hygrometric conditions, etc., must still be considered before the discussion can be accepted as closed. He says:

"The experiments executed in this line show that the *Gradbogen* suspended in the exact center of the cord will cause the vertical component to be too small and the horizontal too large; but the corrections which practical work actually requires are considerably greater than those provided for in the theoretical formulas of the catenary curve. The reason for this is that the hook at the higher end depresses the cord more than the lower one. If, in the accompanying diagram (Fig. 85), a and b are the points from which the *Gradbogen* is suspended; c, the point from which the plummet is suspended; d, the center of gravity of the *Gradbogen*; Q, the weight of it; q, the weight of the plummet, and f, h, i and g the projections of the points a, c, d and b on a horizontal line, then the weight which draws vertically at the point b may be expressed by $\frac{1}{fg}(fh \,.\, q + fi \,.\, Q)$, and the weight which draws vertically at the point a by $\frac{1}{fg}(hg \,.\, q + ig \,.\, Q)$. The sum of these two expressions would be, as it ought to be, the total weight of *Gradbogen* and plummet. As fh and hg do not differ much in length, and the weight q is inconsiderable as compared with Q, it is mostly the leverage fi and eg which decides the depression caused by the hooks a and b. Thus the higher hook, b, will depress the cord in proportion to the degree of the inclined angle. In a very steep angle it can reach a condition where ig will be negative; that is, the lower hook will have a tendency to rise above the cord, and in such cases it must be fastened to prevent this.

FIG. 85.

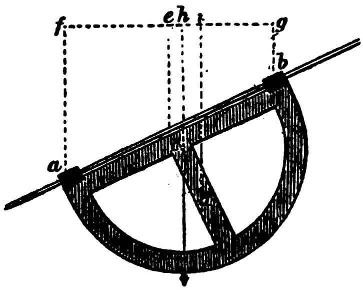

Diagram of Gradbogen.

"The first experiments along this line were made several decades ago by the late Mr. Florian, of Bleiberg, in Carinthia. He made known to several of his acquaintances the results of his very laborious and precise experiments, but I was unable, in spite of many inquiries, to obtain a copy of his original manuscript.

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* *Höhere Markscheidekunst*, Albert von Miller-Hauenfels, Wien, 1868, pp. 286–291.

The resulting rule, however, was communicated to me by the kindness of Berghauptmann E. Hübel, of Olmütz, who found it in the memoirs of his late father-in-law, Bergrichter von Hohenfels. Florian's rule is as follows:

"'*To find the true vertical angle of the cord, the Gradbogen should be suspended approximately one decimal inch from the center of the cord toward the higher end of it for every degree of inclination, so that, at* 45°, *it will be suspended* 50 *decimal inches from the center of the cord.*'

"The weight of the *Gradbogen* is in this case taken as 7 *Loth.** The length of the cord is not given in Florian's calculations; but it seems that it did not exceed 8 *Klafter* (fathoms); for there is a remark to the effect that this length should not be exceeded in determining vertical heights.

"In the *Berg- und Hüttenm. Zeitung*, No. 7, 1862, Prof. A. Junge published experiments also along this line. He measured accurately the vertical and horizontal components of cords, 3 to 7 Freiberg *Lachter*† long, subjected to a tension of 20 kg., and from these figures calculated the true length of the cord, as well as the angle of inclination, comparing these with the angles as actually read. We take from his table the following figures, and add a few columns, which will form the basis of our further consideration:

Number of Experiment.	Length of Cord.	Inclined Angle.		Calculated Suspension Point for Gradbogen.	Average Values.	Suspension Point Determined by Factor .003 for each Degree.	Average Values.	Suspension Point Determined by Factor .004 for each Degree.	Average Values.
		Calculated.	Angle as Read at Center of Cord.						
1	6.80	1° 41′	1° 39′	0.552		0.505		0.507	
2	6.81	3° 22′	3° 21′	0.526		0.510		0.513	
3	6.83	5° 03′	5° 03′	0.500		0.515		0.520	
4	6.85	6° 43′	6° 42′	0.531		0.520		0.527	
5	6.87	8° 22′	8° 21′	0.539		0.525		0.533	
6	6.90	10° 00′	10° 00′	0.500	0.525	0.530	0.518	0.540	0.523
7	6.94	11° 38′	11° 36′	0.569		0.535		0.546	
8	6.98	13° 14′	13° 12′	0.564		0.540		0.553	
9	7.03	14° 50′	14° 48′	0.592		0.544		0.559	
10	7.09	16° 23′	16° 21′	0.581		0.549		0.565	
11	7.15	17° 56′	17° 54′	0.569		0.554		0.572	
12	7.21	19° 26′	19° 24′	0.558	0.572	0.558	0.547	0.578	0.562
13	6.17	24° 54′	24° 51′	0.600		0.575		0.593	
14	6.99	23° 38′	23° 36′	0.563		0.571		0.594	
15	7.43	23° 48′	23° 45′	0.586		0.571		0.595	
16	7.15	26° 34′	26° 33′	0.526		0.580		0.606	
17	7.60	26° 34′	26° 30′	0.616		0.579		0.606	
18	6.72	30° 23′	30° 21′	0.563	0.576	0.591	0.578	0.621	0.603
19	6.38	32° 12′	32° 09′	0.600		0.596		0.629	
20	5.72	36° 28′	36° 24′	0.653		0.609		0.646	
21	5.56	37° 42′	37° 39′	0.667		0.613		0.651	
22	5.40	38° 59′	38° 57′	0.587	0.627	0.617	0.609	0.656	0.645
23	4.67	46° 44′	46° 42′	0.598		0.640		0.687	
24	4.53	48° 35′	48° 33′	0.598		0.646		0.694	
25	4.40	50° 32′	50° 30′	0.598	0.598	0.651	0.646	0.702	0.694
26	3.94	59° 32′	59° 30′	0.667		0.678		0.738	
27	3.85	62° 06′	62° 03′	0.630		0.686		0.748	
28	3.77	64° 48′	64° 48′	0.500		0.694		0.759	
29	3.49	76° 46′	76° 45′	0.729	0.631	0.730	0.697	0.807	0.763

* One German pound or ½ kg. is equal to 16 *Loth.*

† One Freiberg *Lachter* is equal to two *mètres*, or 6.56 feet.

"The first four columns require no explanation. The fifth shows the point of the cord, expressed in decimal parts of it, at which the *Gradbogen* should be suspended in order to obtain a true reading, as shown in the third column.

"The values in the fifth column have been computed by Prof. Junge from readings made at the center and both ends of the cord, according to Lagrange's interpolation-formula. We agree with Prof. Junge that the point for the suspension of the *Gradbogen*, under the same conditions, should be removed from the center upward, in proportion to the length of the cord, which theory has also been verified by Borchers (see *Berg- u. Hüttenm. Zeit.*, No. 25, 1863); and it is to be pronounced an omission by Florian that in formulating his rule he took no account of this important fact. On the other hand, we take issue with Prof. Junge that he has not sufficiently emphasized the effect of the increasing vertical angle upon the correction to be made, to which Florian has attached the most importance. In a word, Florian says the *Gradbogen* should be suspended one decimal inch from the center for every degree of inclination; while Junge summarizes his experiments with the assertion that it should be suspended, on an average, 0.58 of the length of the cord from the lower end.

"To combine these, we must consider whether the absolute values given by each correspond. For the angle of 45° in Florian's rule, with the correction of 50 decimal inches, the values given by each are respectively as accurate as could be desired. By Junge's twenty-third experiment, in which the angle is 46° 42′, the distance of the suspension-point from the center is given at 0.098 of the length of the cord; that is, in this case, $4.67 \times .098 = 0.458$ Freiberg *Lachter*, or $0.458 \times 1.024 = 0.47$ Weimar *Klafter*. Now, according to Florian, the suspension-point should have been 0.52 Weimar *Klafter* from the center of the cord; but if we consider that Florian used a longer cord, as well as that the average values in the sixth column, twenty-third experiment, represent one of those cases in which the point of suspension has been given by Prof. Junge, no doubt, a little too low, we may safely say, as to Florian's correction-limit, that nothing better could be desired.

"Using Florian's rule, we find that by it, and on the basis of Junge's experiments, the best results are obtained if the number of degrees and fractions thereof, as read at the center of the cord, are multiplied by the factors 0.003 and 0.004, and to this result are added 0.50. Figures obtained by this calculation are shown in columns 7 and 9. In columns 8 and 10 the comparative average values show that up to an inclination of 15° the factor 0.004, and with greater angles the factor 0.003, give the best results. Therefore, to read the vertical angle as accurately as possible, the *Gradbogen* should be suspended toward the higher end of the cord at a distance from the center obtained by multiplying the length of the cord, at angles up to about 15°, by 0.004 for each degree, and for larger angles by 0.003.

"It might be said that, in the deduction of this rule, the weight of the *Gradbogen* and the tension in the cord have not been considered. But when two systems of experiments like those cited, made at different times and places, and therefore surely under very different circumstances, gave such similar results without considering the above factors, we are hardly justified in taking them into account."

P. & R. WITTSTOCK* (communication to the author): We read in the *Engineering and Mining Journal* of January 16, 1897, and

* Mathematical instrument-makers, Plan-ufer 92, Berlin, Germany.

in the *Colliery Engineer* for February, 1897, descriptions of Mr. Scott's new mine tachymeter, which so recommended itself to us that we at once undertook its construction. In the meantime we have read Mr. Scott's paper, and have been in correspondence with that gentleman, and he has given us several ideas concerning this latest type described below; but we are particularly indebted to him for suggestions concerning the edge graduation for the vertical circle and the method of mounting a compass over the telescope, to take the place of the striding compass, which has not yet ceased to be popular in this country.

The extension tripod is made of seasoned maple, is of a light pattern, and closes up to three feet in length. The upper ends of the legs have wooden tongues inserted to prevent splitting. The tripod head is cast in one piece, and the connection of the instrument is established by a strong screw-thread of a few turns. This is as simple and effective as is possible, and possesses the advantage of never getting out of order.

The engineer, who has to work occasionally in a chilly atmosphere, will appreciate the unusual size of the four leveling screws. Under any conditions they are a great advantage in connection with instruments having very sensitive levels.

The compound vertical axes of the instrument are turned with the greatest possible precision, are fitted to each other with exacting care, and are of such strength as to give the whole instrument an uncommon rigidity and stability.

Both horizontal and vertical circles are divided on solid silver. The figuring on the horizontal circle runs consecutively from 0 toward the right around to 359° in a single row. That permits the opposite verniers, marked I and II, to be also single. This is the only safe, simple and systematic method, as the angles are always read from left to right, no matter what the size. There is never any danger of reading the wrong set of figures or the wrong vernier, as might happen with the double row of figures and double verniers, which were devised in the mistaken idea of being better adapted to suit all conditions. A special feature of our graduation is its remarkable exactness, which cannot fail to give satisfaction to the most critical and scrutinizing engineer. The figures are placed unusually close to the edge of the graduation, which fact we feel will be much appreciated by those who have experienced the difficulty of reading the point of contact with long lines and distant figures.

The cylindrical ends of the horizontal axis rest in the Y bearings of the U-shaped aluminum standards. The bearings, one of them adjustable, have the usual covers, through which are inserted the friction screws with ivory points. The vertical pillars terminate in screw-threads, just like the extremities of the horizontal axes, to which the interchangeable auxiliary telescope and its counterpoise weight may be attached, and so revolved to any desired position. The pillars are made with large openings, and of such a shape (see Fig. 89) as to interfere as little as possible with the aiming of the main telescope.

Both telescopes are focused by a rack and pinion movement, and protected by a dust-guard slide that is not cut out to provide for the objective-end of the telescope bubble tube, as is very often done. We have crowded the telescope bubble as near to the ocular-end as possible (see Fig. 87), in order to accomplish this desirable result. In this position it is equally effective, and, besides, is more easily observed than when suspended exactly below the middle of the main telescope. All the optical parts are only of the first quality, and the magnifying powers, as stated in the following table, secure for the field of view an incomparable brilliancy; but, whenever we are called upon to employ a power one-third higher, nothing but satisfactory results are still obtained.

On one end of the horizontal axis is the vertical circle; on the other the gradienter screw, which also serves as the vertical clamp-and-tangent-screw. The beveled head is divided into 50 spaces, each of which corresponds to $\frac{1}{100}$ foot at a distance of 100 feet; or if the screw be moved through two entire revolutions, the horizontal hair of the diaphragm will travel vertically over the space of 1 foot, 100 feet away.

The figures placed on the vertical circle divide it into quadrants running each way, up and down, from the central zero-line. In this way an angle of elevation or depression may be read with the main telescope in either a normal or a reversed position. Mr. Scott says, in his estimation it is better to check a vertical angle by reading it in this way than to employ opposite verniers, which increase the risk of ruining the graduations by the grit that is deposited from percolating waters. For this reason one double vernier is provided; and it is now placed in a more convenient position for reading, as will appear shortly.

Table of Dimensions.

Sizes.	A.	B-1.	B-2.	C.
Horizontal circle, ...	4 in.	4½ in.	5 in.	5 in.
Vertical circle, ...	4 in.	4½ in.	4½ in.	5 in.
Main telescope (inverting), .	7½ in.	8 in.	8 in.	9½ in.
Magnifying power, . . .	18 diam.	20 diam.	20 diam.	22 diam.
Object glass, ...	1⅛ in.	1⅛ in.	1⅛ in.	1¼ in.
Can be focused, ...	down to 3 feet.			
Auxiliary telescope (inverting),	5½ in.	6 in.	6 in.	6½ in.
Magnifying power, . . .	12 diam.	14 diam.	14 diam.	16 diam.
Object glass, ...	¾ in.	⅞ in.	⅞ in.	1⅛ in.
Can be focused, ...	down to 3 feet.			
Length of needle, compass attachment, ...	3¼ in.	3¾ in.	3¾ in.	4½ in.
Weight of instrument with attachments, ...	3.58 kg.*	......	3.95 kg.†	......

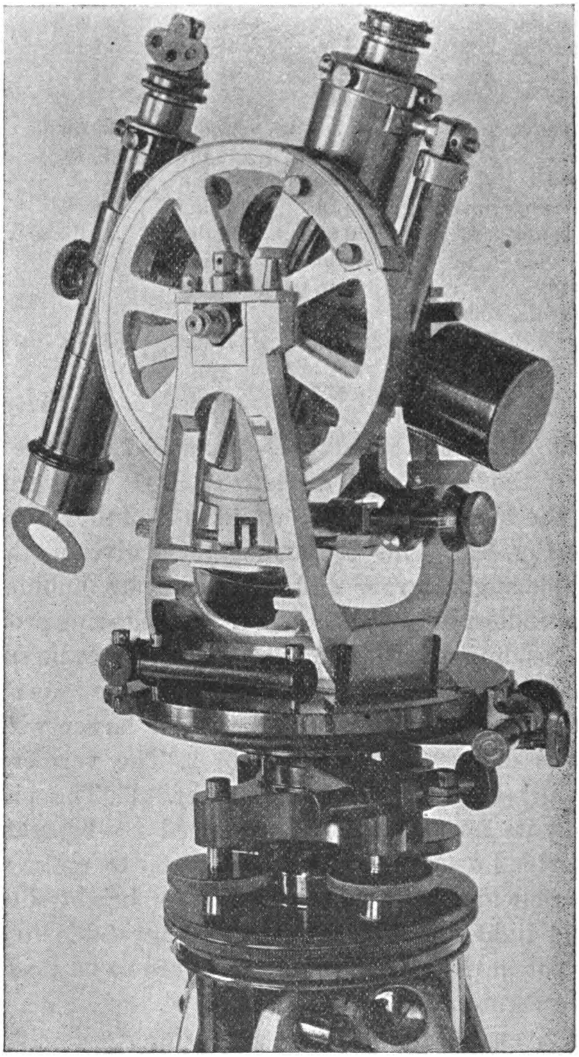
The only difference between B–1 and B–2, as appears, is in the size of the horizontal circle. In B–1 the verniers are placed on the top, as in Fig 86; while in B–2 they occur at the side, as in Fig. 87. This last arrangement gives us the opportunity of placing a larger and more delicate bubble on the plates, and indeed of presenting to the engineering profession a method of reading and illumination which cannot be surpassed. Its special advantages may be enumerated as follows: 1. It is obvious that the size of the graduation is larger without increasing the diameter of the plates. 2. The verniers can be placed at any angle to the line of sight. 3. The plate level may occupy its normal position, and need not be cramped, or made to extend over the edge of the plates to make room for the vernier-openings. 4. The diffusion of bright sunlight, or of artificial light underground, is more agreeable to the eye. 5. When not in use the reflector-shades are to be closed up, to protect the vernier.

Having given above a brief general description of the four types as we make them, we desire now to dwell in detail upon some of the more characteristic features of this new design, which we do not hesitate to say gives us the right and privilege

* 7.89 lbs. † 8.71 lbs.

to denominate Scott's mine tachymeter the most universally convenient and complete instrument ever constructed for mines.

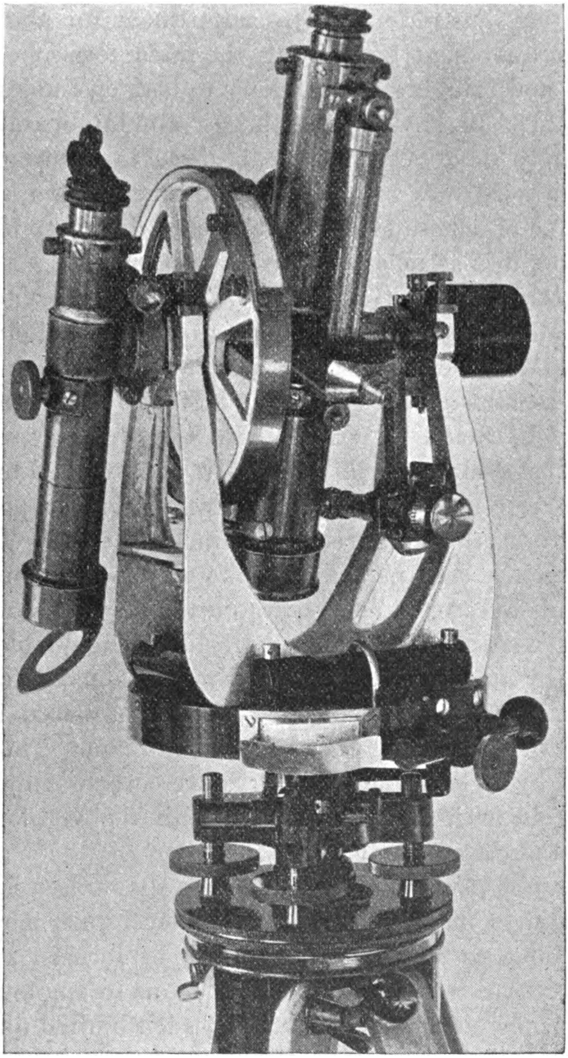
Fig. 86.



Scott's Mine Tachymeter, P. & R. Wittstock's Size A (4 in.).

The Interchangeable Auxiliary Telescope.—In America the auxiliary telescope has been in use for a great many years, but never before has it been possible to use it in more than one position as the case might require. But here is an appliance

FIG. 87.



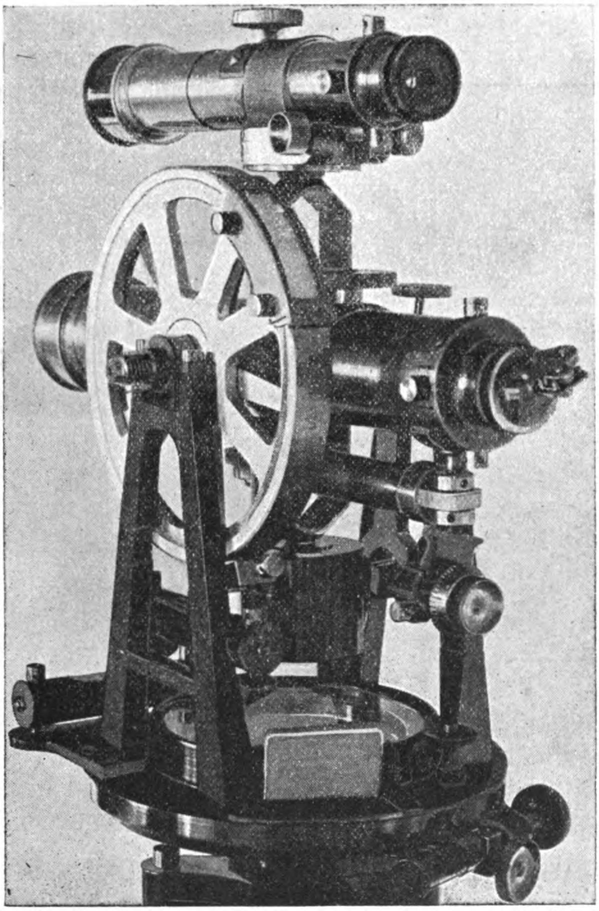
Scott's Mine Tachymeter, P. & R. Wittstock's Size B-2 (5 in.).

which can be used on the top, if a horizontal angle is to be read while the telescope is steeply inclined, or at the side, if an unusually steep vertical angle is to be read; and in each case with positively no correction for eccentricity. It may be attached as desired to any one of the four radial arms of the main telescope, and ranged very quickly and accurately into perfect adjustment with it by two opposing thumb-screws, as shown in all of our illustrations. This adjustment for alignment is secured in a moment by sighting the main telescope at a distant light and bringing the auxiliary to bear on the same light. The necessity for any adjustment for absolute parallelism is now entirely done away with; because in reading vertical angles it is used only at the side, and in reading a horizontal angle at one of whose sides the telescope dips very low below the horizon, it is attached only at the top.

The Vertical Circle.—Generally it will be customary to use the auxiliary at the right side, opposite to the vertical circle; but if it should ever be found more convenient to attach it to the left side, as shown in Figs. 87 and 89, the edge graduation will never be found to conflict with the auxiliary so placed. But the most desirable point which Mr. Scott wished to develop here has reference to occupying a very cramped position in surveying a narrow and precipitous inclined shaft. The engineer in such a case may now make an observation through either of his telescopes, and read both the horizontal and vertical circles without moving in his tracks! The double vernier is carried by an aluminum frame, with ample means of adjustment, that protects the whole circle, and is placed in a convenient position at about 45° above the horizon. The opening is covered by a glass plate of a curvature corresponding to that of the circle, as is indeed the case with the verniers of the horizontal circle shown in Fig. 87.

Disappearing Stadia Webs.—When the diaphragm is made of extra thickness, and the cross and stadia-webs are mounted on opposite sides, so that each group may be focused separately with the ocular, it seems impossible to us to employ equally high telescopic powers satisfactorily in such limited dimensions as are usual in the ordinary size surveying instruments. If, for instance, the focus of the objective is 9 inches, and the telescope of 20 diameters power, then the focus of the first lens in the ocular will be $\frac{9 \times 2}{20} = \frac{9}{10}$ inch, and the distance of the image from the first lens $\frac{9}{10 \times 10} = \frac{9}{100}$ inch. Consequently the thickness of the diaphragm must not be greater than $\frac{8}{100}$ inch, in order to leave a little space between the eye-piece and

Fig. 88.

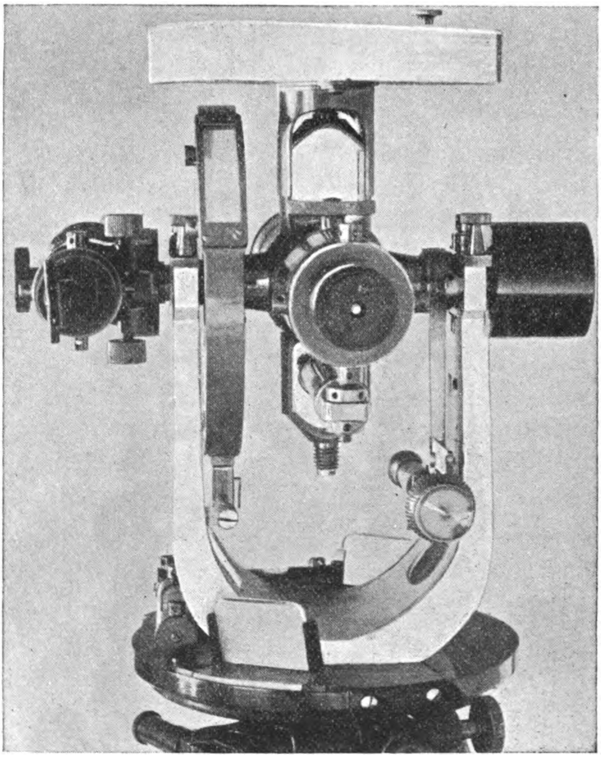


Scott's Tachymeter with Fixed Compass, made by P. & R. Wittstock.

diaphragm when the webs on the further side are in focus. Now, where is the room that should be allowed to suit the varying requirements of the eyes of different operators? Further than this, in such a case the webs that are out of focus are not far enough away to be entirely invisible, but blur the field of view; and, besides, every time it is desirable to change from one set of webs to the other it is necessary to re-focus not only the ocular, but also the objective.

Our construction provides for the usual worm-thread focusing arrangement for the ocular, with ample play to suit the requirements of different eyes. The cross-webs are also mounted

FIG. 89.



Detachable Aluminum Compass, on Scott's Mine Tachymeter, made by P. & R. Wittstock.

in the usual manner on a diaphragm of the usual form and size. It has, however, a tube-like prolongation toward the objective, in which a second diaphragm moves that carries the stadia-webs. By moving this second diaphragm backward or forward, the stadia-webs are brought into the field of view, or moved entirely out of it. The screws which govern this motion from the outside are of ample capacity to do this effectively. It will be understood that by this arrangement the cross-webs are never out of focus, and the adjustment of the line of collimation is, therefore, never impaired; since the eye-piece and object-glass always remain untouched.

Luminous Levels.—We have experimented considerably with luminous levels, and believe we have the honor to be the first house actually to introduce them as suggested by Mr. Scott. We have found that when exposed to a diffused dry light the luminous substance will act longest and best, and in the dark the divisions in the glass and the bubble itself appear quite distinct. When the action becomes weaker, and the luminosity fainter, it is with some difficulty that the bubble can be detected even with a magnifier; but the efficiency in this respect is restored by burning a strip of magnesium before the bubbles. However, it is only on rare occasions that this novelty will be an actual necessity, as Mr. Scott says, and no doubt what we have accomplished will amply suit all requirements.

The Compass Attachment.—To adapt this instrument to all the requirements as demanded still in Germany, England, and elsewhere, a circular compass-box, made of aluminum, is mounted on the upper vertical pillar, in the same way as the auxiliary telescope is attached. Most mine surveyors will have established near their works a true meridian determined by astronomical observation. The instrument should be set up at one end of this line, and, when the other is sighted through the telescope, the needle is brought to read upon the north point by means of the opposing milled-head screws below. By this same means any desired declination can be set off. As the compass-box is very light, weighing only .15 kg., or 5 ounces, there is no reason why observations through the main telescope should not be made at any considerable inclination with the compass still attached and the needle clamped; but before the needle is read, of course, the telescope must be brought back to a horizontal position. We also make a non-adjustable style, as shown in Fig. 89, which can be very easily and exactly attached, and can be carried in the pocket. Of course, there is no limit to the length of needle that may be used in this model, but we recommend those suggested in the table.

EDWIN J. HULBERT* (communication to author): I have been reading with much interest your able article in which (Fig. 31) you have included a description of an instrument which evidently you did not know was designed by the writer in 1854 to conduct surveys in the old Cliff mine on Keweenaw Point. The instrument was designed for the execution of a certain problem, and did it effectively and satisfactorily, though there may be means now in this progressive age still more accurate and rapid. I have fought my fight in the battle of life, and seek not for more recognition from the world than has been thus far observable; for be one an explorer, discoverer, scientist, historian, poet or author, he is bound later on by some investigator to be effectively "smashed." Iconoclasm is an attractive diversion, and will ever be in fashion; of course, there are some bugs larger than others, but each and every one remains still a bug.

It should be borne in mind in examining the problem I had confronting me that in the early days the phenomenal deposits of native copper, without precedent in the history of mining, were looked upon with much doubt as to their persistency in depth. Capital was not abundant—in most cases insufficient—skilled labor wanting, and, therefore, extreme economy enjoined. In fact, mining in the two decades following 1845 should be considered to have been explorative rather than exploitative; the shafts and drifts usually being small and cramped. Shafts were not sunk by an engineer's lines for a direct and regular course, nor for any particular grade, but followed the sinuosities of the footwall. The surveyor was forced to adapt himself to the exigencies presented by the rude bed-planking in the undulating shafts upon which the kibbals† slid to and from the different levels. Upon this no elaborate stations could be erected, and his almost invariable accompani-

* Retired mining engineer, a pioneer in the Lake Superior district, who discovered the celebrated Calumet copper lode on August 27, 1864; now residing at Via Nomentana 257, Rome, Italy.

† Kibbal. (A bucket or little tub. Armoric. Quibell, *idem.*) A bucket in which all work or ore is raised out of the mines. Gear barrels in the North of England. A whym-kibbal is a larger one, which belongs to the machine called a whym, and serves to draw water with, or bring up the ore to grass. Some of these larger barrels or kibbals contain 120 gallons when they are intended for drawing up water out of the mines. (Glossary. Pryce, *Mineralogia Cornubiensis*, London, 1778.) Written also "Kibble."

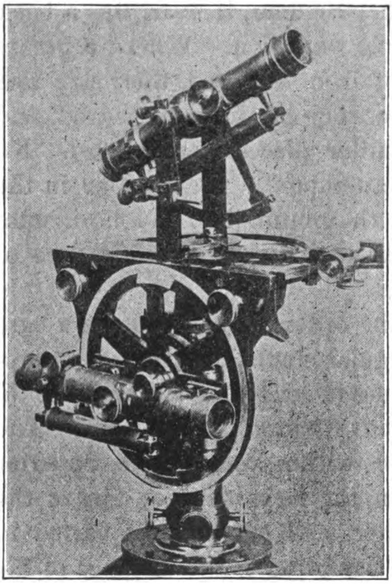
ments were smoke, foul air and precarious surroundings. Convenient and proper instruments were not at his command, and in fact, the necessity for the skill of a mining engineer was looked upon askance, and generally he was regarded by the miners as a genteel supernumerary.

In those early days, mining captains and skilled labor for drift work, for shaft and gallery timbering, and for setting of pumps and of hoisting-engines were brought from Cornwall; many of the captains bringing with them the ordinary compass-dial, depending upon the polarity of the needle for direction and for repeating upon the surface a duplication of the tangents taken in the underground work. Seldom, if ever, was a back sight taken to test for magnetic variation. Where a pump, iron railways or other masses of iron occurred, their size and distance from the compass were very carefully measured, and upon the surface repetition similar pieces were placed. No triangular calculated work was attempted. Inclinations in the shafts were taken by means of the plumb-line, and horizontal offsets and measurements made with linen tapes, the age of which was not often questioned.

It was evident to me, that, in order to carry down a base through these cramped and irregular shafts, and from it to project a tortuous traverse many times its length, no accuracy could be obtained by use of the above enumerated means. The polarity of the needle upon or within these Lake Superior rocks was not to be trusted in the least degree; for, as the electric currents following either wall of the vein varied in force, the deflection also varied according to the distance of the instrument from it. The Cliff mine fissure-vein had a dip to the eastward varying from 83 to 86 degrees; consequently no sight on this inclination could be taken with the ordinary transit telescope.

Before designing an instrument suitable for this survey, some experiments had to be made. Having at hand a rude half-circumferentor, or goniometer, carrying the ordinary slit compass-sights, I attached to the side, overhanging the tripod, a half-circle made of wood, graduated with a penknife, and provided also with slit sights. Beginning on the surface, with the upper main sights bearing upon the base-line of the triangulation, I took the inclination with the side sights directed towards a candle in the mine level below. Then I erected the instrument upon the point occupied by the candle, and with the two sights clamped in the position read at the surface, back-sighted to the surface point; and so established a line underground parallel (or as nearly parallel as it was possible for this improvised wooden model to make it) with the base-line of the surface triangulation. Repeating the work several times, making mechanical corrections for instrumental imperfections, I found the results fairly satisfactory; and being satisfied that with care in the manipulation of a good instrument of like nature good work could be done, I completed the design of the "double telescope transit" (Fig. 90) without the special interjection of French influences presupposed by you. The plans I laid before Mr. Young, of Philadelphia, personally, and he stamped them with his approval.

FIG. 90.



Hulbert's Transit, the "Lake Superior Pattern" of Fig. 31.

At that same visit, I think in 1854, I showed him my sketch of a transit with a base in the form of a horseshoe mounted upon three leveling screws and an open-topped tripod-head, to be used for vertical sighting or for slight deviations therefrom; also another sketch of a transit with hinged standards, so that the telescope could be swung forward beyond the interference of the plates. These last two projects were rejected by this venerable mechanic; for he believed that he could not provide against the spreading of the horseshoe base, or construct a hinged standard so perfectly that it would always project a line twice alike. Mr. Walter Crafts, then superintendent of the old

St. Mary's mine, but now of Columbus, O.,* I think, saw my drawings of the horseshoe transit. At any rate, the proposition for a design similar to Fig. 64 was extant nearly twenty years before Buff & Berger built that one for Mr. G. H. Crafts. The elder Young, now deceased, thought he could not, as I say, insure the absolute stability of the adjustments of either of these models.

In all my experience I have always discredited the efficiency of plumb-lines in shafts of any considerable depth, believing that greater accuracy could be obtained by a sight through a telescope adjusted to the nadir. After "holing" through to the Howe-shaft at the Cliff mine, I tried to close the survey instrumentally by dropping plumb-lines 630 feet in length. The plummet was suspended successively in water, molasses and diluted tar. The air currents were then entirely cut off, but, after several hours' waiting, in each instance the lines had not assumed absolute rest. We next tried the falling of a well-turned plummet from the top of the shaft to its bottom, where we placed a bed of clay to receive the impression. In several trials, however, we did not succeed in getting it to drop twice in exactly the same spot, although we burned off the thread that held it at the surface. But with the instrument (Fig. 31 or Fig. 90) very carefully leveled, and sighting down repeatedly with the zero of the limb turned respectively to the four cardinal points of the circle, we found the four points thus established to coincide very nearly. I do not believe that a plumb-line of any considerable length is going to obey the desire of the engineer so far as to vibrate precisely in any one direction; and I fancy that should Dr. Schmidt's apparatus (Fig. 27) be opened out from the plumb-line after it was supposed to have come to rest, it would begin of itself to renew its oscillations along directions governed apparently by no fixed rule.

I should place more reliance upon a downward sight through a properly constructed and accurately adjusted telescope than in the repose of a plumb-line. We trust the telescope for the

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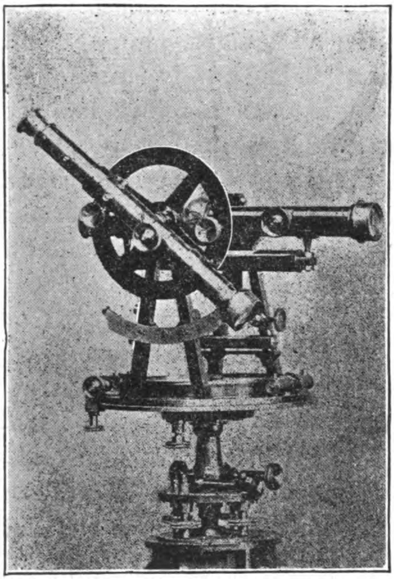
* SECRETARY'S NOTE.—Walter Crafts, born 1839, graduated C.E. at Troy in 1859; studied at Freiberg in 1861–62; afterwards went to Lake Superior; lived several years at Columbus; and died August 2, 1896. For these facts I am indebted to Mr. B. S. Lyman of Philadelphia, Pa.—R. W. R.

measurement of all horizontal distances, and we never question its accuracy in taking inclined angles and observations; now, therefore, why not accord it the same confidence in taking a truly vertical sight? Except for moderately short distances, I always considered the plumb-line a positive nuisance, a consumer of time and a disagreeable tester of patience.

The survey for which the instrument in question was made was one in which cross-cuts from the 30-, 40-, 60- and 70-fathom levels had to be driven back to the position of Avery-shaft (vertical), where we had seven gangs of miners, before the work was finished, raising and sinking against one another,—with an ultimate error of but 4 inches. That may be considered very reasonably close, when mud, slime, smoke and careless, ignorant assistants are given their place in the conditions that militate against one's chances for success.

FIG. 91.



Hulbert's Original Side-Telescope Transit.

In a second survey, involving a traverse of nearly a quarter of a mile, the error in closing was about 3 feet,—not quite so successful; but one cannot hit a bull's eye every time, even under the most favorable circumstances. Put a "newly-fledged chicken" from the Michigan College of Mines into such shafts as we had on Lake Superior forty years ago, and I fancy he would be very careful how he handled his few trumps.

It is particularly fitting to remark here, in this contribution to your paper on the evolution of mining instruments, upon how my second design was evolved from this first parental instrument. In 1856 we were making ready to "hole" into the Howe shaft of the Cliff mine at the 60-fathom level, and for this special piece of work, in that year I designed, and had Young make for me, what was, to the best of my knowledge and belief, the first application of the *side* auxiliary telescope. It is reproduced here in Fig. 91 from a photograph preserved and kindly loaned by Mr. Young, and represents the ordinary flat-center transit instrument of that day with the second telescope mounted at the side. The tripod legs, as was then general, were of solid rigid pieces; though we had those in use constructed of three brass tubes sliding one within the other. The shifting tripod-head was also made at my suggestion by Young, who reaped the pecuniary benefit of its well-merited subsequent popularity. I never occupied myself with the idea of patent right and profit, as you assure me has been the case with yourself.

The method of mounting the auxiliary telescope prostrate upon the vertical circle was very similar to that pursued in my first instrument (Fig. 90), except that it was removed just far enough to escape the edge of the plates. But the combination was mounted now in a more stable position at one extremity, and concentrically with the axis of revolution.

I suppose, in the ethics of instrumental construction to-day, it would be considered necessary to counterbalance with a weight opposite, or at least to put the vertical circle at one side and the auxiliary telescope at the other; but we could not arrive at absolute perfection at once and leave nothing for posterity to accomplish.

With the improvement of the original instrument, however, as now accomplished by you in the "Scott tachymeter," in its solidity and perfect construction, the engineer should be quite content to undertake the solution of the most difficult problem ever presented in the mine.

The Evolution of Mine-Surveying Instruments.

BY DUNBAR D. SCOTT, HOUGHTON, MICH.

(See *Trans.*, xxviii., 679; xxix., 931.)

Continued Discussion.

Alfred C. Young* (communication to the Secretary): Before the appearance of Mr. Scott's paper in these *Transactions* we were not specially interested in the investigation which he has started; but at his request we have endeavored to collect from musty records and the recollection of our old friends a brief chronicle of the progress made by this house.

As 3000 instruments were manufactured by us before any descriptive record was kept, and 2000 more before the record contained more than a statement whether the instrument was a transit or a level, and sometimes its size, we approach the task with timidity, trusting that the reader will bear the difficulties in mind, particularly as the writer's predecessors, from whom, no doubt, the information desired could have been obtained, have passed away.

Instruments for surveying were manufactured by David Rittenhouse, of Philadelphia, as early as 1760; but it was not until late in the first quarter of this century that there was any American market for an instrument outside of the ordinary surveyor's compass. With the advent of canals and railroads, and the more extensive development of the Pennsylvania coal-fields, arose a demand for surveying-instruments to meet problems in engineering beyond the limited field of the compass.

On May 1, 1820, in which year the practical mining of anthracite coal in Pennsylvania began, William J. Young, who had served his apprenticeship with one Thomas Whitney, started in business on Dock Street, in Philadelphia. Recognizing the fact that compasses, or "circumferentors," as they were

* Conducting the establishment of Young & Sons, Philadelphia, Pa.

commonly called, were not equal to the demands made upon them, and that the English theodolites had too many parts liable to injury, were cumbersome and ill-adapted to transportation, Mr. Young commenced to plan an instrument that would permit horizontal angles to be taken independently of the needle, and allow "back-sights" to be obtained without reversing the telescope in its bearings.

In 1831 he introduced the first "American engineer's transit" (Fig. 60* of Mr. Scott's article). From that time to the present *all* improvements have been merely in the perfecting of details and the addition of attachments to meet special requirements—so well were the fundamental principles thought out by the inventor, even to such minor features as the placing of the verniers at one side of the standards, so as not to risk disturbance of the instrument while readings were taken.

In July, 1858, he patented the "shifting-tripod-head." On simply loosening the leveling-screws, the transit can be shifted a short distance in any direction after the instrument has been approximately set up. No improvement has been made in this invention since its introduction.

The first compound "long-center" transit was made for J. Simpson Africa, Esq., President of the Union Trust Company of this city, who, in a letter dated February 1st, 1899, says:

"I am reminded that the first long-center transit-instrument mentioned in your books was purchased by me November 11, 1853.

"My engineering records and papers being at my old home (Huntingdon, Pa.), the only information I can give now is from recollection. Through my instructor in practical engineering, Mr. Samuel W. Mifflin, I made the acquaintance of Mr. William J. Young, the founder of your house. One of my duties was to test, in actual surveys, transits that he had made for a railroad then in progress of construction. All these had short reversible telescopes, and verniers for the plates were *within* the compass-box.

"Needing in my own business an instrument with which I could measure angles with greater precision than could be attained by those mentioned above, I suggested to Mr. Young to construct for me a theodolite somewhat after the English model. He convinced me that a transit with a long center, wider plates than were commonly used, verniers outside the needle-box, and a long telescope, would meet my requirements, and be more satisfactory than a theodolite. This conference resulted in my giving him an order for the instrument you mentioned.

"I used it with great pleasure and satisfaction for many years in general engineering work, and especially in the laying-out of towns, and in defining disputed boundaries, where the greatest attainable accuracy was desired. Many years later

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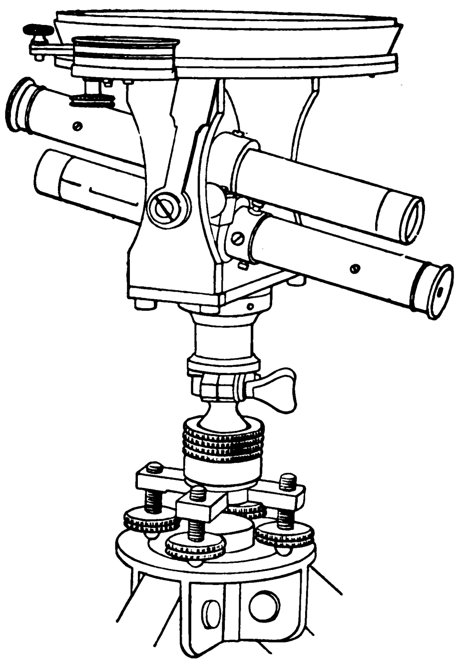
* Page 66.

I had another transit made at your establishment, built on the same general plan with the then modern improvements added. This instrument took the place of the one made in 1853, and is now in use by one of my sons."

As to the dates of the introduction of the various forms of mining attachments to engineers' transits, and the names of those who suggested these improvements, our early records supply but meager information. Fortunately, however, some of the instruments are still in existence, from which photo-

FIG. 92.

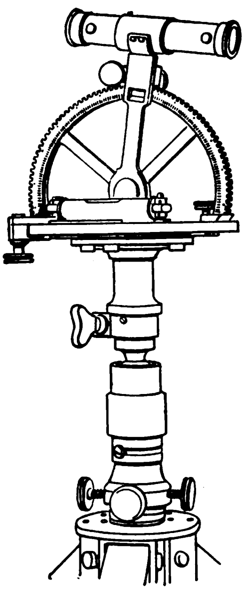


Bartelot's Mining Compass.

graphs have been obtained, leaving in doubt only to whom the honors may belong. The following list comprises mining instruments made by this house at various times, and not hitherto mentioned in this discussion.

Fig. 92 (our shop No. 3366) represents an instrument made in April, 1855, for a Dr. Bartelot, who seems to have lived in the anthracite coal regions of Pennsylvania. The instrument was intended only for magnetic surveys, so that the compass-box was placed conspicuously above, where observations of the needle would be least obstructed. The compass was provided with what was then known as a "Nonius-plate"—a simple marginal indicator that marked off the degrees, and the larger subdivisions thereof, to be used in allowing for variation. I suppose Pedro Nuñez, the Portuguese mathematician, who lived in the first half of the sixteenth century, was the first to use this device, but Rittenhouse is said to have been the first to use the vernier for this purpose. The complete revolution of a telescope in a design of this peculiar kind was impossible; and the method resorted to, of using duplex telescopes for forward- and back-sighting, makes this model, so far as we know, unique among mine-surveying instruments. The only other type at all similar is Mr. Hoskold's (Fig. 39*), which he was perfecting some two years later; but the methods employed in each case will scarcely permit a comparison. The duplex telescopes revolved about 20° from the horizon each way, upon a common axis, that could be adjusted for horizontality by means of the capstan-head screws shown in the figure just below the base of the standards; but their adjustment for parallelism could only be secured by the maker. The instrument was leveled by the ball-and-socket base, the four leveling-screws and the box-bubble at the side of the compass-box.

FIG. 93.



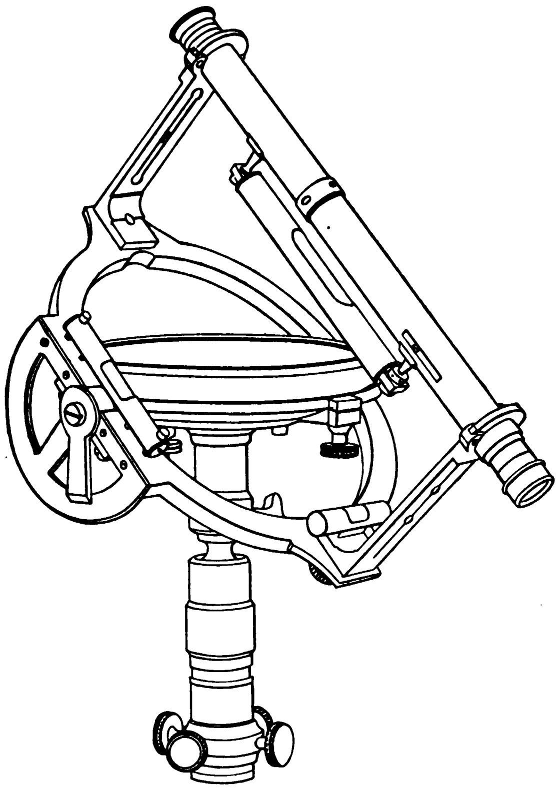
Mulloney's Mining Dial.

Fig. 93 (our shop No. 3448) represents a mining instrument made in October, 1855, for J. F. Mulloney. It is decidedly of English parentage, possessing the same rack-movement shown in Fig. 16,† and an arch much as it appears in Fig. 15.‡ The horizontal plates were maneuvered by the same kind of rack-work. But the most remarkable feature is the substitution of "Locke's sights" for the telescope. These sights are practically what are known to-day as Locke's hand-level, invented by Prof. John Locke, M.D., of Cincinnati, in 1850. I suppose Mr. Mulloney wished to use the sights for

* Page 44. † Page 18. ‡ Page 17.

leveling purposes, and, as they did not permit accurate centering, he very wisely demanded that the arch be graduated and read by a simple index to only ½°. The base of this instrument is very tall, slender, and really an ill-proportioned type, though it was very common in those days. From the ball there extended down through the barrel a square shank, upon the faces of which worked the opposing screws shown

FIG. 94.



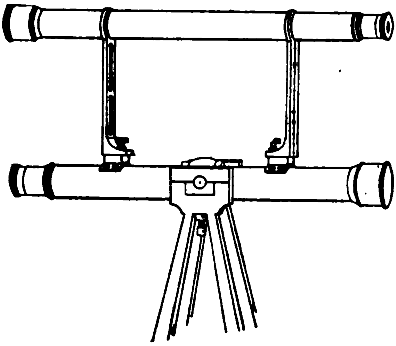
The Smith-Hedley Dial.

just above the tripod head. After clamping the ball and socket tightly, the instrument could be brought to a more perfect level by use of these screws. Two extra tripods with sockets for holding candles, as is common in Cornwall to-day, were furnished with this instrument.

Fig. 94 (our shop No. 3545) represents a modification of the Hedley dial, made in October, 1855, for Thomas Smith, of

Luzerne county, Pa., and bears the distinction, we believe, of being the first Hedley dial ever provided with a telescope, Mr. Stanley's instrument (Fig. 40*) not being made until 1874. The Smith-Hedley dial had within the compass-box a horizontal plate, graduated to read minutes, that was governed in its movements also by rack-work. The rocking limb was 10 in. long and provided with a side arc upon which grades as great as 70° could be observed before the limb came in contact with the base. In this particular, this style of base or support is superior to the Hoffman-Harden tripod-head used by Mr. Stanley, until he remodeled the rocking limb (Fig. 63†), so as to permit vertical sights. However, these instruments are out of date now in this country, though there was a time when they were widely used in railroad construction. It is from this instrument that compasses designed to give horizontal angles independently of the magnetic needle received, and still bear, the name "railroad compasses."

FIG. 95.



Petherick's Mine Transit with the First of Top-Auxiliary Telescopes.

It was but a step in the line of progress to mount the telescope in Y's, as shown in Fig. 95, and attach it to the instrument shown by Mr. Scott in Fig. 34.‡ We believe that this was the first American top-auxiliary telescope, and that the opinion ascribed to Mr. Knight (page 39) is not well founded. We are not positive as to the exact date of introduction, but we present in Fig. 95 what was doubtless the pioneer instrument of the top-auxiliary type, and as far as we have been able to determine, it was made for Mr. Wm. Petherick, Superintendent of the Copper Falls Mines, Mich., 1855–60, apparently from drawings furnished by him.

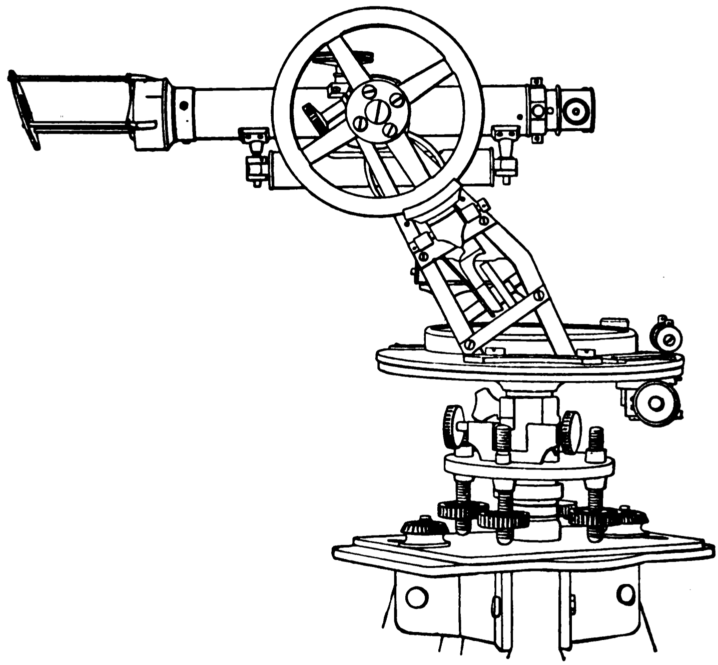
As first made, the auxiliary telescope was clamped on the main telescope, about the same as compass-sights, but would never clamp in line with the main telescope. Then the uprights

* Page 45. † Page 75. ‡ Page 39.

were attached permanently to the transit-telescope, and the auxiliary only was made detachable, as well as reversible, "end for end" (somewhat as shown in Fig. 94); but in this form the uprights would get bent in the mines, and render the attachment useless. A hinged upright was then tried, similar to the folding compass-sight (Fig. 34, above cited), but the hinge-pin would wear, and the uprights rattle.

The writer's plan, introduced in 1891, is to mount the

FIG. 96.



McNair's Original Inclined-Standard Mine Transit.

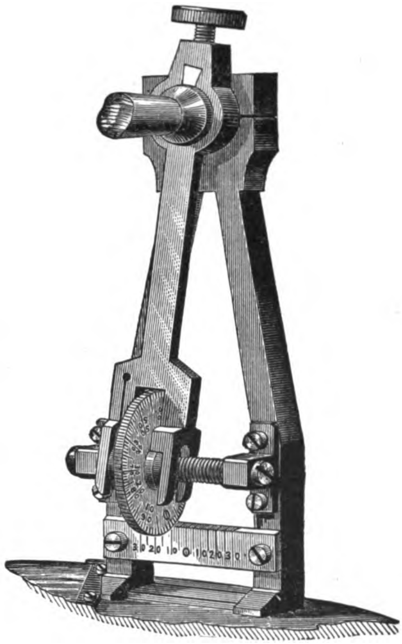
uprights upon a base-plate, and attach it to the main telescope by "Y" bearings.

When Mr. Scott assumes* that the inclined-standard mining-transit came down through Seibert's solar, he is not entirely correct. As a matter of fact, the first inclined standards made by this house were made in July, 1854, for Alexander Roberts, of Hamburg, Pa. In the next year we made one of the same kind with long center, double verniers and telescope-level, but

* Page 47.

no vertical arc, for the Philadelphia, Wilmington and Baltimore R.R., but we have no photograph or further description of these instruments. From this time on, no others of this pattern seem to have been made by us until that made in 1875 for Thomas S. McNair, then mining engineer for the Lehigh Valley Coal Company at Hazleton, Pa. It was at this time that our Mr. Thomas N. Watson, in the course of the argument, suggested the principle of the "hinged standards" by revolving a draughtsman's triangle on one of its corners. The idea was rejected; but it seems to us now that if unusually large journals had been used and the adjustment had been secured as in the horizontal axis of the telescope, it could have been made to project correct alignments.

FIG. 97.



Young's Gradienter.

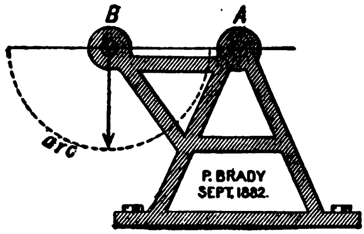
Mr. McNair's instrument is still in use, and is reproduced here (Fig. 96) from a photograph kindly prepared by that gentleman especially for this discussion. The credit for first having used this type in mining work is possibly due to Mr. McNair; but he modestly refuses to accept it without reserve, observing, "The ancients, you know, are said to have infringed on our inventions." Attached to this instrument will be noticed the style of gradienter introduced by this house in 1872, the first, we believe, to appear in America. It is shown more in detail in Fig. 97. We use it still, for the reason that it is not so exposed as the other style, and is equally easy to read and manipulate.

Of distinctively mining transits, there are probably more of the inclined standard type in use than any other, all objections to its eccentricity and "overhang" melting away wherever it has once been used. It has achieved this recognition without any special recommendation on the part of the makers.

From this time on, the desirability of combining the advantages of McNair's model with those of the concentric type began to occupy the minds of engineers. In 1882, Mr. Peter Brady, then connected with the Glendon Iron Co., Easton, Pa., suggested to the writer the advisability of designing a mining instrument (Fig. 98), substantially what is known to-day as the duplex-bearing mine-transit. It was pointed out to him that the structure, with all the necessary appliances, would be so cumbersome as to merit the present well-deserved name of "steam-engine;" that there would be great difficulty in keeping the bearings free from grit and in proper adjustment, and great liability of the changeable parts to injury; so, upon due consideration, the idea was abandoned.

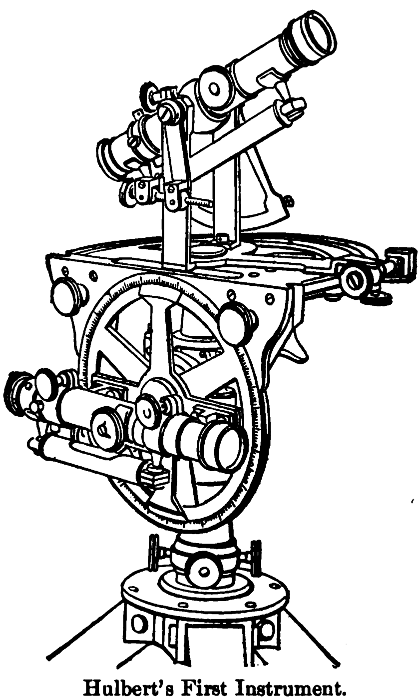
In 1854, Edwin J. Hulbert ordered of us, as he has explained, an instrument (Fig. 99*) known then as the "Lake Superior pattern." Figs. 99 and 100 show some features not clearly seen in the illustrations given by Mr. Hulbert. In Fig. 99 the upper plate was semicircular, 8 inches in diameter, reading by a single vernier to minutes. The vernier was in the clamping-arm or alidade of the upper limb, and was also provided with a small tangent-screw. The telescope was provided with a vertical arc, clamp and tangent-screw and loose vernier-arm, as

FIG. 98.



Brady's Proposition.

FIG. 99.



Hulbert's First Instrument.

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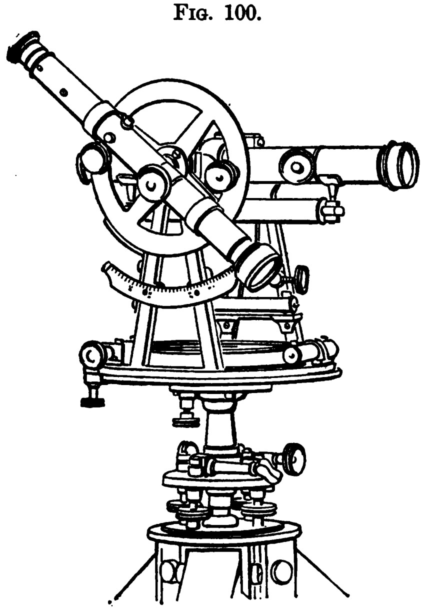
* Compare Fig. 90, Page 148.

introduced by Alfred Young in 1850. The side-telescope, having a level attached, was mounted on a free vertical circle, 6½ inches in diameter, reading by two verniers to minutes; a clamp and tangent were also provided; all mounted on a compound ball-and-socket with leveling screws. Not many of these instruments were made. While seeming to fulfill particular requirements in the copper regions of Michigan, they were not favorites with the instrument-maker, on account of the peculiar shape of the plates, the contraction and expansion of which were apt to destroy the adjustments; and the absence of the needle was at that time a popular objection on the part of the engineer.

Fig. 100.



Hulbert's Original Side-Telescope Transit.*

Fig. 100 shows what was probably the first side-auxiliary telescope attached to a mine-transit in America or elsewhere. It was made for Mr. Hulbert, from designs furnished by him, as he explains, in 1856. A full vertical circle was connected permanently with the axle of the transit-telescope. The auxiliary telescope, which alone was detachable, was attached to the vertical circle by means of two milled-head clamp-screws.

Fig. 101 illustrates an improvement in Mr. Hulbert's pattern. The telescope is much shorter and larger in diameter, and is permanently connected with the full vertical circle, which is also made detachable.

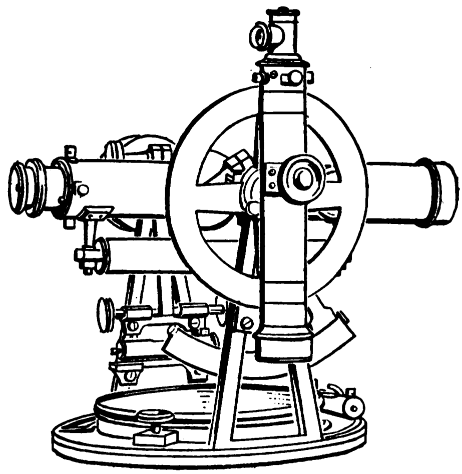
Later, several methods were adopted to simplify the attachment of a side-auxiliary, one of which was a perforation of the horizontal axis large enough to permit the insertion of a spindle attached to the telescope (as shown in Fig. 28†). The objec-

* The same instrument as the one of Fig. 91, page 150. † Page 34.

tion to this was that, unless the horizontal axis was made very heavy, it was weakened at a vital point.

Another method was to terminate the horizontal axis in an enlarged threaded hub beyond the outside of the standard and to screw the telescope on with a clamping-nut, as in Fig. 38,* but as the threads wore, the alignment of the telescope was destroyed; and while the parallelism of the two telescopes was not disturbed to any marked degree, the zero (level) points were, and it was necessary for the engineer to allow for this index-error, or insert a piece of tin foil between the hub at-

FIG. 101.



Improvement on Hulbert's Mine-Transit.

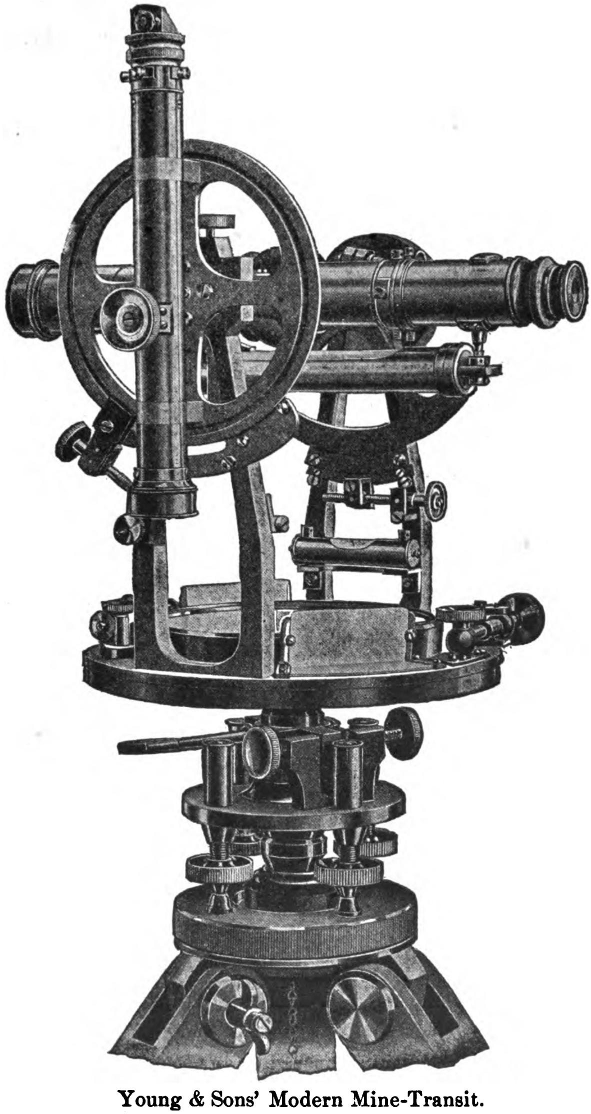
tached to the telescope and the side of the standards. Of late years it has been customary to add a tangent-screw or two opposing screws to remedy this objection.

Fig. 102, illustrating the style in use at present (1899), is taken from a transit made for use in the Kimberley mines, South Africa. The auxiliary telescope is attached permanently to the vertical circle (5 in. in diameter, and reading by a single vernier to one minute), and is provided with a clamp and a tangent-screw. The graduations are on the inside of the circle, to protect them from injury, and to facilitate the reading of the vernier. The telescope (non-extension, dust- and water-

* Page 42.

proof), 7 in. long, is furnished with a diagonal (prism) eye-piece and a reflector for cross-hairs (the latter not shown in the

FIG. 102.

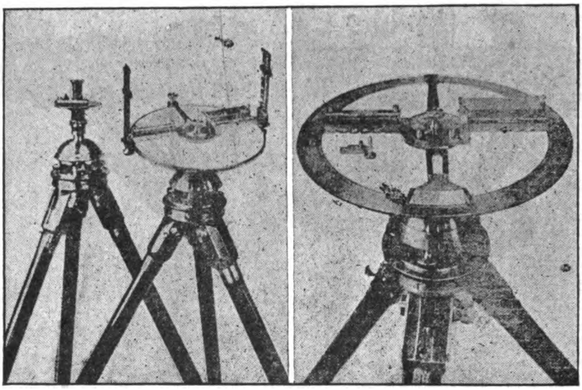


Young & Sons' Modern Mine-Transit.

figure). All the attachments, with the counterpoise, are detachable, and when they are not in use the engineer has still a complete transit, with all modern improvements, having a graduated plate 6⅜ in. in diameter, level to telescope, clamp and opposing screws (not shown in the figure) and vertical arc.

Frank Owen, London, Eng. (communication to the Secretary): The following detailed description of the "Henderson Rapid Traverser," alluded to by Mr. Scott* and by Mr. Brough,† may be of interest. I am indebted for it to the courtesy of the inventor, my former teacher, Mr. James Henderson, M. Inst. C. E., of Truro, Cornwall, England. He previously in-

Fig. 103.



Henderson's Rapid Traverser.

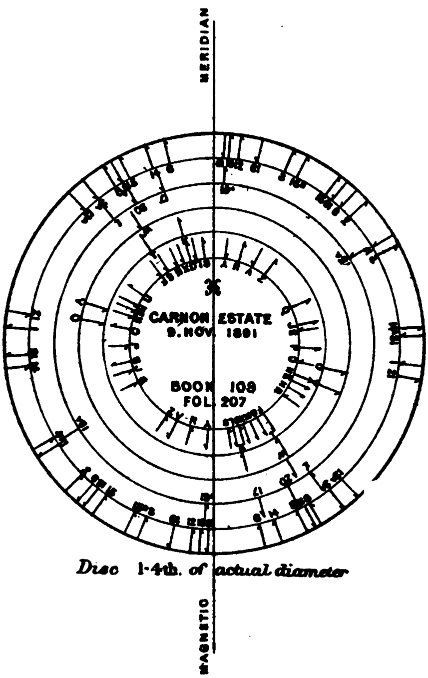
vented the Henderson dial,‡ a circumferentor with four sights, described by Brough in his *Mine Surveying*, and by Stanley in his *Surveying Instruments*. The present account is based on a paper read by Mr. Henderson before the Mining Association and Institute of Cornwall in December, 1893. The illustrations, Figs. 103 and 104, are taken from the catalogue of Messrs. E. T. Newton & Son, Camborne, Cornwall, the makers of the Traverser.

The Rapid Traverser is a circular brass table of about 10 in. in diameter, mounted on a tripod-stand with the usual leveling-screws, and having a brass alidade or ruler that revolves around a fixed center-pin, and that has at each end a vertical sight, capable of being replaced by an arc or quadrant when angles of considerable elevation or depression are to be measured. On the top of the table, a disk of enameled zinc is securely fixed by small screws and nuts and by a central holding-down brass plate, over which the alidade freely passes. Rain or dropping water, or even washing with soap and water, will not obliterate the pencil-marks; yet hard scrubbing will remove them, and the disk can be used repeatedly.

* Page 13. † Page 69. ‡ Page 17.

The surface of the disk has five concentric rings scratched or marked upon it by means of a pencil inserted in five small notches in the thick edge of the alidade, and held fast while the disk is revolved. The fiducial or feather edge of the alidade has corresponding marks, numbered and with a rectangular notch opposite each division, to allow the letter or number of each course or station to be marked on the disk. The concentric rings are to prevent the overcrowding of traverse lines in any one direction, and enable separate surveys to be made with the same disk without interference. The table carrying the disk can be firmly clamped to the tripod head, and the alidade to the table when required. The clamping screws for each are distinguished by a difference in form.

FIG. 104.



Disk of the Rapid Traverser in Use.

In use, the fiducial edge should always be on the observer's right hand. After clamping the table and sighting the alidade, the direction is marked with a fine pencil-line drawn across the space between any two adjacent concentric rings. The leading direction is indicated by a single barb, or half arrow, at one end of the line; and the number or letter of the course is written within the notch cut in the edge of the alidade. For hilly ground, the sight at each end of the alidade is marked in degrees up to 25, and has a sliding-bar so fitted that by looking through the eyehole at the top of one sight and setting the sliding-bar on the forward object, the angle of inclination can be read and noted. Or, for greater accuracy, the quadrant can be substituted for the sights, and the angles read to minutes. The telescope attached to the quadrant revolves on a vertical axis, so that by revolving 180° to a mark made for the purpose, back sights can be observed without shifting the alidade. In going from one station to the next, the Traverser is removed from its stand, and fixed, with the alidade still clamped, on the forward stand, and sighted back to the former tripod and clamped. Then the alidade is unclamped and a sight taken to the next station, or to any subsidiary station. It is recommended that three tripods be used in a traverse either underground or on the surface. The magnetic meridian can be taken at any convenient station by means of a trough-compass placed temporarily against the back of the alidade. The distances from station to station are measured separately, and are entered, as usual, in a note-book.

For plotting, the disk is removed from the brass table, and placed in proper position upon the intended map, with one or more meridian lines upon it, and is held firm by a weight or two. Then, with a parallel ruler, best a rolling one, the successive courses of the survey are transferred to the map. The disk becomes a protractor of great accuracy, and the plotting is more rapid than usual. The disk may be kept for future reference, or can be cleaned off by scrubbing with soap and water, or with india-rubber. If desired, the bearings can be read off rapidly, by means of an alidade moving about a pin in the centre of a protractor over which the disk has been placed.

The Traverser can be used either in mines or on the surface; and for setting out railway or other road lines by chords of any length previously drawn on the disk, with the lengths thereof noted in the field-book.

Clearly, the Traverser is based on the plane-table method, and is really a goniograph or angle-drawer without any reading or booking of angles; but, unlike the plane-table, it is not used for plotting the survey in the field. The advantages claimed over other surveying instruments are: 1. A great saving of time. 2. Simplicity of construction, and consequently comparative cheapness. 3. Portability, and without liability to damage. 4. Great simplicity in the subsequent plottings.

R. W. RAYMOND, New York City: A few additional notes may help towards the more complete elucidation of Mr. Scott's main subject.

Astrolabe.—Reinhold* explains that the surveyor's astrolabe (in German and late Latin, *astrolabium*), the lower part of Fig. 105 (see also Fig. 83†), is properly a whole or a half-circle of brass, graduated, the whole circle to 360°, the half one to 180°, with a pair of fixed sights at the ends of the diameter, and with an alidade revolving about the center and bearing at the ends another pair of sights. The *Encyclopædia Britannica* (under *Navigation*) gives the simpler, older form of the astronomical astrolabe, as described by Martin Cortes in his book, *The Art of Navigation*, Seville, 1556, and copied in the upper part of Fig. 105. It is a polished circular plate of copper or tin, 6 or 7 inches in diameter, purposely weighty, so as to hang

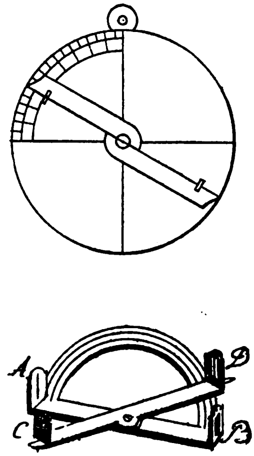
* *Geometria Forensis oder die aufs Recht angewandte Messkunst*, C. L. Reinhold, Muenster, 1781, 1st pt., p. 106.

† Page 122.

steady and plumb by a hole at the top; and graduated to degrees in the upper left-hand quadrant, and some years later in both upper quadrants; and there is a pointer of the same metal, with two sights upon the "line of confidence," that passes through the center.

Reinhold further says that the astrolabe has later been enriched and improved with accessory appliances, as he illustrates by Fig. 106, showing one that he has found the most perfect. AB is the whole circle divided into 360°; CD, the alidade, with a vernier at each end indicating 5, 20, 30 or 60 minutes; EF, sights high enough to see over the fixed sights GH. The telescope, JN, revolves about O vertically, with a spirit-level on top, and with the half-circle, MLK, joined below and read with the index L. The compass P rests on the alidade. The telescope QR, as well as JN, takes the place of the sights in the case of distant objects. It is plain that the instrument is essentially a theodolite, much resembling the instruments of Figs. 16 and 17,* except that the telescope is supported by a single central standard instead of two side ones, and the verniers are upon arms, or an alidade, instead of a plate.

Fig. 105.



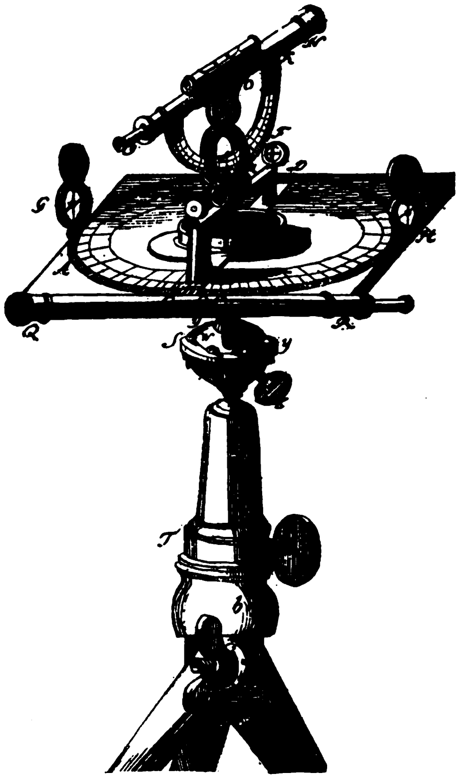
The Astrolabe, Simplest Forms: the Upper, Astronomical; the Lower, for Surveying.

Evidently, then, the word astrolabe had, in surveying, a very wide range of application, from the simplest semicircle with an alidade and two pairs of sights up to a theodolite with two telescopes, with verniers, or even with a compass.

Zollmann's Disk.—Reinhold says† that Zollmann's disk, Fig. 107, is a round wooden board with a frame to enable paper to be stretched. There is an alidade, movable horizontally about a pin in the middle of the disk. The instrument is nearly allied to the plane-table, but resembles yet more closely Douglas's Infallible, of 1727,‡ and, like that, might be called in some sort a progenitor of Henderson's Rapid Traverser.

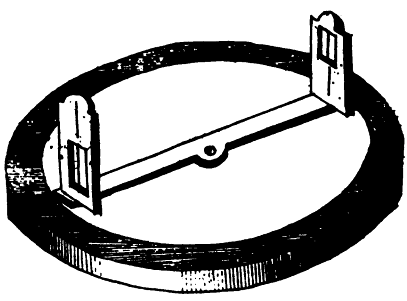
* Pages 18, 20. † *Op. cit.*, p. 137. ‡ Page 69.

FIG. 106.



Reinhold's Best Astrolabe.

FIG. 107.



Zollmann's Disk.

Iron-Disk (*Eisenscheibe*).—Von Hanstadt* explains that the iron-disk (*Eisenscheibe*)† is so called, not on account of its ma-

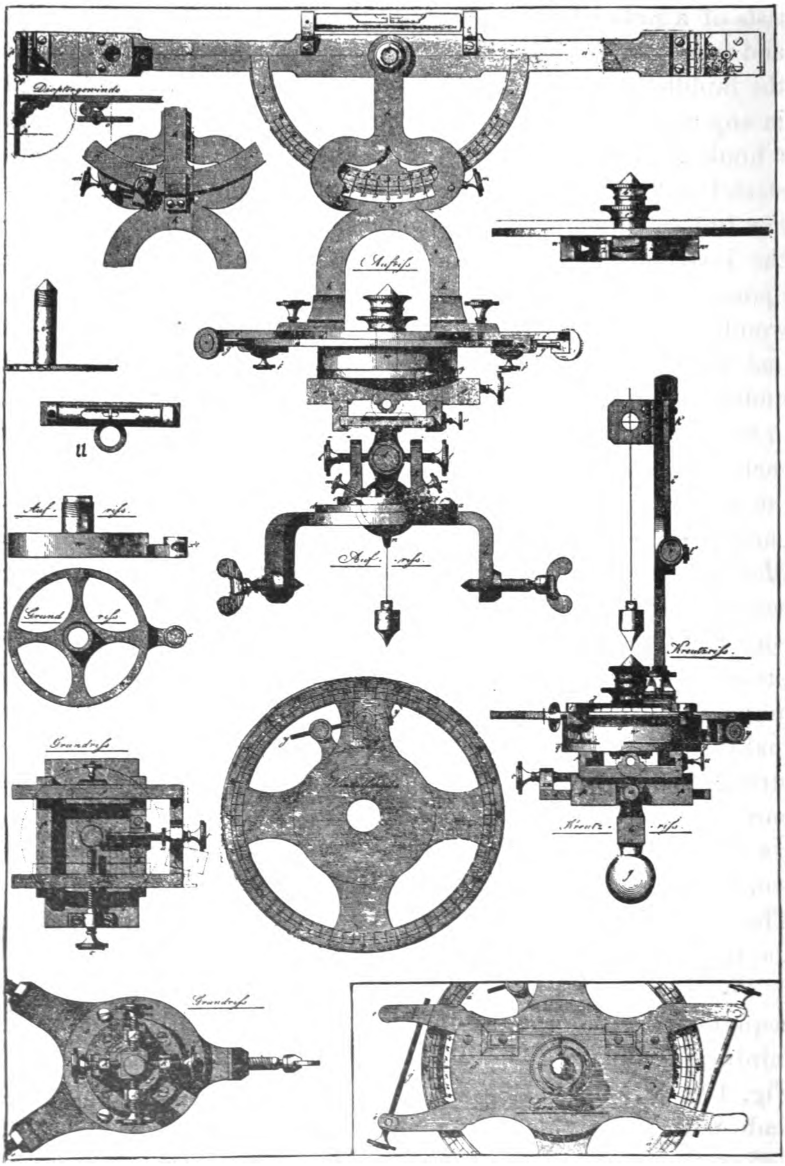
* *Anleitung zur Markscheidekunst*, J. N. L. von Hanstadt, Pesth, 1835, p. 201.
† Mentioned, and illustrated in one form, by Scott, page 11.

terial, but because of its use in iron-mines. He says it consists of a rather large brass disk, graduated to degrees merely, and from left to right, like a plane-table compass. It turns at the middle about a ball-and-socket joint, both horizontally and in any vertical plane. There are two revolving arms, each with a hook at the end, to which are attached the measuring cords stretched to the fore and back stations. There are three hollow brass cylinders, one for each of these stations and one for the instrument-station, with iron screw-points below, to screw upon a plank or timber set across a mine-gangway* or upon a wooden plug. The three cylinders are of exactly equal height and large enough inside to receive the ball-and-socket joint under the disk. But when the instrument with this joint is set in the middle cylinder, the fore and back cylinders are filled each with a wooden plug having a projecting hook, to which the measuring cords are attached. Von Hanstadt says the apparatus is pretty clearly illustrated and described in Moehling's *Markscheidebuch* of 1793; but is not to be recommended for accurate surveys: 1. Because you do not dare to stretch the cord tight enough, since the screw-points of the cylinders easily break or bend. 2. At stations where the courses make a sharp angle, the ball-and-socket joint is under a strong pressure, that makes the turning of the disk difficult, and causes pretty strong friction upon the two brass arms, so that you cannot be sure the correct angle is indicated. 3. It is often difficult to set the instrument again precisely over a station for subsequent work, since the cross-plank cannot always be left in place. 4. The reckoning up of the courses of an extensive survey takes too much time and patience.

Von Hanstadt's Mine-Theodolite.—Von Hanstadt says he consequently devised another instrument that may fitly be called a mining-theodolite. This is, perhaps, sufficiently illustrated in Fig. 108, compiled from his fragmentary drawings. The alidade with the sights is about 2 feet long. The brass plate *q*, before the instrument proper is set upon it, is first leveled with a movable spirit-level, *ll*, and bears the fixed spindle *v*, about which the upper part of the instrument revolves. This theodolite, rightly so called, has the telescope replaced by sights,

* See page 38, Fig. 33.

FIG. 108.

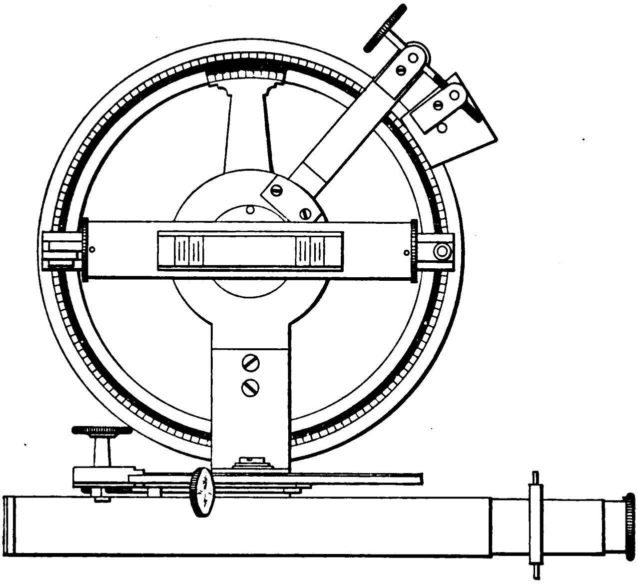


Von Hanstadt's Mine-Theodolite, Nearly $\frac{1}{6}$ Full Size.

with virtually a single central support for them; but has the semicircle attached below them, in the way peculiar to theodolites.

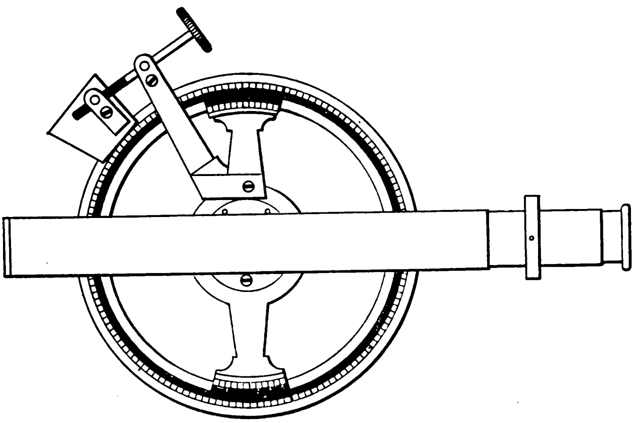
Combes's Mine-Theodolite.—The mine-theodolite of Prof.

FIG. 109.



Combes's Mine-Theodolite, Plan.

FIG. 110.



Combes's Mine-Theodolite, Side View.

Combes, of the Paris *École des Mines*, was described by him in 1836,* in an article giving full details of its construction and

* *Mémoire sur les levés de plans souterrains et description d'un nouvel instrument, propre à remplacer la boussole et le demi-cercle suspendus; par M. Combes, professeur d'exploitation à l'École royale des mines.* (*Annales des Mines*, 3d series, vol. ix., 1836, pp. 81 and 217.)

examples of its use. Figs. 109 and 110 will sufficiently explain it for the purpose of this notice. Fig. 109 is a plan of the instrument, as seen from above, and Fig. 110 a lateral view of the telescope and vertical circle.

Combes calls the instrument a mine-theodolite; and it is a theodolite in a common, wide sense of the word. But the telescope has the characteristic that distinguishes the transit from the theodolite; namely, the capacity of completely revolving in a vertical plane. The telescope, however, is supported on only one side, just as it is in the astronomical mural circle, first devised by Maskelyne and used at the Greenwich Observatory in 1811; and just as it had been in the *lunette murale*, and again in the yet older mural quadrant, first described (of course, with sights instead of the telescope) by Ptolemy* about A.D. 150, and constructed, avowedly on his model, by Nasir-eddin in Persia in 1260, but formerly supposed to have been invented by Tycho Brahe about 1581. Since the telescope supported on only one side tends by its weight and wear to sag downward, so as not to revolve in a truly vertical plane, it is now discountenanced, especially for observing, not a vertical angle, but the transit of a star across the meridian; and preference is given to the astronomical transit-telescope, which is supported on both sides, and has, moreover, an axle capable of reversion, end for end,—the invention of Roemer in 1700.

History of Solar Surveying Instruments.

BY J. B. DAVIS, CLEVELAND, OHIO.

(Canadian Meeting, August, 1900.)

THIS paper has been prepared at the suggestion of Mr. Dunbar D. Scott, to supplement his "Evolution of Mine-Surveying Instruments."

Before entering into a detailed history of solar instruments, a few remarks will be made touching upon land-surveys in general, and on what has led to the development of these instruments.

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* *Tycho Brahe*, by J. L. E. Dreyer, Ph.D., Director of the Armagh Observatory; Edinburgh, 1890; p. 320.

Importance of Solar Surveying.

The True Meridian Needful.—First of all, there is strong reason for the opinion that *all* land-surveys should be referred to the true meridian.

Description by courses and distances is found in most deeds conveying real estate, and in records perpetuating the results of surveys. There are two noteworthy exceptions: namely, in cities and villages, conveyances of land are often made by lot-numbers; and the United States government describes the land granted by its patents by reference to its general rectangular system of public land-surveys, without special rehearsal of the courses and distances bounding each grant. Outside of these exceptions, the description by courses and distances is perhaps the most simple and comprehensive method available; at all events, long custom has decreed its employment.

Survey-lines are usually marked or monumented; but the marks are not always suitably clear and prominent, and duly recorded in the conveyance. Moreover, they may be lost or destroyed through carelessness and ignorance of their value; and, sooner or later, the lines must be retraced by a new survey—with what difficulty, when the original courses were taken by needle, only the surveyor knows. All that he can do is to turn for help to the facts of possession, or to adjacent surveys; or, if an original corner can be found as a starting-point, to satisfy himself, as to courses, with the limit of error in a needle-instrument, while, as to distances, he must determine, as nearly as may be, the difference in length between his steel tape and the worn and kinky Gunter's chain of the former survey. These perplexing problems we must continue to encounter until more accurate modern surveys shall have replaced the original ones.

The remarks apply also to the rectangular system of surveying United States lands, so far as the relocation of sub-divisional lines may be affected by the uncertainty of the indications of the magnetic needle.

But I wish to call particular attention to what may be termed an inconsistency in our modern land-surveys. Increased accuracy in them is demanded by the increase of land-values. Hence, measurements are more accurately made; a transit is used; and more care is taken in monumenting; so that the surveys may be retraced with little difficulty, provided monuments enough are left for starting-points. At the same time, custom having prescribed the method of description, we still use courses, determined not by the needle, as originally, but by deducing the bearings from the transit-angles taken; and we use as a base the bearing of some one line, either measured in the field or copied from a deed. Right here comes in the inconsistency: we care nothing whether the bearing of the line we start from be a true one or not. We are well satisfied if it be only approximately true; we rely on the harmony of our survey, the fact that we have set monuments, have taken the angles with a transit, and have made our measurements carefully; and we assume that there can be no future difficulty in retracing the survey we have made. But the bearings of the lines in this modern and accurate survey, taken individually, mean absolutely nothing so far as the retracing of an accurate survey is concerned; only collectively are they of any value.

If we are to make an accurate survey, and are by custom forced to the use of bearings in our descriptions, why not have the bearings mean something, and be consistent with the rest of the survey? But that is not all: monuments are lost, and the cases are not infrequent when only one can be found; and then trouble begins, and care and good judgment are required in the solution of the problem. Evidently, the remedy is to refer the survey to the true meridian. This can be done by observing the north star, or an altitude of the sun, or by a solar instrument. Only by a reference to the true meridian can the "one stone problem" be at all times satisfactorily solved.

Old Methods of Meridian Determination.—The earliest instrumental methods of determining the true meridian in this country, as well as in Europe, were, first, by observing the polar star, taking into account its travel in an orbit the distance of which from the projected axis of the earth is known; secondly, by an altitude-observation of the sun and the subsequent calculation of the spherical triangle of which the sun, the zenith and the pole are at the vertices.

Surveyors do not take very kindly to observing the north star, and will resort to it only when absolutely necessary, because they object to the requisite night-work. The method of determining the azimuth by an altitude of the sun does not seem to be popular, since it requires too much time for the calculation of the spherical triangle.

Davis's Solar Screen.—It is appropriate here to mention the solar screen invented by Prof. J. B. Davis, of the University of Michigan, Ann Arbor, Mich., and perfected by the firm of Buff & Berger, Boston, Mass. It has been illustrated and described by Mr Scott,* Fig. 59. The invention does not belong in the same class as the mechanical solars to be described below; for it is not, strictly speaking, a solar attachment, but rather an appliance for more conveniently sighting the sun centrally in a direct solar observation. The use of the solar screen does not reduce the necessary computation, so far as the solving of the spherical triangle is concerned; for this work must still be done after the altitude of the sun is observed.

Historical Sketch of Solar Surveying-Instruments.

As the theory and practice of solar work are now fully treated in all standard text-books on surveying, their full discussion is not deemed desirable here, and in what follows, a sufficient knowledge of astronomy in its application to solar work is presupposed.

Government Land-Surveys.—On May 7, 1784, the committee appointed by the Continental Congress, of which Thomas Jefferson was chairman, recommended that all public lands be divided into squares ten geographical miles on a side, and these sub-divided into lots of one square mile; but a subsequent amendment, made April 26, 1785, in which is recorded the first mention of "townships" and "sections," required that the main divisions should be only seven miles square, marked by lines running *due north and south*, and others crossing at right-angles. This ordinance, as still further amended, May 20, 1785, with a provision for townships containing thirty-six sections each, must be regarded as the actual beginning of our present government system of land-surveys; and General Rufus Putnam must be looked upon as its founder.†

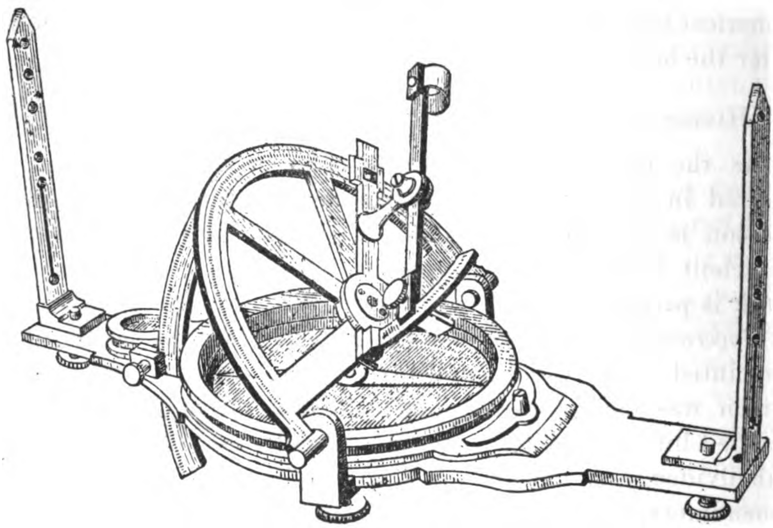
Burt's Solar Compass.—In 1833 Wm. A. Burt, of Mt. Vernon, Mich., received an appointment as U. S. Deputy Surveyor, and

* Page 65.

† See the article by Col. H. C. Moore in the *Jour. Ass'n Engineering Societies*, vol. ii., p. 282.

began work with an ordinary compass-instrument, as prescribed by the government. He found frequent occasion to reprove his chainmen, believing them to be guilty of gross inaccuracies. It turned out that the chainmen were correct enough in their work, and that the trouble was due to the treacheries of the magnetic needle. Mr. Burt satisfied himself that he could not sufficiently rely upon the accuracy of the indications of the needle; and he must also have concluded that the methods of determining the meridian by sighting Polaris or observing the sun's altitude were not practicable in the class of surveys upon which

FIG. 111.



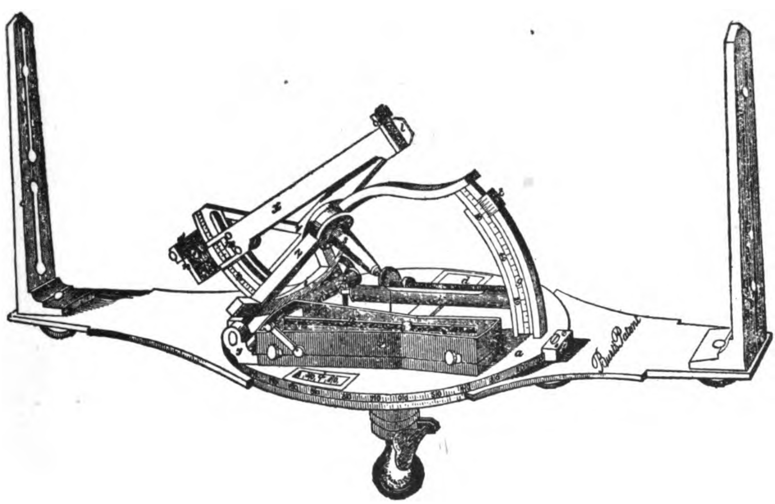
Burt's Original Solar Attached to a Compass.

he was engaged. At all events, he began systematical work in developing a mechanical solar. By 1835 he was in Philadelphia, placing the model of his device in the hands of instrument-maker Wm. J. Young; and in the same year his completed instrument received the Scott medal from the Franklin Institute. That instrument, shown in Fig. 111, was designed to solve mechanically the celestial triangle, and consisted mainly of three arcs—the latitude-arc, the declination-arc, and the hour-circle.

Burt's solar compass did not attain perfection until about

1850. It then came into general use, and was for many years the standard instrument used in surveys of the United States public lands. He exhibited the perfected instrument (Fig. 112) at the London Exhibition of 1851; and Sir John Herschel then said: "I have long understood the elements of your instrument, but could not see how they would be carried out mechanically. It has fallen to your lot, Sir, not only to conceive the necessary astronomical elements, but also to carry them into practical effect mechanically." The same instrument was a part of the government exhibit at the Columbian Exposiion in Chicago, and has now been added to the instrumental

FIG. 112.



Burt's Improved Solar.

collection prepared for Paris. It is probably not too much to say that with Burt's solar, or some adaptation of it, fully 80 per cent. of the public lands of the United States have been laid out. The opinions of authorities on solar work in connection with government surveys would indicate that Prof. Baker's broad statement, quoted by Mr. Scott,* is without warrant and misleading.

Yeiser's Meridian Instrument.—In 1861 Frederic Yeiser, of Danville, Ky., introduced a meridian-instrument, Fig. 113, the operation of which was founded on the ancient method of

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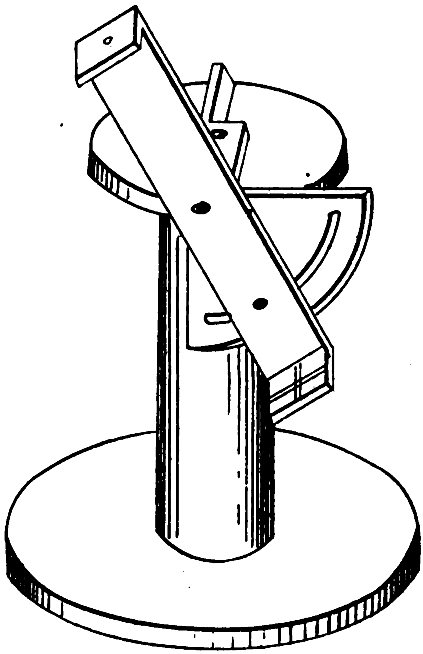
* Page 43.

bisecting the arc found by the observation of equal altitudes of the sun. Two parallel disks were connected by a vertical pillar. On the face of the upper plate revolved a sort of alidade beveled along one edge at one end, and carrying at the other end the lens-bar of the Burt solar. An observation was made at a certain hour in the morning, and the lens-bar was clamped to the vertical quadrant. In the afternoon, at a corresponding hour, the upper part of the instrument was moved about on the

FIG. 113.



Yeiser's Meridian Instrument.

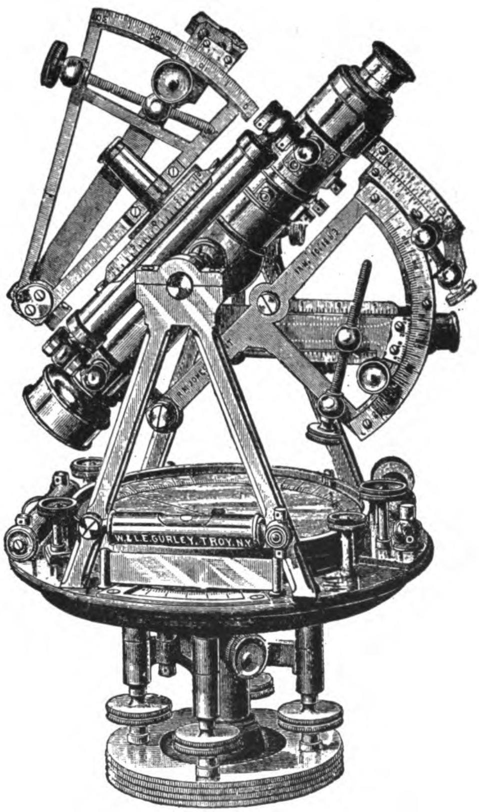
central pivot until the sun's image fell at the intersection of the "equatorial" and "hour" lines. Having drawn a pencil-line along the beveled edge of the alidade at each observation, the line that bisected the intervening space or arc was accepted as the meridian.

Schmoltz's Solar Transit.—The next modification of the Burt solar has been referred to by Mr. Scott* as having been introduced in 1867, when the transit was coming into more general

* Page 43.

use, by Wm. Schmoltz, an instrument-maker of San Francisco. Since 1874 it has been mounted by Gurley, as in Schmoltz's model, upon the transverse axis of the transit-telescope, but with a means of adjusting the polar axis to movement in a truly vertical plane (see Fig. 38*). It is essentially the Burt declination-arc mounted upon its polar axis, which is now re-

FIG. 114.



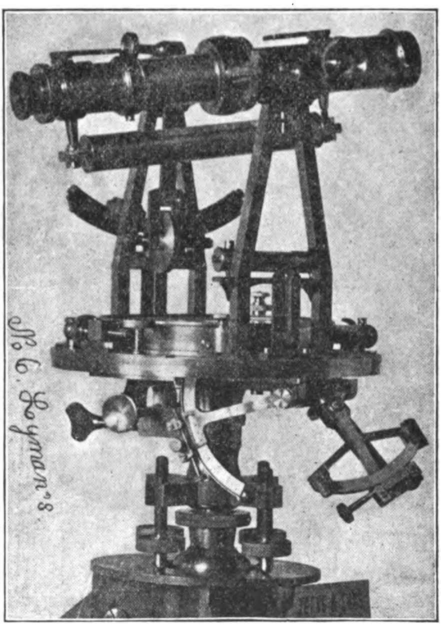
Schmoltz-Gurley Solar Transit, with Jones's Latitude-Arc.

versed from its position in Burt's compass, and may be secured to the telescope, or removed, by means of the thumb-screw at the top of the polar axis. It was customary to lay off the latitude on the transit's vertical circle or arc; but in the Schmoltz-Gurley model, reproduced in Fig. 114, the patent latitude-arc introduced by R. M. Jones in 1883 is used instead.

* Page 42.

This arc consists of an inner quadrant reading to minutes, and an outer segment reading to ten seconds of arc. The inner quadrant carries a reversible bubble-tube, which is adjusted for exact horizontality when the sun is in the meridian; and in all subsequent settings of the latitude the bubble is simply brought back to the center of its scale. This design of Schmoltz was one of the first, if not the very first, of the successful attempts to combine the solar attachment with the ordinary transit-instrument; though there had been a great deal of experiment-

FIG. 115.



Lyman's Solar Transit.

ing to improve on Burt's last model, in which a small telescope was mounted upon one of the sights, or set in Y-bearings across the top of both sights.

Lyman's Solar Transit.—In 1869 Benjamin S. Lyman, of Philadelphia, devised the solar apparatus shown in Fig. 115. Wm. J. Young & Co. (that is, Mr. Young and his partner, Charles S. Heller) had strongly advised him against placing the solar apparatus on the top of the telescope, and against using inclined standards for the telescope. The apparatus was, therefore, placed beneath the plates, for steadiness and protection against exposure; and was so designed that it could be used with a plane-table or other surveying instrument. The usual six-inch lens-bar was reduced in length to only two inches; but the proper focus and size of the sun's image was maintained by the total reflection of two rectangular prisms. Mr. Lyman filed a caveat of his invention in September, 1869, had the same description privately printed as specifications in December, 1870,* secured letters-patent in 1871, and the first instrument was made in 1872.

"It is true," says Mr. Lyman, "that, owing to the greater length of the lens-bar in Burt's compass, the latitude-arc has a decidedly longer radius and the declination-arc one slightly longer; but the radius of both arcs in the solar transit is two inches and a half, or the same as for the vertical and horizontal graduations of the transit proper, the size that is usually found convenient for reading to a single minute with a vernier."

When the vernier of the latitude arc reads 90°, the polar axis is truly vertical. The entire attachment weighs about a pound. In 1877 Young & Sons so constructed it that it could be attached and detached at pleasure.

Seibert's Solar Transit.—About 1869 (but it is not now possible to determine the exact year) F. R. Seibert, then with the U. S. Coast Survey, had Wm. J. Young & Co. make for him a transit with inclined standards, and place the solar apparatus directly over the compass, very much as in the original Burt instrument. The standards were inclined forward, so as not to cast a shadow, or otherwise interfere with the successful manipulation of the solar apparatus. It was to this instrument (Fig. 116) that Mr. Scott assigned† the probable origin of the inclined-standard mine-transit; but from Mr. A. C. Young's contribution it appears that inclined standards were used as early as 1854 in Mr. Roberts's instrument.‡ Still, it is possible that the inclined standards made for him were inclined toward each other, forming a truss-support for the telescope.

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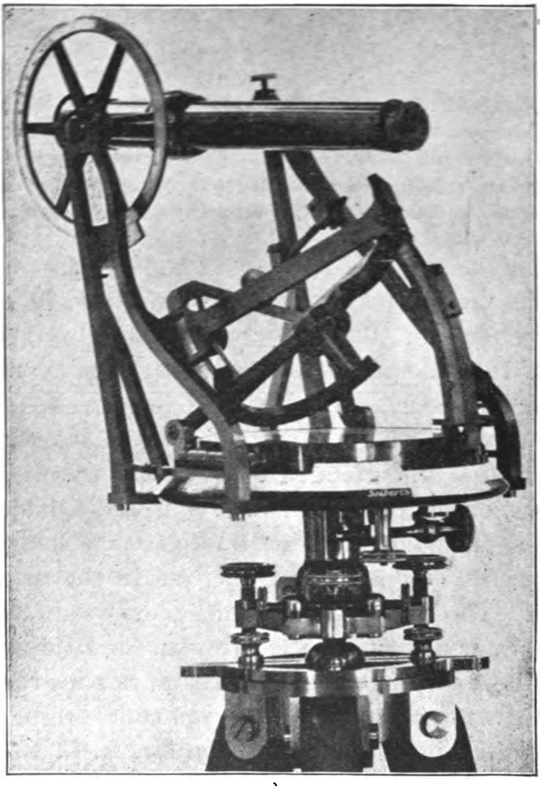
* *Specifications of Improvements in Solar Compasses.* B. S. Lyman. Bengal Printing Co., Calcutta, 1870. The specifications and caveat mention the former use of inclined standards, undoubtedly Seibert's plan, showing that it dates at least as far back as 1869.

† Page 47. ‡ Page 158.

Pearsons's Solar Attachment.—On July 27, 1875, Harrison C. Pearsons, of Perrysburg, Mich., patented an attachment (Fig. 117), having the polar axis parallel to the optical axis of the telescope, and the hour-circle at right angles to it. As usual, the declination-plate revolved upon the polar axis; but the lens-bar was provided with a vernier as well as a lens and equatorial

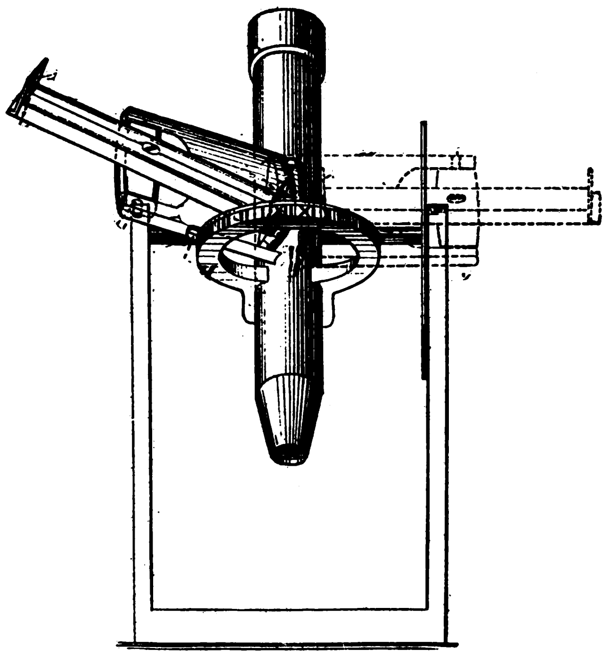
FIG. 116.



Seibert's Solar Transit.

lines at *each* end, and was mounted upon gimbals or a universal joint, whereby it could be brought at will to the surface of either broad face of the declination-plate. Also, the declination-plate was graduated on both its broad faces, so that it was possible to reverse the apparatus, in order to correct errors arising from unavoidable imperfection of construction and adjustment. It was the inventor's idea, as expressed in his letters-patent, to utilize the telescope itself as the axis of the hour-arc; and this, to the best of my knowledge, is the first suggestion of letting the telescope of the transit-instrument become the polar axis. The manufacture of the attachment was first placed in the hands of the Gurleys, but the alliance between the manufacturers and the inventor was not a successful one.

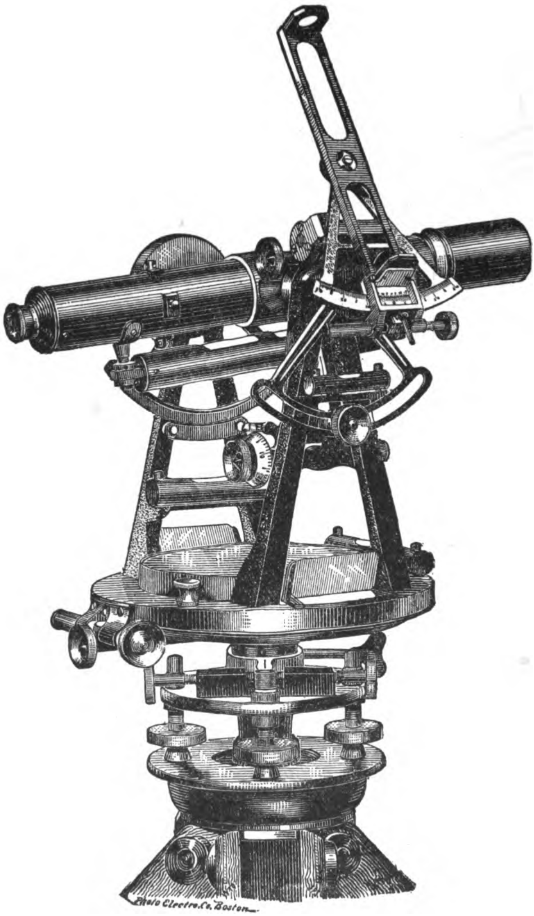
FIG. 117.



Pearsons's Original Attachment.

Buff & Berger's Pearsons Solar Attachment.—As first made by Buff & Berger, in 1878 (Fig. 118), the polar axis, while still parallel to the optical axis of the telescope, was placed over the bearings at one side, and was provided with a spirit-level on the "clamping-arc," to regulate it for true horizontality before elevation to the observer's latitude. This was especially desirable, as it was a part of the improvement to make it possible to attach or detach the whole apparatus as desired. After the latitude was set off, and the "clamping-arc" carrying the solar was clamped to the standard, the telescope was free to move in altitude without interfering with the position of the attachment. The lens-bar was made single, instead of double, with a ground-glass focal plate, so that the sun's image could be observed from the rear with the ordinary reading-glass. But in 1879 Mr. Berger began substituting for it a small telescope of half-inch aperture and six-inch focus.

FIG. 118.

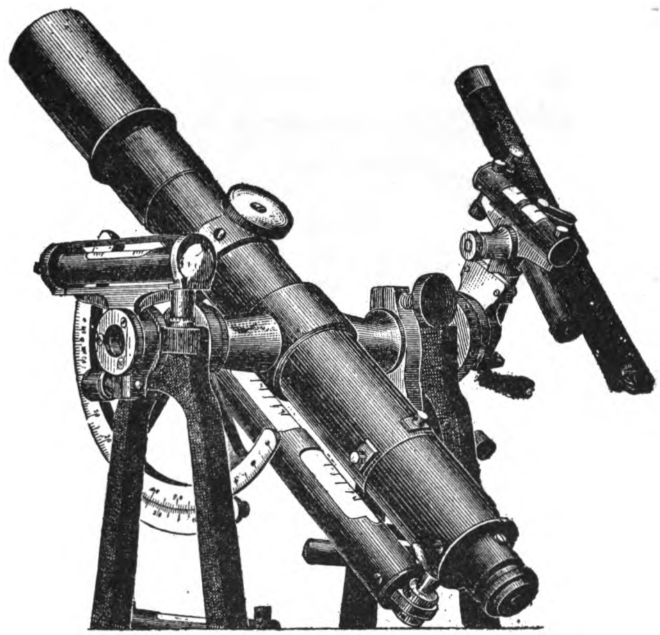


Buff & Berger's Pearsons Solar.

Buff & Berger's Solar Attachment.—In 1882 the Pearsons patents were assigned to Buff & Berger; and in 1885 the general design was changed so that the declination, as well as the latitude, could be laid off by the vertical circle. Fig. 119 shows this last-mentioned model. The attachment is fastened by a screw to an extension of one end of the transverse axis of the telescope, and to the other end is clamped the latitude-level.

Holmes's Solar Theodolite.—In 1878 J. W. Holmes, instrument-maker in Batavia, N. Y., placed the telescope of a theodolite so as to work upon the declination-arc, or circle, in a very remarkable manner (Fig. 120). Between the standards, in the usual position of a telescope in an ordinary transit, he placed, in a plane at right angles to the vertical, a second circle, called the "dial-plate," graduated to read minutes. Within this ring re-

FIG. 119.

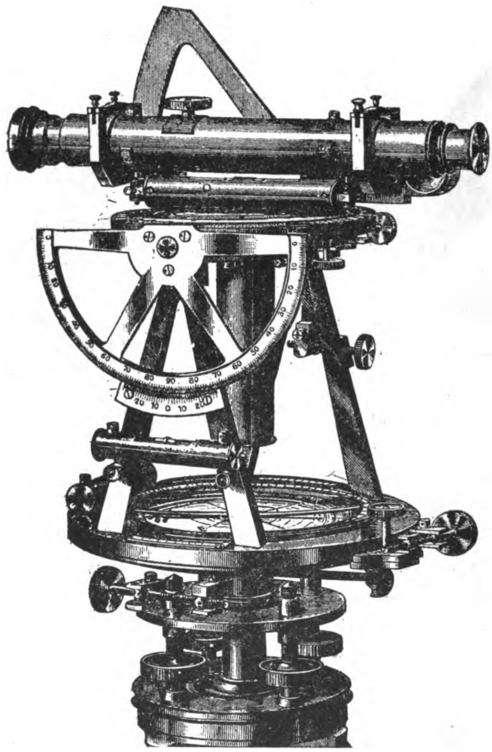


Buff & Berger's Solar Attachment.

volved, upon what might be termed the polar axis, a disk that, together with the "dial-plate," was also journaled at right-angles in the axis of the vertical arc. The disk carried the telescope on Y-bearings centered over the plates below; and upon the disk was fastened the declination-arc at one side of the telescope. The telescope was pivoted to the declination-arc by means of the Y-bearing nearest the ocular and could be moved in altitude at the objective end as required, and regulated to the nearest ten seconds of arc. Mr. Holmes's instructions for the use of the instrument are:

"Clamp the vertical arc to the latitude of the place, turning the dial-plate toward the north, if in north latitude. Move the telescope upon the declination-arc to the angular value of the sun's declination, corrected for time and refraction. But if the observation is made in south latitude, the telescope should be reversed in its Y's so that the object-glass shall be at the pivot of the declination-arc. Turn the upper part of the instrument upon the dial-plate, and the whole instrument upon its vertical axis, if need be, until the telescope can be centered upon the sun. Now the upper, or equatorial plates, are in a plane parallel to that of the equator; and when [ever] the telescope is [afterwards] brought back to the zero of the graduations, it is in the true meridian."

Fig. 120.

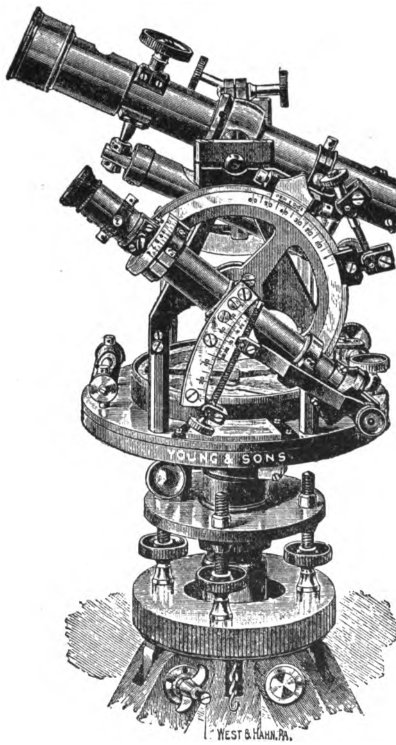


Holmes's Solar Theodolite.

The theodolite-type of the instrument made it necessary to counterbalance the eccentricity of the telescope and the other superimposed parts, by elongating the polar axis and considerably increasing its weight.

Smith's Solar Transit.—On September 14, 1880, Benjamin H. Smith, of Denver, Colo., made the telescopic polar axis a practical invention. To do this, however, he employed an entirely separate telescope, to which are attached declination- and latitude-arcs, as shown in Fig. 121. To the side of a specially-designed standard is fixed a latitude-arc, in the form of a semicircle, carrying two collars or bearings on its diameter, in which the solar telescope is free to rotate on its axis to any required position, as indicated by the hour-circle which circumscribes it. At the object-end of the telescope is a prism or reflector,

FIG. 121.



Smith's Solar Transit.

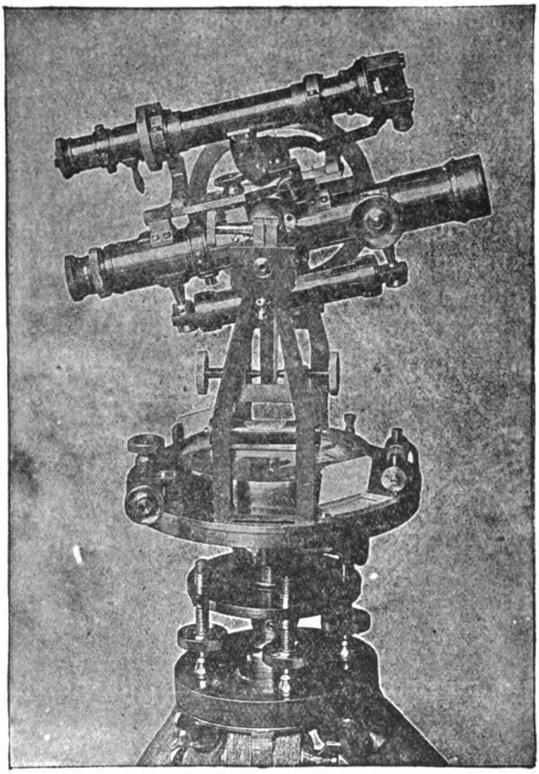
to which is attached an arm, at whose opposite end is a vernier that reads zero on the declination-arc when the plane of the reflector is at 45° to the optical axis of the telescope. Hence, if, after the proper latitude and declination are set off, the telescope is rotated on its own longitudinal axis, the reflected line of collimation will describe a celestial equator; and, both telescopes being in parallel planes, each will be in the plane of the meridian.

Since 1895, Mr. Young has mounted the solar telescope in

Y-bearings on the top of the main telescope, as shown in Fig. 122; and so has dispensed with the original design of the latitude-arc, in favor of the vertical circle.

Gardam's Solar Transit.—In the next year (1881), Joseph Gardam, of Brooklyn, N. Y., patented a device, in which the main telescope became the polar axis, upon principles very sim-

FIG. 122.

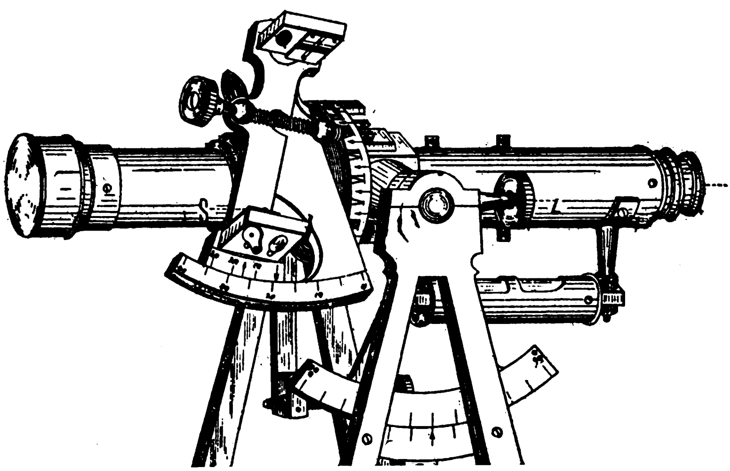


Smith's Improved Solar.

ilar to those suggested by Pearsons. As shown in Fig. 123, a flanged collar about the telescope is fixed and adjusted to the hub of the telescope by means of angle-pieces and capstan-head screws. A semi-annular ring, with its attached hour-circle and declination-arc, is placed over this collar, and held in any position by a set-screw that travels in a groove provided specially for it. In revolving on this collar-bearing about the telescope, the declination-arc took up so much room that the length of the telescope-bubble was reduced to about half the ordinary length.

Saegmuller's Solar Transit.—In 1881 Geo. N. Saegmuller, instrument-maker, in Washington, D. C., with the advice of certain government officials on the Coast Survey (with which department he was at one time connected), designed and patented a telescopic solar attachment, shown in Fig. 124, mounted upon an instrument of his own make. Mr. Scott has discussed the application of the enlarged attachment to mine-surveys;* but only the use of the smaller model in solar work will be touched

FIG. 123.



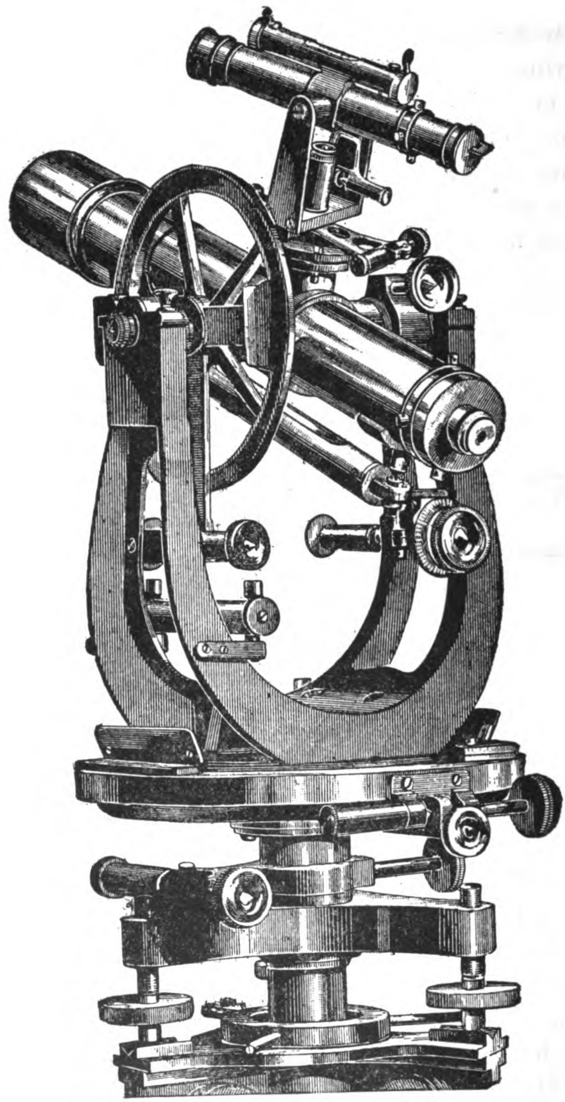
Gardam's Solar Transit.

upon here. The attachment is fastened to the top of the main telescope upon a polar axis very similar in design to Schmoltz's modification of Burt, and is kept at right angles to the main telescope by means of capstan-head screws operating between the plates. The angular value of the declination, corrected for refraction and hourly change, is laid off on the vertical circle; the transit-telescope being depressed or elevated as the declination is north or south. The solar telescope, being previously adjusted to the same vertical plane with the main telescope, is then brought to a horizontal position, as indicated

* Page 51.

by its own longitudinal bubble. This arrangement, as already noted, makes it possible to employ the vertical or latitude-circle

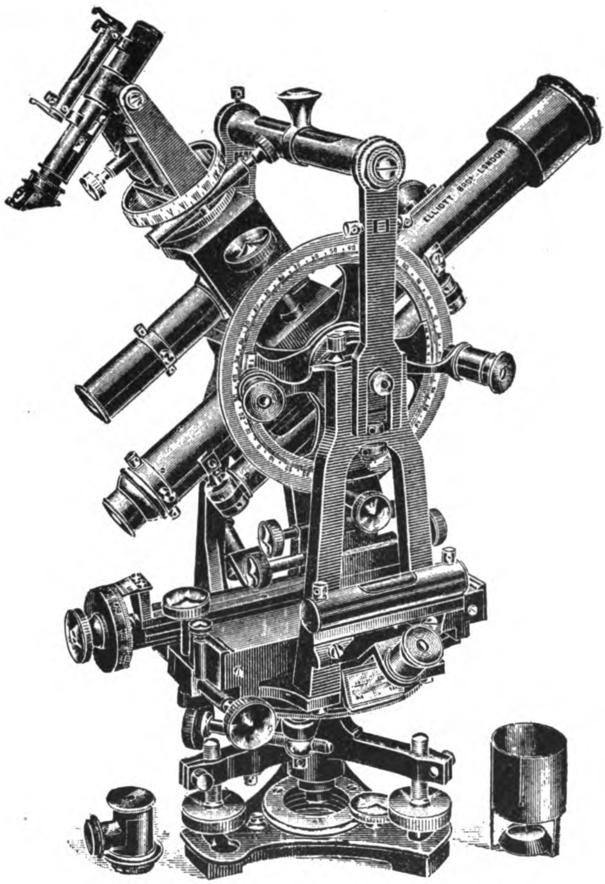
FIG. 124.



Saegmuller's Solar Transit.

as a declination-arc. The two telescopes will now form an angle equal to the declination, and the inclination of the solar telescope to its polar axis will be equal to the polar distance of the sun. In this relative position, both telescopes are now so inclined that the vernier of the vertical circle indicates the co-latitude of the observer; and thus, on rotating the instrument upon its vertical axis until the sun's image is brought into the solar's field of view, the transit-telescope will be in the me-

FIG. 125.



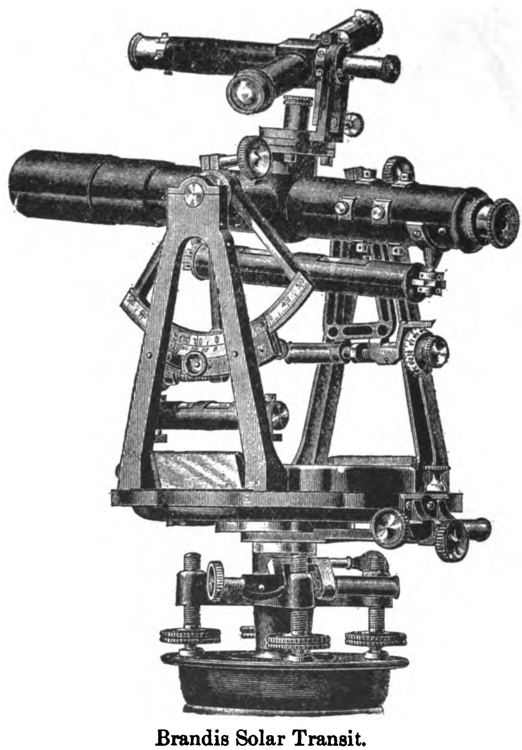
Bell-Elliott-Eckhold Omnimeter, with Saegmuller's Solar.

ridian. In recent years Elliott Brothers, of London, have been adding this attachment, provided with its own hour-circle, as shown in Fig. 125, to the Bell-Elliott improved Eckhold Omnimeter.

In 1887 F. E. Brandis' Sons, of Brooklyn, N. Y., introduced a modification of the Saegmuller solar (Fig. 126), in which the small telescope is "broken" in the usual way, by placing a prism between the objective and ocular. For this device is claimed greater convenience in sighting the sun, as the eye-piece is always at the side of the instrument. The attachment is nicely balanced by placing the bubble opposite the objective-end of the broken telescope.

Walter Scott's Solar Attachment.—July 1, 1890, Walter Scott, of Hot Springs, Dak., patented an attachment of the Smith type,

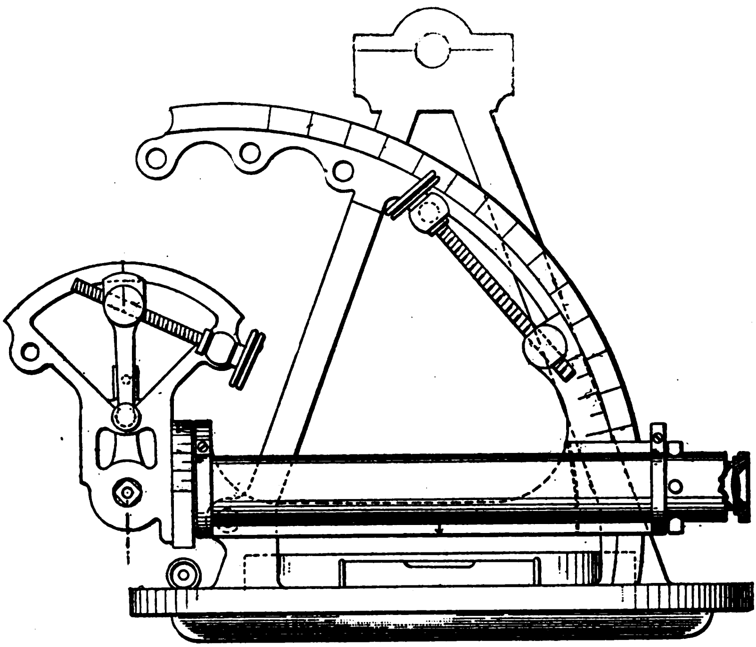
FIG. 126.



Brandis Solar Transit.

which he claimed could be readily attached to any ordinary transit-instrument. This, no doubt, is too great a claim. The sighting-tube having a single smoked lens in the ocular, and cross-hairs only at the objective-end, rested upon a base-plate pivoted to the lower end of one of the standards. The latitude-arc was permanently fixed to the same standard, and extended somewhat beyond at the upper end (Fig. 127), terminating in three extra perforations for the reception of the swivelblock of the tangent screw. At the lower end of the vernier-arm of the declination-arc is a prism, or mirror-reflector, whose plane of reflection is at 45° to the axis of the sighting-tube, when the vernier of the declination-arc reads 0; and at the upper end of the vernier-arm there is a convex lens to converge the sun's rays upon the reflector. The vernier of the time-circle is a part of one of the collars which supports the sighting-tube. What has been said concerning the operations of the Smith solar will apply generally in this case: the main differ-

FIG. 127.



Walter Scott's Solar Attachment.

ence in construction being the rigidity of the latitude-arc in the Scott attachment.

THE DAVIS SOLAR TRANSIT.

History of Origin.—It having been claimed that solar instruments, or attachments for solving the spherical triangle mechanically, were not sufficiently accurate and certain in their indications to be used in transit-surveys, a committee was appointed, in 1894, by the Ohio Society of Surveyors and Civil Engineers, to test the accuracy of solar transits. The members of this committee were Charles S. Howe, Professor of Mathematics and Astronomy, Case School of Applied Science, Cleveland; C. H. Burgess, a civil engineer of Cleveland; and the writer. Mr. Burgess being unable to give to the matter his personal attention, the investigations were made by Prof. Howe and myself. The committee succeeded in getting together solar instruments of all the prominent makers except one, so that ample opportunity was had for tests.

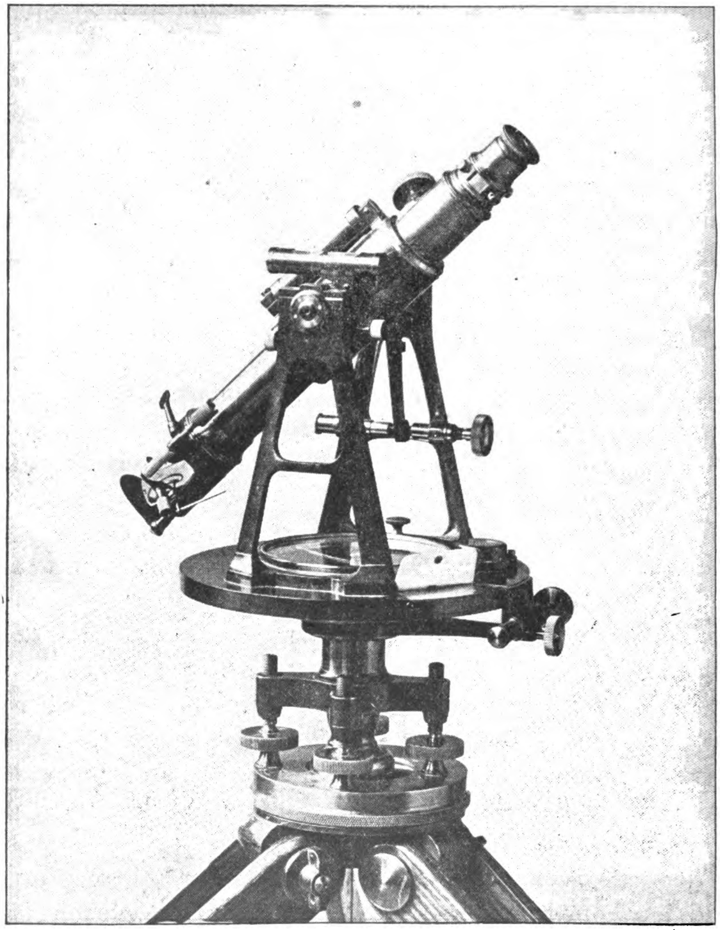
The report of the committee will be found in the annual volume of the Society for 1895. It states the conclusion that "errors of one minute, or even one and one-half minutes either way, are not infrequent, and any single observation would be uncertain to this extent." The observations referred to fall within an arc of three minutes. The committee also found it essential to have an accurately established meridian on which first to test the solars; since, when the sun was brought into its proper relation to the equatorial lines, the true meridian would not at all times be indicated. In order, therefore, to get close to the meridian, the instrument must first be set on an established meridian, and the actual relation of the sun's image to the equatorial lines must be determined. It was found that the sun's image would be sometimes above and sometimes below its proper central position. The further work had to be done in accordance with that determined position. We concluded that the difficulty arose from our inability to adjust the instrument exactly. From experience gained in these tests, the writer became satisfied that much of the objection of the profession to the mechanical solar is due to the fact that additional adjustments are required, that the adjustments are difficult to make, and that their maintenance is a matter of some uncertainty.

Believing that an instrument from which these difficulties are eliminated would be desirable, the writer began experiments to that end; and the first instrument, constructed by Ulmer & Hoff, Cleveland, O., was shown before the Ohio Society of Surveyors and Civil Engineers at their annual meeting at Dayton, O., in February, 1896. This transit-instrument had a vertical- or latitude-arc and a telescope capable of rotating in a sleeve about its longitudinal axis. The telescope had a fixed object-end, before which a mirror was so securely attached as to partake of any rotative motion of the telescope, yet capable of revolving about an axis at right angles with the line of collimation. In 1898, the writer discovered that a small level placed upon the transverse axis of a telescope so constructed would enable the vertical- or latitude-arc to be eliminated. For, by setting off the latitude-angle on the horizontal limb, the mirror, reflecting a target, could be placed at the proper angle with the optical axis of the telescope, and then, by rotating the telescope through 90°, the same angle could be transferred to the vertical plane. As to measuring a vertical angle on the horizontal limb, it is not intended to do away with the vertical-arc in general practice, but only to replace the latitude- or vertical-arc in the J. B. Davis solar transit when the arc is only wanted for solar work. For practical reasons, this method of setting off a vertical angle is not applicable for latitudes much lower than 20°; but these are much lower than any within the boundaries of the United States. Articles describing the J. B. Davis solar transit have appeared in the *Journal of the Association of Engineering Societies*, November, 1896; *The Colliery Engineer*, July, 1897; *Engineering News*, April 28, 1898; and *Mines and Minerals*, April, 1899. It was patented January 21, 1897, and February 28, 1899.

Description.—Figs. 128 and 129 represent the J. B. Davis solar transit, as made by Ulmer & Hoff, Cleveland, O., without vertical-, latitude- or declination-arc; all angles being measured upon the horizontal limb. Fig. 128 shows the solar transit with the reflector attached, and Fig. 129 with it detached. The solar transit is constructed with or without a vertical-arc, as may be desired. As the construction of a solar transit without a vertical-arc is a new departure, the method of operation without the arc will be described; the operation with a vertical-arc will then be obvious.

The transit-telescope is the polar axis in this instrument, and is so constructed inside a sleeve as to be capable of rotating on its longitudinal axis. Its object-end is fixed, and a reflector is securely attached to it. The usual vertical- or latitude-arc is dispensed with; but a level is placed upon the transverse axis of the telescope. The reflector is so constructed as to be capable of rotating with its frame about the line of collimation of the telescope as an axis, and also of revolving on an axis in its own plane at right angles to that line; so that by sighting to a target the reflector may be placed in proper angular relation to the line of collimation in each meridian and latitude observation. This reflector-construction, together with the rotating transit-telescope, results in

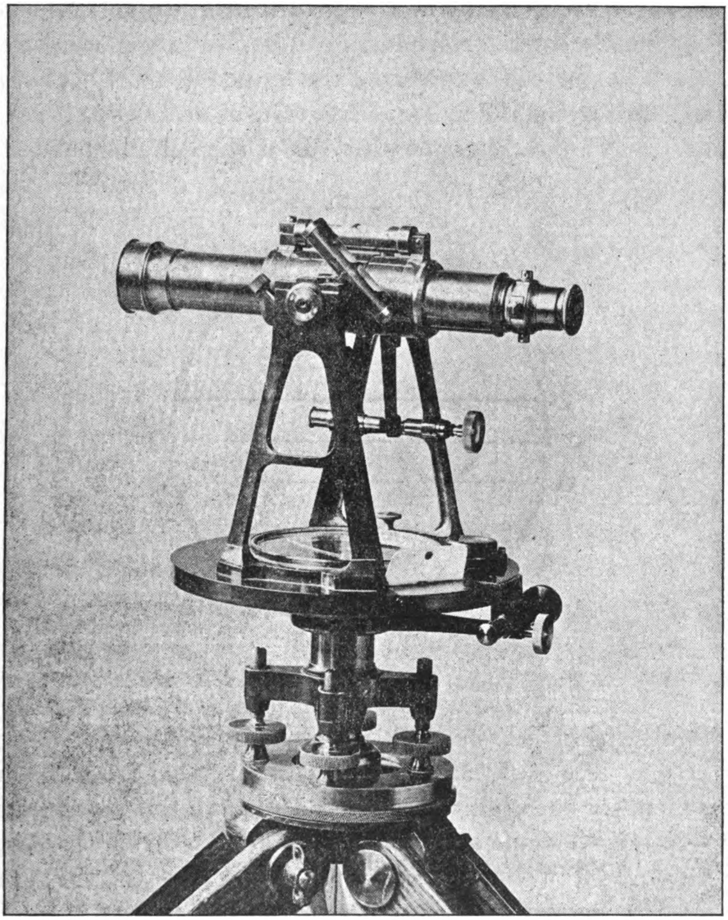
FIG. 128.



J. B. Davis Solar Transit, Reflector Attached.

doing away with the maintenance of all solar adjustments. Thereby, as the transit-telescope is used for solar work, not only is the accuracy of the instrument increased, but the certainty of its indications as well; because adjustments of special solar apparatus are difficult to make, are sensitive, and consequently easily disturbed. All solar transits heretofore constructed require the maintenance of certain adjustments additional to those of the engineer's and surveyor's transit; and the majority have separate latitude- and declination-arcs. In

FIG. 129.

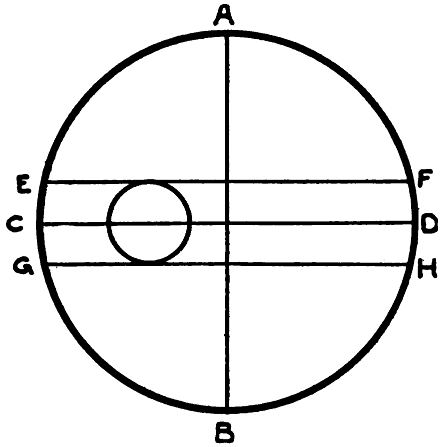


J. B. Davis Solar Transit, Reflector Detached.

this solar these arcs are dispensed with, and all angles are measured on the horizontal limb of the transit.

At the eye-piece end of the telescope is placed the cross-hair ring, or diaphragm, provided with the usual vertical and horizontal transit-hairs, AB and CD, and the two solar hairs EF and GH, Fig. 130. The small circle between the solar or equatorial hairs represents the sun in the field of view. Fig. 130 shows the diaphragm in its normal position for terrestrial work. The line of collimation can be adjusted on a fixed point by rotating the telescope in its sleeve, as an engineer's wye-level on its wyes. The solar hairs and rotating telescope are a convenience, even when only terrestrial work is required of the transit; for the solar hairs can be used for stadia-work, and the operator can, by rotating the telescope, quickly provide himself with a single hair for either transit- or level-work. At the eye-end of the telescope there is a shaded glass slide for

Fig. 130.



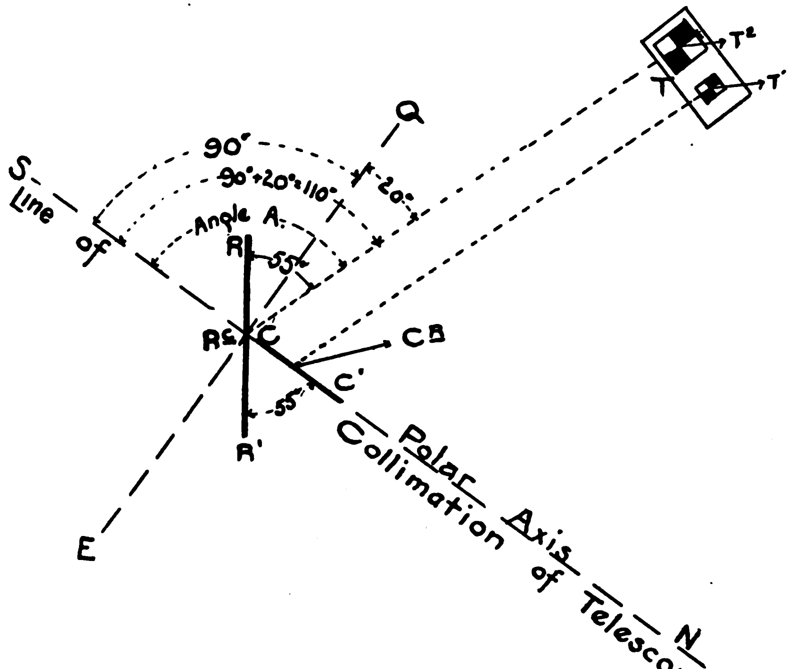
Transit and Solar Cross-Hairs.

use in observing the sun. A diagonal prism is not required, as the eye-piece is elevated, in the position most favorable and convenient for the observer. The needle and the time-graduations on the telescope act jointly as a finder, to bring the image of the sun within the field of view. When the transit is not required for solar work, the reflector can be removed from the object-end of the telescope, and the telescope secured in its normal position by a set-screw. The central cross-hair is then vertical, and the telescope is firmly fixed in its sleeve.

The advantages obtained in this solar transit are: (1) simplicity; (2) the use of but one telescope for solar and transit work; (3) the omission of the usual declination- and latitude-arcs, the graduated horizontal limb of the transit serving their purpose; (4) the elimination of the maintenance of all adjustments of solar parts; (5) the obviation of all necessity of counterpoising the solar parts or attachments—the reflector weighing no more than the sun-shade; (6) the absence of projecting parts liable to injury.

With this instrument, solar work in keeping with the accu-

FIG. 131.

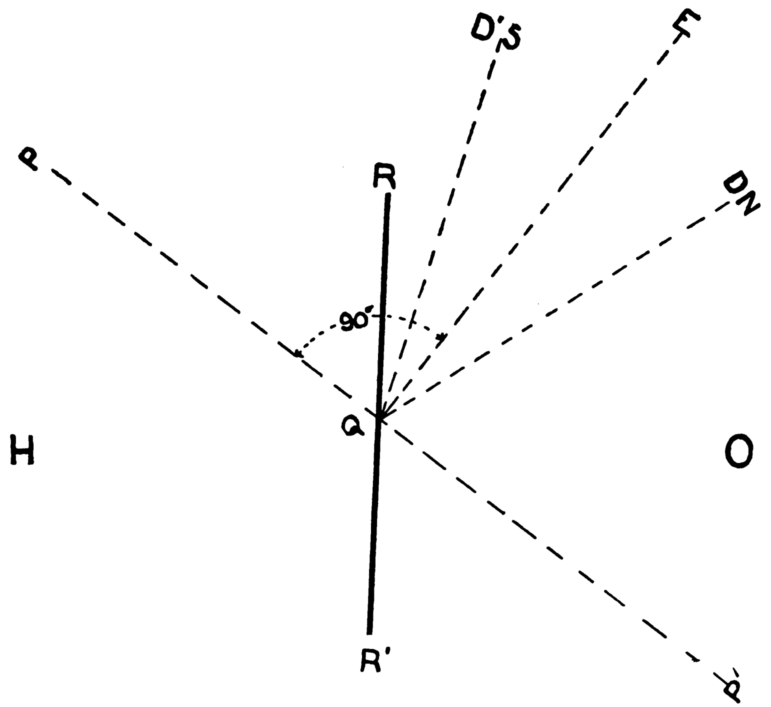


NS, Line of collimation of the telescope and polar axis. EQ, Equator. CC^1, Transit-telescope. RR^1, Reflector. R^c, Position of the image in the reflector-plane. C^B, Center of revolution of the transit-telescope. T, Target. T^1, Stationary sighting-point. T^2, Movable sighting-point. Angle A, South polar distance of the sun. The declination of the sun, corrected for refraction, = 20°.

racy of an engineer's transit can be done, if the proper hours of the day for doing it are selected. The writer is satisfied that solar work requiring the closest possible results can only be done in the middle of the forenoon or afternoon. Close work cannot be done, and need not be attempted, with any solar, very near noon; because an error then made in setting off the exact latitude or declination is considerably multiplied in the azimuth. A want of knowledge on this point has led many into error, and some to doubt the efficacy of solar work entirely, under the wrong presumption than any hour of the day is equally favorable to such work.

Operation.—Fig. 131 illustrates the target-sighting method of setting the reflector in its proper relation to the line of colli-

FIG. 132.



HO, A horizontal plane. PP¹, Line of collimation of the transit. RR¹, Reflector-plane. EQ, Line from the point Q at right angles to the line of collimation. QDN and QD¹S, Declination-lines.

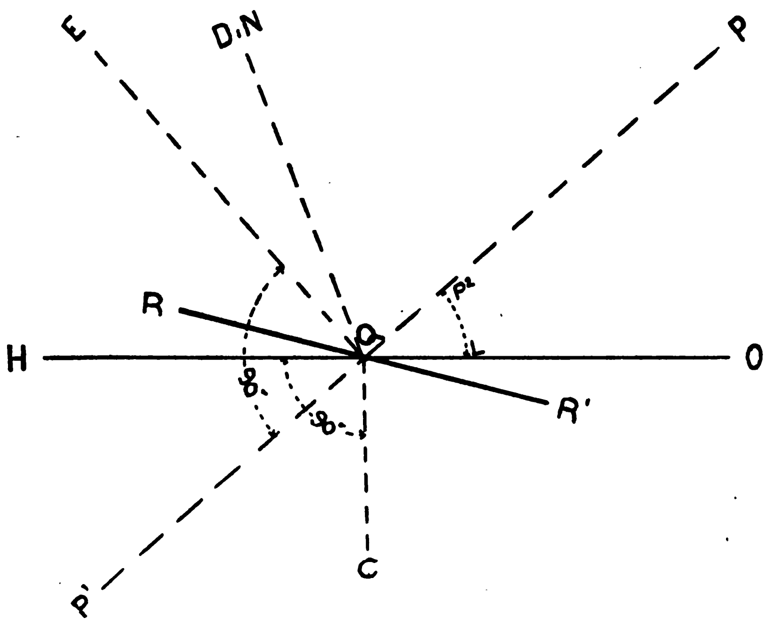
mation for a meridian or latitude observation, and will be referred to, as the operation of the instrument is described in detail.

The optical axis of the telescope CC¹, the sighting-point, T¹ or T², and the image of the same in the reflector RR¹, are all in the same horizontal plane when the image of T¹ or T² is thrown into the line of collimation. When the reflector is placed at an angle of 45° to the line of collimation, the line of sight of the telescope is deflected 90°, and will represent the equator; and when the reflector is placed at an angle to the line of collimation of 45° plus or minus one-half the declination of the sun (according as the declination is north or south), the line of sight of the telescope will be deflected by an angle equal to the south polar distance of the sun. The target, as indicated in Fig. 131, has two sighting-points, T^1 and T^2; T^1 alone is used in setting off the latitude; T^1 and T^2 are together used in setting the reflector in a meridian observation, as will hereafter be explained. The target T remains stationary and is set at right angles to a line drawn from the target-point T^1 to the transit-center; therefore, when the angle A is 90°, the distance $T^1 T^2 = C^R R^c$. When the angle A becomes more or less than 90°, the distance $T^1 T^2$ must be reduced, so as to equal the perpendicular distance of R^c from the line $C^R T^1$. To provide for this, the sighting-point T^2 is movable on the target, and an index-point and graduations enable the operator to set it in proper position for any angle A. The following statement will show the principles on which the operation of the solar is based.

Place the line of collimation of the transit-telescope PP^1 (Fig. 132) in the horizontal plane HO, and intersecting the reflecting-plane RR^1 at Q, with the reflecting-plane so placed (at 45°) that any point E situated in the horizontal plane and in a line at right angles to the line of collimation from the point Q will be reflected along the line of collimation; or, again, in such other position that reflection in the line of collimation will take place from any point, such as D N and D^1S, lying in the horizontal plane and situated either to the right or left of the point E and in the line from the point Q that makes an angle with the line EQ equal to the declination of the sun at the time. The reflecting-plane will now be perpendicular to the horizontal plane, in which the line of collimation lies; and the horizontal angle between the line of collimation and the intersection of the two planes will be such as the declination of the sun at the time of observation may require.

If, then, keeping this angle unchanged, the line of collimation PP^1 be inclined, as in Fig. 133, to the horizontal plane HO, at an angle equal to the latitude of the place, P^2L (in the manner to be presently described), and the reflector-plane be rotated about that line as an axis, the sun can be followed in its passage from east to west, in case the line of collimation is in the plane of the meridian. The line of collimation may be brought into that plane by a horizontal circular motion about QC, the vertical axis of the instrument, at right angles to the horizontal plane. At the same time the line of collimation, and with it the reflecting-plane, is rotated about itself as an axis, until the center of the image of the sun is seen exactly in the line of collimation. The line of collimation will then be in the meridian plane of the observer.

FIG. 133.



Again, returning to Fig. 131, let it be understood that in the operation of this instrument the optical axis of the telescope, or the line of collimation, is what is termed the polar axis in other solar instruments; so that any line perpendicular to the optical axis from a point in the reflector-plane at its intersection with the optical axis of the telescope produced will be in the plane of the equator. The sun in its position, on one or the other side of the equator, in its varied positions of declination throughout the year, will be represented by the correspondingly varied horizontal-angular position of the target as sighted to in each observation. This varied position of the target with reference to the aforesaid equatorial line is determined by the angle A, which varies with the sun's declination. It will thus be seen that the target is made to bear the same relation to the optical axis of the telescope, and the aforesaid line perpendicular thereto, as the sun bears to the polar axis and equatorial line at the time of observation; and that if the telescope be dipped, with reference to a horizontal plane, sufficiently to conform to the position of the earth's axis at the point of observation, *the sun's image can only be seen in the optical axis of the telescope when the telescope has been brought into the plane of the meridian.*

To Set the Telescope to the Latitude-Position.—1. See that the usual transit adjustments are carefully made. Loosen the set-screw which passes through an arm of the telescope-axis and engages the telescope, so that the telescope can be rotated in its sleeve until the solar lines have become vertical. When the rotation has been made, secure the telescope by the same set-screw. Clamp the solar reflector-frame to the object-end of the telescope, placing it so that the reflector will be approximately in a vertical plane and parallel to the line of collimation, so as not to obstruct the view through the telescope. Place the transit-center vertical by means of the plate-levels and the telescope-level; and then, while the telescope is level, sight a target (at any convenient distance, 20 to 200 feet from the transit) with the stationary sighting-point T^1 on both the central vertical and the horizontal cross-hairs, and the movable sighting-point T^2 on the horizontal cross-hair only. (See Fig. 131.)

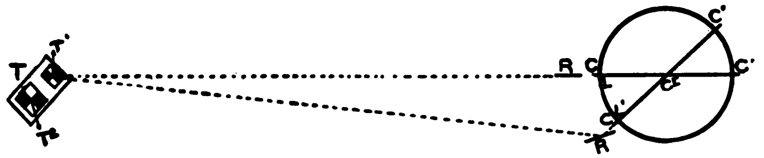
2. Observe the reading of the horizontal limb, and then set off on that limb an angle equal to the latitude of the place of observation; and, with the telescope still horizontal, by rotating the reflector about its own, then vertical, axis, bring the image of the target-point T^1 into the line of collimation of the telescope. (See Fig. 134.)

3. Without changing the angle made by the reflector with the line of collimation, return to the first reading of the limb; the telescope will then again be directed to the target-point T^1. Loosen the set-screw before referred to, and rotate the telescope 90°, securing it by the set-screw in this position. Dip the telescope until the reflected image of the target-point T^1 appears in the line of collimation; and then bring the bubble of the

transverse-axis level to a central position. (See Fig. 135.) The telescope is now dipped to the required latitude-angle, and the axis-level enables the operator at any time to restore the telescope quickly and accurately to the proper latitude-position.

To Determine the Meridian.—1. Again place the solar hairs

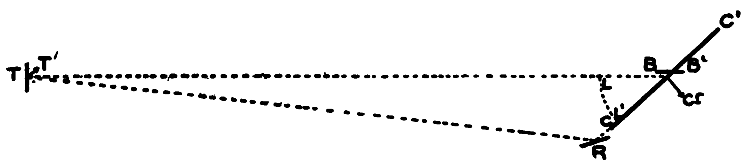
FIG. 134.



Showing the Latitude-Angle in a Horizontal Plane. T, Target. T^1, Stationary sighting-point. T^2, Movable sighting-point. C C^1, Transit-telescope in two horizontal positions. C^r, Center of horizontal revolution of the transit-telescope. R, Reflector. L L^1, Latitude angle. T^1, C^r and the image of T^1 in R are in a horizontal plane.

perpendicular, remembering that the transit-telescope will be directed to the target-point T^1, when the transit-limb is made to indicate the first angle read in the operation of dipping the telescope to the latitude position. Now, set off an angle equal to 90°, plus or minus the corrected declination of the sun at he time of observation, according as the sun is north or south

FIG. 135.



Showing the Latitude-Angle in a Vertical Plane. T, Target. T^1, Stationary sighting-point. C C^1, Transit-telescope. C^r, Center of revolution of the transit-telescope. R, Reflector. L L^1, Latitude angle. B B^1, Transverse-axis level. T^1, C^r and the image of T^1 in R are in a vertical plane.

of the equator. This angle is the south polar distance of the sun, and is indicated as angle A in Fig. 131. With the telescope level, place the reflector in such a position that the image of the target-point T^2 will appear exactly in the line of collimation of the telescope. (The target-point T^2 is sighted to, for the purpose of allowing for the parallax due to the reflector's being at the object-end of the telescope, and not at the transit-center; and the distance T^1 T^2 is controlled by the angle A, as before explained.) By this operation, the plane of the reflector is made vertical, and at the same time its intersection with the horizontal plane of the collimation of the telescope will be at such a horizontal angle with the collimation as the declination of the sun at the time of observation requires. (See Fig. 131.)

2. Having now placed the reflector in proper angular relation to the line of collimation, turn the object-end of the telescope south; dip it from a horizontal position by an angle equal to the latitude of the place of observation, by means of the transverse-axis level (previously set to indicate the proper latitude); and securely clamp the telescope. Loosen the set-screw, so that the telescope rotates in its sleeve. It will be seen that the sun can then be followed in its daily motion. Rotate the telescope in its sleeve, and at the same time turn the whole instrument horizontally, until the sun appears exactly between the solar hairs, and the perpendicular hair approximately bisects it. Then firmly clamp the transit-center. *The telescope will then be in the true meridian.*

3. Bring the telescope back to its normal position in its sleeve, and secure it by the set-screw. Unclamp the telescope-axis and fix the meridian-line by suitable points. In doing this the reflector is unclamped and placed parallel to the line of collimation. In this position it forms no obstruction whatever to the line of sight.

To Determine the Latitude.—1. Place the reflector in proper angular relation to the line of collimation (as in the instructions for determining the meridian), so as to reflect into that line the sun's image when at noon-declination. Rotate the telescope 90° in its sleeve, and secure it by the set-screw.

2. Dip the telescope, and follow the sun until it has attained its greatest altitude. Then set the latitude- or transverse axis level in a horizontal position, in order that the telescope may be returned to the proper latitude-position whenever desired.

3. To read the latitude-angle from the transit-limb, first place the telescope in the vertical plane passing through the target-point T^1, by returning to the same reading of the limb as indicated when the target was first sighted, in the operation of setting the reflector to its declination-position. Still retaining the telescope in its established latitude-position, change the reflector so as to throw the image of the target-point T^1 into the line of collimation. Now place the telescope in a horizontal plane, rotating it 90°; and then move it horizontally

until the target-center is again seen reflected in the line of collimation. (See Figs. 134 and 135.) Then read off the latitude from the transit-limb.

Remarks on Mine-Surveying Instruments, with Special Reference to Mr. Dunbar D. Scott's Paper on their Evolution, and its Discussion.

BY H. D. HOSKOLD, INSPECTOR GENERAL OF MINES OF THE ARGENTINE REPUBLIC, BUENOS AIRES, S. A.

(Canadian Meeting, August, 1900.)

SYNOPSIS.

I. INSTRUMENT-PARTS AND IMPLEMENTS.

Cross-hairs; Stadia-measurement; Fineness of Graduation; Cylindrical Graduation; Nonius; Vernier; One Vernier or two; Leveling-Screws; Troughton & Simms' Shifting Tripod-Head; Hoskold's Shifting Tripod-Head; Hoskold's Extensible Tripod; Electric Lamp; Plumb-lines; Chain.

II. INSTRUMENTS.

Compass (Mine-compass of 1518, Compass of 1541, and Agricola's of 1556, Voigtel's Setz-compass, Circumferentor, Stanley's Hedley Dial, Compass on Telescope, Hanging Compass, Lack of Precision); Plane-table; Octant and Quadrant; Theodolite and Transit (Evolution of the Theodolite, Scott's Tachymeter, Hoskold's Engineer's Theodolite, Angleometer, Precision of Mine-Theodolites).

I. INSTRUMENT-PARTS AND IMPLEMENTS.

Cross-Hairs.—Mr. Scott* says Lean's dial

"might also have been provided with a diaphragm and cross-hairs; for Huygens discovered that any object placed in the common focus of the two lenses of a Kepler telescope (1611) appeared as distinct and well defined as any distant body. Following this established theory, in 1667 Jean Picard, Marquis Malvasia and others crossed silken fibers in the common focus of their astronomical instruments."

If by this Mr. Scott means that Huygens and Picard first devised and applied cross-hairs to the focus of the telescope, the writer cannot agree with him. Huygens did not describe "his telescope without tubes until 1684, in his *Astroscopia Compendiaria.*"† Moreover, it is recorded that the English astronomer, Gascoigne,‡

* Page 19. † *Universal Biography*, Mackenzie, p. 968. ‡ *Ibid.*, p. 564.

"was the first who placed crossed filaments at the common focus to mark the center, axis or line of collimation of the telescope, enabling that line to be directed towards the object to be observed."

In another place it is stated that this invention took place in 1640.* Picard, originally a priest, did not become an assistant astronomer to Gassendi earlier than 1645.

Stadia-Measurement.—If Mr. Brough and Mr. J. L. Van Ornum† intend to convey the idea that James Watt, in 1770–1771, was the first to discover special means for the determination of distances upon the surface, without direct measurement by a chain or other linear measurer, then they have fallen into a grave error; for, it is recorded that Gascoigne "invented the micrometer, which by measuring the apparent size of the image ascertained the angle subtended by the object."‡

Gascoigne's two inventions—placing cross-hairs in the focus of the telescope, and the micrometer—by which the telescope was first adapted to observing exactly the position and apparent size of the heavenly bodies and of "distant objects on the earth, are the most important improvements which have been made in astronomical and geodetical instruments since the invention of the telescope. Their date lies somewhere between 1638 and 1643."§ Again, it is declared‖ that the micrometer of Gascoigne "may be considered the prototype of our best spider's line micrometer." Gascoigne also measured the diameter of the sun and moon and the angular distances of the stars in the Pleiades by his micrometer in 1640.¶ Oughtred also received a letter from Gascoigne in 1640–41, referring to his newly invented micrometer.** Townley†† says of Gascoigne:

"Before our late Civil Wars, he had not only devised an Instrument of as great a power as M. Auzout's, but had also for some Years made use of it, not only for

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* Hoskold upon *Ancient and Modern Surveying and Surveying Instruments*, *Trans. Am. Soc. Civ. E.*, vol. xxx., pt. ii., pp. 135–154 (1893).

† Page 70.

‡ *Universal Biography*, Mackenzie, p. 564, and Pearson's *Astronomy*, pp. 92–93, 1829.

§ *Universal Biography*, Mackenzie, p. 564, and *Phil. Trans.*, 1737.

‖ Pearson's *Astronomy*, p. 93, vol. iii., 1829.

¶ Flamsteed's *Prolegomena*, *Historia Cœlestis*, vol. iii., p. 95.

** *Phil. Trans.*, vol. xlviii., p. 191, 1753.

†† *Phil. Trans.*, No. 25, p. 457, May, 1667, and Pearson's *Astronomy*, p. 92, vol. iii., 1829.

taking the Diameter of the Planets, and Distances upon Land ; but had farther endeavour'd, out of its preciseness, to gather many Certainties in the Heavens; amongst which I shall only mention one, *viz.*, The finding of the *Moons Distance.*"

The micrometer or distant-measurer of Gascoigne was capable of marking 40,000 divisions in a foot with the help of two indexes. The result was that he could measure an object to a single second of arc.* The micrometer employed by Auzout and Picard only measured from 20 to 30,000 parts of a foot.† The words just quoted, "distances upon land," are exceedingly important for the purpose of determining the question under discussion; for, although James Watt may have made such an invention in 1771 as that attributed to him, still the authorities quoted place it beyond doubt that Gascoigne was the first Englishman to invent and apply a distant-measurer.

Fineness of Graduation.—Mr. Scott declines to continue the discussion of the relative merits of the *minute-graduations* as compared with finer divisions; but the writer is of opinion that after the demonstration given by him‡ the minute-division theory is untenable. As Mr. Scott has pointed out,§ if we assume an isolated case, and say that there would be an error of 30″ on a line of 100 feet, the deviation would be too insignificant to be noticed; and, although the proposition is ingeniously put, still it is not stating the whole case. Taking it for granted, as Mr. Scott says, that a minute-vernier can be read without greater error than 30″, the error would be a continuous one, frequently repeated, and increasing according to the number of lines in the survey minus one; and if the distances were equal and the error angle had the same sign, we should be tracing a slow curve, and the total deviation-error in arc would equal the number of lines minus one multiplied by 30″. The same principle is involved in an underground survey, with the difference that the length of the lines would vary. To be sure, the error-angle would sometimes be a positive and at others a negative quantity, and for this reason some engineers, surveyors and mathematicians have stated that the one would balance the other. But they forget that such an effect could

* Pearson's *Astronomy*, p. 92, vol. iii., 1829.
† *Phil. Trans.*, No. 21, p. 373, Jan., 1666.
‡ Page 114. § Page 127.

not result unless the lengths of the lines were equal, and the error-angle always had a positive and negative effect alternated, or in reciprocal succession, conditions which could not occur. There is no excuse or reason in advocating that, because some careless persons elect to use a rough line-measuring instrument, the divisions of a theodolite-vernier should be no finer than a minute of arc.

Cylindrical Graduation.—Messrs. Wittstock's idea of putting the graduation on the edge of vertical circles, instead of upon the flat side, is not new.* Instruments were divided on the cylindrical edge some thirty years since by Troughton & Simms, of London. The writer once inspected in their noted establishment various instruments of this kind which had been constructed for use in the great Indian Survey. The mathematical instrument-maker Cooke, of York, adopted the same plan many years since for his new form of transit-theodolite, Fig. 136.

Nonius.—The reading of fractional parts of a degree on astronomical and surveying instruments was much facilitated by the invention of Nonius or Nuñez,† about 1542; but his plan gave place to the more accurate mode of Digges.‡ Tycho Brahé is said to have adopted this invention—*i.e.*, the subdivision of a degree into fractional parts by means of diagonal lines—and applied it to his quadrant, dividing it into minutes, somewhere between 1566 and 1570.§ This system was employed in Germany for a considerable time afterwards.

Vernier.—The plan of subdividing by diagonal lines was finally superseded about 1631–2 by the more accurate, convenient and facile system of subdividing introduced by Vernier, a method that has not been superseded nor ever will be; except for excessively fine readings, which can only be conveniently obtained by the use of the *micrometrical microscopes* applied to the larger instruments.

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* *Trans.*, xxix., 1001, 1899.

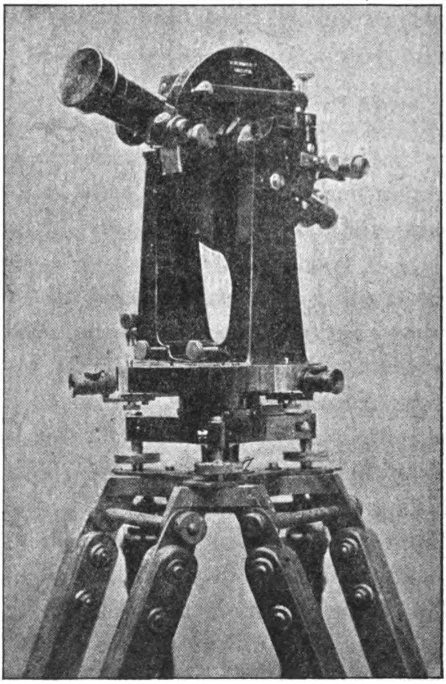
† The system is explained in the book of Nonius entitled *De Crepusculis.*

‡ *Alæ Seu Scalæ Mathematicæ*, Thomas Digges, London, 1573. [See also pages 122 and 123, for an illustration and the history of this method of subdividing angles, the so-called diagonal scale, or method of transversals.]

§ *Universal Biography*, Mackenzie, p. 854. [Brahé's great quadrant of 14 cubits, about 19 feet, in radius, was built at Augsburg in 1569. See Dreyer's *Tycho Brahé*, 1891, p. 32.]

One Vernier or Two.—The one double vernier described by Messrs. Wittstock* is much less satisfactory than two single verniers placed on oppôsite sides of a circle; simply because the latter plan affords the means of taking an average of readings from two parts of the circle at the same time, so as to reduce the effect of eccentricity and errors of graduation. But with one vernier, although double, as proposed by Messrs.

FIG. 136.



Cooke's Theodolite.

Wittstock, such errors, if they exist, must remain without correction. Possibly, however, this objection may be met by the statement that such refinement is not required for mine-surveys. The best English mathematical instrument-makers, writers and other scientific men have long since recognized the principle just noted, and have provided means for the reduction of such errors to a minimum. Generally, therefore, three equidistant verniers are provided for the horizontal circle of theo-

* Page 139.

dolites from 6 to 8 inches in diameter. As far back as 1858 three verniers were attached to the vertical circle of the miner's transit-theodolite, Fig. 74;* and the same plan has been continued and applied to the horizontal circle of Fig. 75,† also with the addition of double readings to the vertical semicircles.

Leveling-Screws.—With reference to the mode of leveling-up surveying and spirit-level instruments, Mr. Stanley admits that there is a "strain put upon the axis of the instrument by the use of four leveling-screws," but he considers it "unimportant." It is nevertheless certain that anything defective in the construction of an instrument tends to disturb or destroy its absolute stability; and, for that reason, any defect, however small, should be removed. The strain referred to is augmented when the instrument is top-heavy. The four conjugate screws formerly attached to theodolites and spirit-levels, and admired so much by the old school in England, until a new practice was introduced, were placed between the parallel leveling-plates, with so short a leverage from the vertical axis of the instrument to the center of the screws that they never admitted of a facile and permanent mode of leveling. Especially has this been felt when surveys were made upon severely-inclined land; so that the difficulties have led inexpert persons to introduce the Hoffman patent joint attachment, as an additional means to assist in leveling with four screws. However, in the hands of expert surveyors, this appendage is unnecessary.

The tendency of each pair of leveling-screws placed between the parallel leveling-plates is to produce opposing forces, with the result that there is an expansion of the weakest part of the metal forming the small diameter of the screws; and consequently a corresponding displacement of the spirit-bubbles and of other parts of the instrument ensues. Besides, a locking of the screws sometimes takes place; and the retouching of the screws for any small displacement, as well as the original leveling-up, requires the use of both hands.

The present practice in England, and through a large part of South America, Australia, etc., requires a long equilateral triangular framed base, with three large leveling-screws attached to the theodolite; and this arrangement is very effective,

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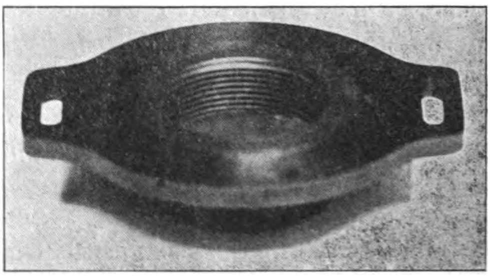
* Page 98. † Page 100.

and a complete remedy for all such defects and inconveniences as are experienced from the old-fashioned form of four leveling-screws and parallel leveling-plates. With three leveling-screws there is no opposite pulling effect, because each screw is independent in its action of the others; and for correcting any displacement of the spirit-bubbles the use of one hand only is required.

Troughton & Simms' Shifting Tripod-Head.—Figs. 137, 138 and 139 exhibit separate parts of the triangular centering-apparatus—three horizontal plates, all turned upside down, as if the tripod had been completely overturned, with its feet pointing to the sky, and with the plates fallen apart downwards in regular order. Fig. 140, copied from Troughton & Simms' Catalogue of 1900, shows the whole apparatus right side up, as in

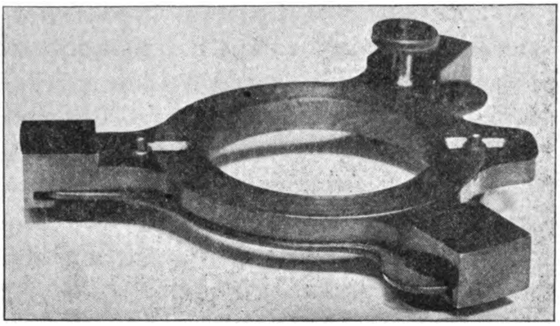
FIG. 137.



Shifting Tripod-Head, Bottom-Plate, Inverted.

use. The plate of Fig. 137 has a narrow slit about an inch long through it near each end; and a short, shouldered metal pin moves freely in each slit, and likewise fits into and moves freely in a corresponding slit near each end of the plate of Fig. 138, that, in use, rests upon the plate of Fig. 137. The slits of Fig. 138 are cut at right angles to those of Fig. 137; consequently the plate of Fig. 138 moves freely in two directions, at right angles one to the other, while both plates are held together by the shouldered metal pins. The large hole in the center of the plate of Fig. 137 has a female screw inside of it, and screws fast upon a corresponding male screw on the top of the tripod-stand head. To the upper side of the plate a hollow thin cylinder is cast, projecting upwards, with a male screw cut upon it. This projecting male screw passes through the large central hole in the plate of Fig. 138 above; and is worked upon by the female screw inside the central hole of the circular clamp-plate, Fig. 139, which clamps the other two plates together. The plate of Fig. 139 has three small circular projections upwards (as shown in the figure, downwards), equidistant

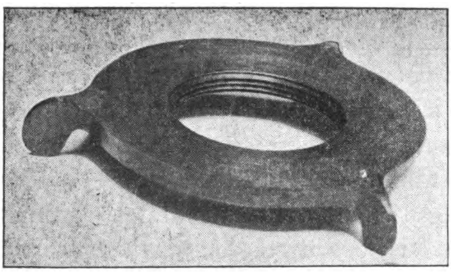
FIG. 138.



Shifting Tripod-Head, Shifting-Plate, Inverted.

one from the other (seen also in Fig. 140), forming an equilateral triangle, to which the thumb and fingers are applied when it is necessary to clamp and unclamp the plate. When the apparatus is put together for use, right side up, as in Fig. 140, the three conical-shouldened leveling-screws of the theodolite are

FIG. 139.

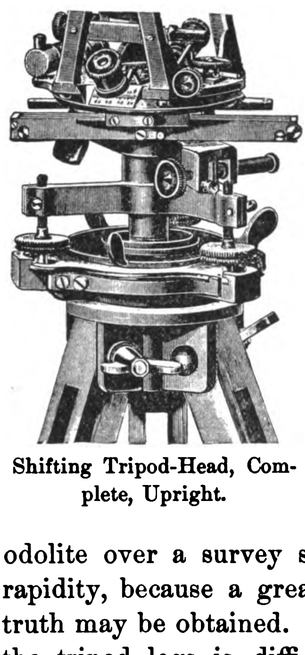


Shifting Tripod-Head, Clamping-Plate, Inverted.

placed in angular cavities in the upper surface of the triangular projecting ends of Fig. 138, and are then locked in that position by another thin plate, which has a slight horizontal motion, and is thereby secured in a groove by a conical head turned in the shank of the leveling-screws. Part of this thin plate is seen projecting from under the (inverted) plate of Fig. 138, and it is clamped in position by the milled-headed screw also seen in Fig. 138. The construction and use of this simple, light and effective apparatus are well known. It is the invention of Troughton & Simms, and is supplied with all their instruments.

When the theodolite is locked in position upon this leveling and centering apparatus, and it is required to center it over a fine point marking a survey station, it is first done roughly by moving the legs of the tripod-stand, leveling up; and then the clamp-plate, Fig. 139, is unscrewed a little, leaving the theodolite and upper part of the leveling and centering apparatus, Fig. 138, free to move in two directions, at right angles one to another, upon the plate of Fig. 137, which is fixed upon the tripod-stand, until the fine point of the plumb-bob coincides with the center of the survey station. The circular clamp-plate, Fig. 139, is then screwed down tight, fixing the instrument in position for immediate use. The whole of these operations may be effected almost instantaneously.

FIG. 140.



Shifting Tripod-Head, Complete, Upright.

It is very important to possess some such means as those described to enable the engineer to center the theodolite over a survey station-mark with great precision and rapidity, because a greater geometrical approximation to the truth may be obtained. To do this perfectly by simply moving the tripod legs is difficult and almost impossible; and the attempt is the fertile source of a small repeated accumulating error, the total amount of which in an extensive survey cannot be estimated or determined until an irregular polygon has been described. The facilities for such control in underground surveys do not often exist.

Hoskold's Shifting Tripod-Head.—The top part of a theodolite-stand invented by the writer in 1866 consisted of a circular metallic box, to the underside of which the legs were attached;

and in the middle of the upper part a strong circular plate was fitted, having a circular motion of about one inch in all directions horizontally. At the center of the plate a large hollow screw was cast, projecting upwards to a height of about 1½ inches, upon which the theodolite was screwed; but not close down, until, by moving the theodolite and plate about, the plumb-bob was centered over the station. The instrument was then screwed down ready for use.

Hoskold's Extensible Tripod.—That theodolite-stand of 1866 was planned for underground use, and each leg consisted of three tubes sliding one into another. On the outside termination of each tube a screw was cut, and the ends of the tubes were, at two places in each, slit up two inches in length by saw cuts, in order to compress the outer tubes against the inner ones when a stout outside collar screw was brought into action at each joint. In that manner the tubes were effectually clamped together. The stand could be set up from 18 inches to about 4 feet in height. But after some time the sliding of the tubes and the action of the collar-screw clamps were much impeded by water and dirt. Besides, the stand was too heavy. All of those inconveniences caused it to be abandoned. It may, however, be possible to construct a stand of this type in aluminum metal alloyed, so as to be of service. Nevertheless, three short stands of a special construction would be preferable. Part of the construction of the tubular stand noted was similar to that of Mr. Stanley's, referred to by Mr. Scott.*

Electric Lamp.—The small portable electric lamp mentioned by Mr. Scott is exceedingly convenient and useful, setting aside the use of candle lights and oil lamps, and facilitating in a high degree the reading of theodolite verniers underground. A diagram or graphic representation of it when in use in mine-surveys should have been introduced in Mr. Scott's discussion. Probably he will favor us with it on some future occasion. Fig. 84† shows to what extent inventions have been applied in order to achieve a similar purpose; but it is a cumbrous mode, and cannot be compared to the efficient little lamp described by Mr. Scott.

Plumb-Lines.—Mr. Hulbert is right in saying:‡

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* Pages 46, 47. † Page 127. ‡ Page 149.

"I should place more reliance upon a downward sight through a properly constructed and accurately adjusted telescope than in the repose of a plumb-line. We trust the telescope for the measurement of all horizontal distances, and we never question its accuracy in taking inclined angles and observations; now, therefore, why not accord it the same confidence in taking a truly vertical sight? Except for moderately short distances, I always considered the plumb-line a positive nuisance, a consumer of time and a disagreeable tester of patience."

He could also have added: without any positive certainty, for either long or short distances. It is nevertheless to be feared that persons will always exist capable of trying every obsolete fad.

Chain.—A steel standard chain is an expeditious measuring-instrument for underground work, and excellent results may be obtained by its use; at the same time, it is well to carry a pocket-rule divided to tenths of inches, for measuring any odd part of a link which may coincide with a station. Any tunnel or other important drivage from two opposite points, or otherwise, depending upon the survey, may then be carried out with confidence. For still more accurate work, another class of linear measuring instrument could be devised similar to those employed to measure base-lines in trigonometrical surveys, though simpler; but it would only be used on rare occasions.

II.—Instruments.

Compass.

Mine Compass of 1518.—Figs. 141 and 142 are two forms of mine-surveying compasses taken from the old rare German mining book, *Eyn woldgeordent und nützlich büchlin wie man Bergwerck suchen uñ finden sol.* Edition 1518. This work with three other editions, namely, 1527, 1534 and 1539, are preserved in the Royal Mining Academy at Freiberg in Saxony. The 1504 edition of that book, the rarest of all, does not exist there. The compasses for mine-surveying—if they were so used—represented by Figs. 141 and 142 differ somewhat in form and size in all the editions of the book referred to. For example, Fig. 141, which appears to be the oldest, is divided into twice 12 hours, and has a small circle inscribed round the central point, upon which probably a small magnetic needle was placed. Fig. 142 has two concentric circles, each divided into twice 12 hours, one end of the magnetic needle being forked.

Compass of 1541 *and Agricola's of* 1556.—Mr. Brough, in discussing Mr. Scott's paper, said:*

"The author is inaccurate in stating that the use of the compass in mine-surveys is first described by Agricola."

It is, however, curious that Mr. Brough has conveyed the same sense and employed nearly the same words in his little book on *Mine-Surveying* from 1888 to 1899. At page 26 he says:

FIG. 141.

Earlier Mine-Surveying Compass of 1518.

"The use of the magnetic needle for surveying mines is first described by Georgius Agricola, in the fifth book of his *De Re Metallica*, 1556.

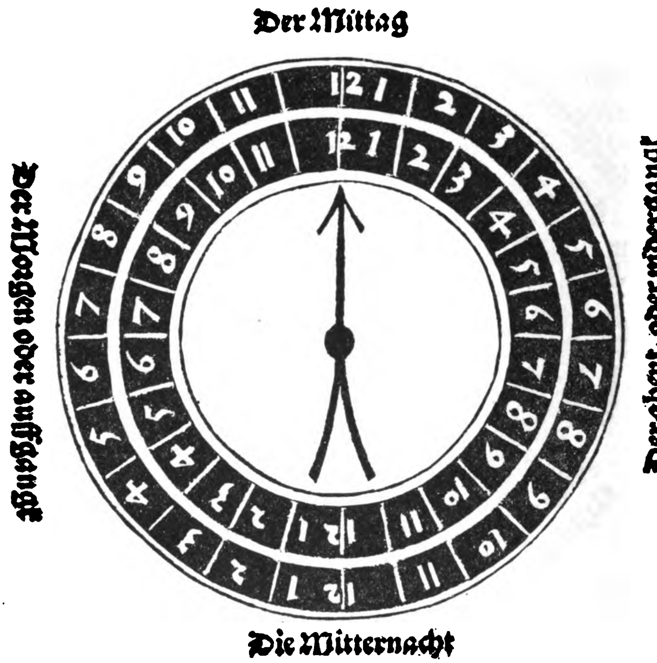
"The compass there described is of a very primitive character. . . . . An old compass of this type is preserved in the collection of the School of Mines of Clausthal, in the Harz. It bears date 1541."

The comparatively limited space of only three circular concentric grooves filled with wax, upon which to indicate the direction of underground roads, is, in the writer's opinion, enough to prove that the Clausthal compass is an older form than Agricola's. The latter was provided with seven circular concentric grooves filled with wax, and was consequently capa-

* Page 68.

ble of being employed in more extended surveys, such as a progressive system of mining operations required. No doubt the mine-surveying compass of 1541 and Agricola's of 1556 are improvements upon the older forms, Figs. 141 and 142, of 1504 and 1518; for in these it would appear that anything finer than an entire division of one hour had to be estimated by some other means. On the contrary, the actual direction of any un-

FIG. 142.



Later Mine-Surveying Compass of 1518.

derground road was indicated by a scratched line on the wax of the Setz-compass and Agricola's compass.

Voigtel's Setz-Compass.—Mr. Scott has referred* to a very curious form of mine-surveying instrument, the astrolabe, a simple plane circle supported in a horizontal position, illustrated in an excellent old German book;† but he has omitted to note the Setz-compass of the same work, although it is equally interesting.‡ It has the same form as the surveying-

* Page 120. † Voigtel's *Geometria Subterranea*, p. 146, 1686.
‡ *Ibid.*, p. 72.

compass of Fig. 141, date 1518. It seems, therefore, probable that that class of instrument may have been used for a period of two centuries, or more. The words midnight, midday and other names corresponding to certain defined points, engraved outside and around the circle or compass, indicate that it may have been a copy or a modification of some other more ancient instrument, say an astrolabe employed for some other class of observations, such as a rough estimation of time and general direction. A very curious group of ancient mathematical instruments forms part of the artistically engraved frontispiece of the same book, and would be worth reproducing.

Circumferentor.—The circumferentor described by Bion is nearly the same as the miner's dial-circumferentor with plain sights as constructed to-day, but is a little ruder in form than Fig. 12* in Mr. Scott's paper. It appears that Pryce did not know anything about this old dial in 1778.

Stanley's Hedley Dial.—Mr. Stanley recently introduced, as he says, a new form of Hedley dial, patented, Fig. 63.† It is constructed with an oval-shaped curved cradle carrying the telescope, and having a vertical circle attached, instead of with a ring and semicircle, as in the old type dials, Figs. 25 and 40.‡ The principal advantage to be derived from a vertical circle is that it offers means for obtaining two readings, one opposite the other; but Mr. Stanley has not availed himself of this established principle, making the circle, therefore, no more important than a semicircle. In this age of unprecedented progress, facility and accuracy of working, no practical person should prefer the old-fashioned and coarse method of engraved corrections "in hypothenuse and base" upon an instrument, when the same thing in an accurate form is included in a table of natural sines and cosines.

Mr. Stanley says: "It is the first dial of the Hedley style, I believe, which may be used for sighting in true verticality." But he has provided no means to adjust the horizontal axis upon which the cradle and telescope work; at least, such an adjustment is not described, nor does it appear in Fig. 63. Consequently, there is no certainty that the vertical hair of the telescope would under all conditions revolve permanently in the

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* Page 14. † Page 75. ‡ Pages 31 and 45.

same vertical plane. Considering this and the comparatively rough construction always inherent in this class of instrument, the writer is of opinion that it would not be a convenient or absolutely trustworthy instrument for carrying out that very delicate and important operation of connecting underground workings one to another and to the surface, for the purpose of executing some important and costly work. If, however, the contrary held good, the telescope is not conveniently constructed for facile work; neither is it sufficiently powerful except for comparatively short distances down pits or severe inclines, or for surveys of no great importance. The instruments of both Figs. 40 and 63 and all others of that type are comparatively cumbrous, rough in construction, and neither the one nor the other can ever be made to approach the nice and beautiful construction of a well-proportioned and high-class theodolite. Doubtless, however, many persons will employ the one of Fig. 63 for second-rate underground surveys in which great accuracy is not considered a *sine qua non*.

If Mr. Stanley desires to improve his instrument, and so render it of greater value for mine-surveying, it would be well to provide an adjustment to the horizontal axis, supply an axis level and means to illuminate the cross-hairs in the focus of the telescope. The best means of doing this is exhibited in Figs. 76 and 77.* An oblong hole is cut in the side of the telescope near its eye end and filled with glass, with a slide for protection. A reflector may be placed inside to throw the light upon the wires. If a magnetic bearing is of any value, the instrument of Fig. 63 would preferably have a more open dial face; for, in its present form, it would be difficult to obtain a clear view all round the circle, even when the cradle and telescope are tilted to the perpendicular. If the magnetic compass should be required at all, it would be best mounted on the top of the telescope, as is the case in the writer's Engineer's Theodolite, Fig. 76.†

Compass on Telescope.—The sliding magnetic compass was attached to the telescope of the theodolite, Fig. 17,‡ many years since by the writer; and the same plan has been continued for his Engineer's Theodolite, Fig. 75.§

* Pages 105 and 106. † Page 105. ‡ Page 20. § Page 100.

Hanging Compass.—Referring to the remarks of Mr. Johnson* upon Mr. Scott's opinion as to the magnetic hanging compass in mine-surveying, the writer agrees with Mr. Johnson in a limited sense. That is, when the purpose of the survey is merely to obtain a rough diagram of the workings in a mine, the general direction of any mineral vein, and a variety of other things, without aiming at an exact map or plan of such underground objects with relation to the surface, to boundary lines, to the formation of a tunnel from two opposite points, or to striking any given bore hole, and to other important matters; then, any handy inexpensive magnetic compass may be employed, and time, inconvenience and money saved. It is evident, therefore, that a finely divided theodolite should not be taken into every hole and corner of a mine. However, when all the conditions just indicated are reversed, then such instruments as would enable the surveyor to produce the most accurate results should be employed, and the amount of time and expense necessary to effect this should not be considered.

Lack of Precision.—It is strange that some men continue to urge that the use of the magnetic compass is sufficient for underground surveys, and it is difficult to assign a reason; though we may assume that facility and simplicity of use, hereditary custom and the comparatively small cost of such instruments are some of the chief reasons why the miner's compass is still clung to in some form or another so tenaciously. But in the face of a well-known law of Newton are we to ignore the results of the modern solution of some of the most curious, difficult and important natural physical problems?

The scientific men of to-day have proved that even the highest class surveys, which have been conducted upon the most refined and rigid mathematical principles, are affected in a variable degree through the deflection of the plumb-line by close neighboring mountain masses and rocks of the greatest density. One of the most interesting and important records we possess is that which relates to the setting out of the boundary-line between the territory of the United States and the possessions of Great Britain between the Lake of the Woods and the Rocky Mountains. The part of the report of the chief

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* Page 129.

astronomer and member of the mixed commission that relates to the deviation of the boundary-line, as set out, from the true astronomical parallel of latitude, is applicable to the question to which the writer desires to direct attention. He says:*

"The fact of local deflection being established, the attention of mathematicians was turned to the investigation of the causes and probable corrections. In this much ingenuity has been displayed, but with very small results. Starting with the general law [of Newton], that every particle of matter attracts each other particle with a force varying directly with the mass and inversely with the square of the distance, the attraction of masses of mathematical forms on distant particles was found by dividing mountain-ranges and other elevations into volumes bearing known mathematical relations. The probable deflection of the plumb-line due to such causes was found for different distances, on the supposition that the mean density of the large volumes was uniform for different parts of the earth's crust [—a thing quite impossible]. Thus, it was found that at the northern station of the great Indian arc the attraction of the Himalayas should cause a deflection of 28″; which should decrease at the next two principal stations by 15″.9 and 21″.1, respectively, while the deficiency of matter in the ocean should produce similar northern deflections. These calculations were not absolute, since the contour of the mountains and of the ocean-bed was only approximately known; but the approximations were supposed to be sufficiently close. It was found, however, that the actual deflections were much smaller than those given by calculation; and that, in many cases, the deflection was towards the ocean. The explanation of this lies in the varying density of the earth's crust. The facts discovered indicate that the density is greatest in the depressed, and less in the elevated portions."

From the doctrine here laid down, upon Newton's law, we must conclude that the maximum density and effect occurs from the presence of intrusive dikes which have penetrated the earth's crust to a great extent; and, although some of those dikes are not visible, still the denser masses of such intrusions produce very great effect. As every one knows, the magnetic needle consists of a light bar of steel suspended freely upon a fine central point, and in a horizontal position. Consequently it is liable to be acted upon and deflected an unknown quantity by the greater and denser masses of rocks which form intrusive dikes. This effect may exist, although not suspected; but whatever its amount may be, it is independent of the deflection of the needle caused by ferruginous masses and the

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* *Reports upon the Survey of the Boundary between the Territory of the United States and the Possessions of Great Britain*, Department of State, Washington, 1878, p. 263. Also in *Executive Documents, Senate of United States*, 1877, No. 41, p. 26, Washington, 1877.

other common deviations to which the magnetic needle is subjected.

The writer is nevertheless aware that magnetic surveys are sometimes conducted in places more or less free from natural disturbances; and, in such a case, when great care has been taken in manipulating the instrument, and when there has been a large share of good luck, close approximation to the truth has resulted. But such favorable conditions cannot always be expected to be realized. It would therefore be dangerous to place too much reliance upon the accurate performance of the magnetic needle on all occasions and under varying circumstances. The history of mine-surveying proves that some persons have placed absolute reliance upon the magnetic needle, and have come to grief. The erratic behavior of the magnetic needle, and consequently the uncertainty of the observations made with it, as just indicated, are confirmed by Mr. Hulbert*; and in addition to the list of disturbing elements previously noted, he has noted another, namely, "electric currents following either wall of a vein" of mineral.

Plane-Table.

Referring to Mr. Scott's discussion, a plane-table similar to that described under Fig. 62† was in use in England and France more than 120 years earlier. An old English work translated from the French‡ says, in substance, somewhat condensed:

"The plain-table is a parallelogram of wood, 15 inches long and 12 broad," having "a box-frame to fasten a sheet of paper upon the table, by forcing down the frame and squeezing in the edges of the paper, so that it lies firm and even upon the table; and thereby the plot of a field, or other enclosure, may conveniently be drawn upon it. On both sides of this frame, near the inward edge, are scales of inches subdivided into 10 equal parts, having their proper figures set to them. The use of these scales is for ready drawing of parallel lines upon the paper, and also for shifting the paper when the sheet will not hold the whole work. Upon one side of the box-frame are projected 360 degrees of a circle, from a brass center hole in the middle of the table. Each degree is subdivided into 30 minutes, and to every 10th degree are set two numbers, one expressing the proper number of degrees, and the other the complement of that number of degrees to 360. This is done to avoid the trouble of subtraction in taking angles. On the other side

* Page 147. † Page 74.

‡ Stone's Bion, *Construction of Mathematical Instruments*, p. 127 and Fig. F, plate xiii., London, 1723.

of the frame and upon a part of its width are projected the 180 degrees of a semicircle from a brass centre hole in the middle of the table's length. Each degree is subdivided to 30 minutes; to every 10th degree are set likewise, as on the other side, two numbers; one expressing the proper number of degrees, and the other the complement of that number of degrees to 180. . . . . All these degrees will make the plain-table a theodolite or a semicircle, according to what side of the frame is uppermost. There is a box with a needle and card, covered with a glass, fixed to one of the long sides of the table. There is also belonging to the table an index, which is a large brass ruler, at least 16 inches long and 2 inches broad, and so thick as to make it strong and firm, having a sloped edge, and two sights screwed perpendicularly on it. Upon this index it is usual to have many scales of equal parts; as also diagonals and lines of chords," etc.

From this and the description given by Mr. Scott,* there appears to have been no improvement in plane-tables from 1657† to 1834, when Simms wrote.

Octant and Quadrant.

In an old Latin book on surveying and astronomical instruments,‡ an instrument called an octant—the eighth part of a circle—is exhibited, together with various diagrams illustrative of its application. That work contains evidence that the instrument referred to was used prior to 1604, and at least up to 1612. Fig. 143 is a reduction of the original diagram of the octant, the length, or radius, of which was 15 inches. The limb has 5 concentric arcs engraved upon it, and it is a good example of subdividing the degrees into parts by diagonal lines. The distance from the first divided arc to the exterior one is 1½ inches, and the diagonal lines are drawn from the whole degree points on the first arc to the half degree points on the exterior arc. The diagonal lines are, moreover, divided by fine dots, so as to read to every two minutes. Fig. 144 shows two such instruments set up, with four observers determining a distance.

A quadrant without subdivisions by diagonal lines was used in England for surveying operations by Delamain in 1632.§ Circles were, however, employed before 1529 in Spain and

* Page 74.

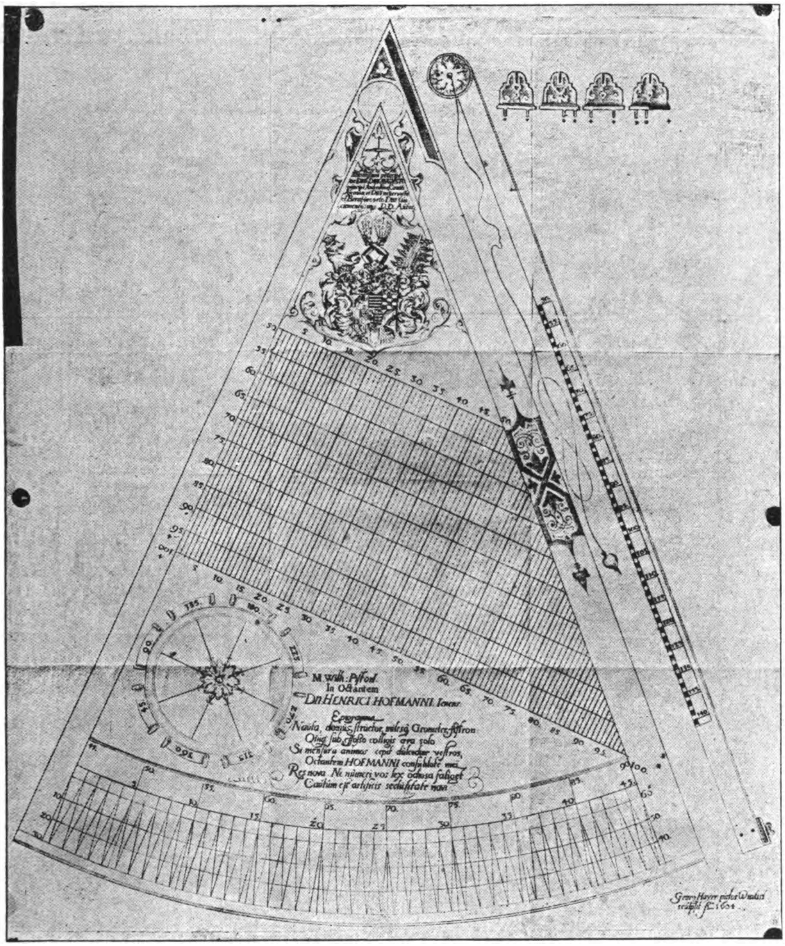
† *The Complete Surveyor, Containing the Whole Art of Surveying of Land by the Plane-Table, Theodolite, Circumferentor,* etc. Second edition, W. Lebourn, 1657.

‡ *De Octantis Instrumenti Mathematici Novi Geodætis, Astronomis, Nautis Usu,* etc. Henrico Hofmanne, Jena, 1612.

§ *A Mixed Trapezium or Horizontal Quadrant for Mathematical Practice,* Delamain, 1632.

other places. It is, therefore, somewhat strange that the use of octants and quadrants should have been continued in preference.

FIG. 143.



Octant.

Theodolite and Transit.

Evolution of the Theodolite.—The German instrument of Fig. 145 is illustrated in a curious black-letter book of 38 pages on surveying;* and, at the time, was considered to be of great

* *Instrument zur Mechanica*, A. Albrecht, 1673.

importance. It is possible that it was employed in mine-surveying. In the original description, A is a small compass-box, containing a magnetic needle, with the four cardinal points marked. B shows an indicator to which the compass-box is screwed, both of which revolve horizontally. C is a fixed graduated circle placed under the indicator B, and is divided

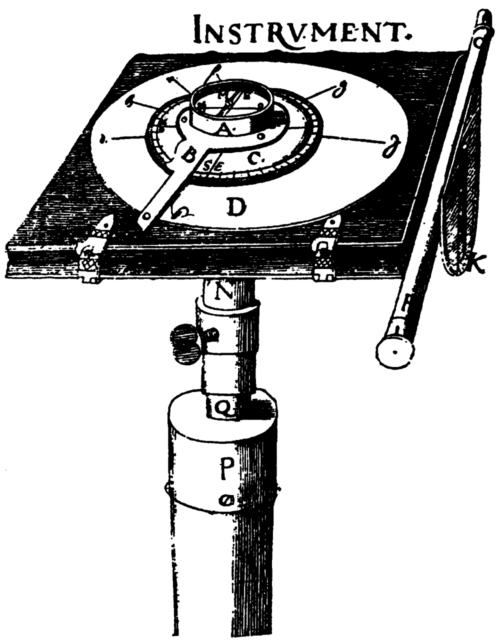
FIG. 144.

Octant in Use.

into 360°; also the four cardinal lines are marked upon it. D is a circular writing-table placed under the divided circle and extending concentrically beyond it. E is a bound book, part of the instrument, to which all the other parts, previously described, are firmly attached. The book was intended for writing and drawing. FG represents a tube or telescope, attached by means of a short axis and appendage to the side of the book.

A vertical semicircle was also fixed to the underside of the telescope, and the vertical angles were indicated by swinging pendulums suspended from the short horizontal axis previously noted. NQP represents the upper part of the stand, with joints for giving horizontal motion to the instrument. The cylindrical part at N appears to have been divided. When in use, the telescope of this instrument was directed to an object and the index bar, B, was then moved by hand round the divided circle,

FIG. 145.



Albrecht's Instrument.

until the magnetic needle pointed north and south; and the bearing angle of the observed object was then obtained from the divided circle.

The instrument* shown in Fig. 106† seems to be an improved form and probably derived from that of Fig. 145. In an old English book,‡ translated from the French, a graphometer, or surveying horizontal semicircle, is represented with

* *Geometria Forensis*, Reinhold, 1781, p. 106 and plate xii. † Page 168.

‡ Stone's translation of Bion, on *Mathematical Instruments*, p. 121, 1723.

double sights, the one fixed and the other movable, as in the instrument of Fig. 106, but without vertical motion for either of the sights. The upper telescope of Fig. 106, however, has a vertical motion, proving that it is of more recent construction, and approaching towards the simplest form of theodolite. The idea of attaching a vertical arc to the telescope of the instrument of 1781, Fig. 106, seems to have been derived from the large geodetic altazimuth of Ramsden, which at that time was so well known throughout Europe. Semicircles with plain sights were, however, mounted upon the diameter of horizontal circles about 1766.

The great inventor Ramsden completed his dividing-engine in 1773, after ten years of incessant labor, and his great 36-inch diameter theodolite, Fig. 146, soon after. Delambre styles him a "celebrated English optician, the greatest of all artists, and the inventor of the theodolite." To Ramsden is attributed the introduction of the vertical in combination with the horizontal circle in the same instrument. Ramsden constructed two 36-inch theodolites, one for the Royal Society, and the other for the English government. It is understood that both the instruments were employed on the English Trigonometrical Survey. One of them is still preserved in good working condition in the Ordnance Survey Offices. A notice of both instruments will be found in the *History of the Royal Sappers and Miners.** The horizontal circle appears to have been read by four micrometrical microscopes and to one second of arc. The telescope was used for distances up to 112 miles.

Scott's Tachymeter.—The writer has made no objection to Mr. Scott's "interchangeable auxiliary telescope when placed on the top of the main telescope under conditions almost identical with the others mentioned."† All that can fairly be deduced from the writer's observations‡ is, that he considers the models Fig. 45 and Fig. 55 superior to all the other preceding ones described by Mr. Scott. It was not intended to include Figs. 56 and 57 in that list; but between these two a comparison was made in reference to the mode of attaching the auxiliary telescope, with its possible effects. However much experience a man may have,

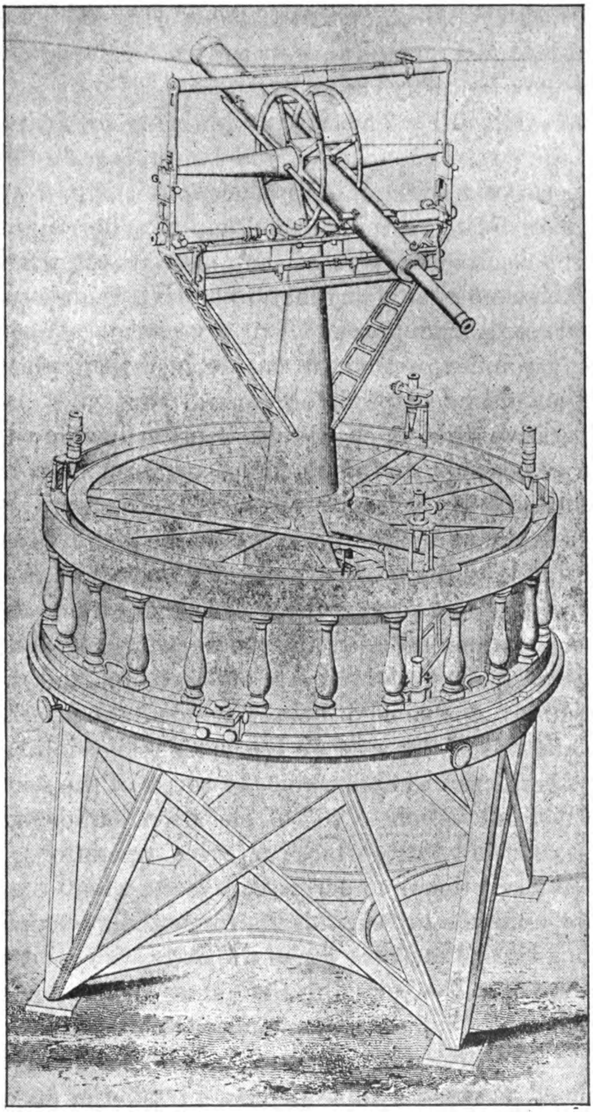
* *Royal Engineers*, 1857, vol. ii., p. 408.

† Page 121.

‡ Page 109.

it would be exceedingly unwise to attempt to criticise in too strict a manner the merits or demerits of an instrument he had not

FIG. 146.



Ramsden's 36-Inch Theodolite.

seen or proved. Considering, therefore, that Mr. Scott's form of instrument is a recent introduction, he naturally must be the best expert with reference to its advantages and use, and we must consequently hear him, and give credit to his evidence. It is, however, difficult to convince men that the form of instrument they have been accustomed to use is not the best. This is the way and prejudice of the world, and it is a hard matter indeed to supplant entirely the old for the new, although the latter may be vastly superior.

Hoskold's Engineer's Theodolite.—Referring to Mr. Scott's remarks,* the writer cannot find sufficient reason to change the present form of his Engineer's Theodolite, Fig. 75,† to the form of an ordinary transit theodolite. The description which the writer has already given of that instrument‡ was intended to be sufficient to enable anyone to perceive the reason why it was constructed in its present distinctive form. When the design was last under revision, it was decided that, whilst the instrument should be adapted for general surveying use, it was also imperative that it should be kept as low down in construction as possible, and in as compact a form as convenience would permit. These conditions were necessary, considering that an instrument in that form would be better appreciated and useful among the more experienced surveyors in collieries and other mines and places where severe angles of depression do not so commonly occur, and where a higher and a more top-heavy instrument would be objected to, and would, in general, stand the chance of being excluded altogether.

The standards of the writer's Engineer's Theodolite, Fig. 75, are only 5⅛ inches in height, and the range of the semicircle is about 60° of depression to 70° of elevation, sufficient for most purposes, especially in surface-surveying operations. But, to meet a few exceptional underground cases, where the angle of depression amounts to 70°, the instrument may be planted at the bottom instead of at the top of the excavation, and the angle so measured would be equal to the one of depression. In the second place, the limit for the standards of this instrument is from 6⅝ to 7 inches in height; and, in this case, the instrument is capable of measuring an angle of depression of 66°, and one of elevation of 76°. However, if desired, the standards could be made 7½ inches high without detriment, and an angle of ele-

* Page 120. † Page 100. ‡ Page 102.

vation could then be measured greater than 76°. Naturally, in extreme exceptional cases, such as those noted by Mr. Hulbert,* where the dip ranges from 83° to 86°, special means must be employed.

But when a mineral vein has a great dip "varying from 83° to 86°," as Mr. Hulbert says was the case in the Cliff mine, it is an error on his part to state that "no sight on this inclination could be taken with the ordinary transit-telescope." *The angle of depression of any given inclined plane observed from the top is equal to the angle of elevation of the same plane measured from the bottom.* If, therefore, an ordinary transit-telescope will not measure an angle of depression of 86°, or a larger angle, when the standards of the theodolite are only of a moderate height, it will measure that angle on the bottom of the excavation when the instrument is constructed in the form of Fig. 74.† That instrument is capable of measuring angles of elevation up to the zenith; and although the construction is comparatively simple, still it is very portable and handy, as also very effective. It was the favorite instrument of the writer in 1858, and a large number were, and still continue to be, constructed by various English makers for local and foreign use, especially in various parts of South America. It is, however, preferable when mounted upon a triangular leveling-base with three leveling-screws, as shown in the diagram in the right hand lower corner of Fig. 74.

The writer has clearly explained how his Engineer's Theodolite, Fig. 75,‡ can be applied in order to perform the work of a transit-theodolite; consequently there is no need to give it the form Mr. Scott suggests, or to introduce in it a cyclotomic circle; a plan, by the way, that Mr. Scott recommends, and does not adopt for his own instrument. The instrument of Fig. 75 is constructed with as much perfection as the present practice of mechanical and mathematical principles and skill will admit; and that fact, taken in connection with the exceptional advantages pointed out by the scientific Jury of Awards at the Chicago Exhibition, 1893,§ advantages experienced, too, in the practice of other engineers with the instrument, insures that it is unrivaled.

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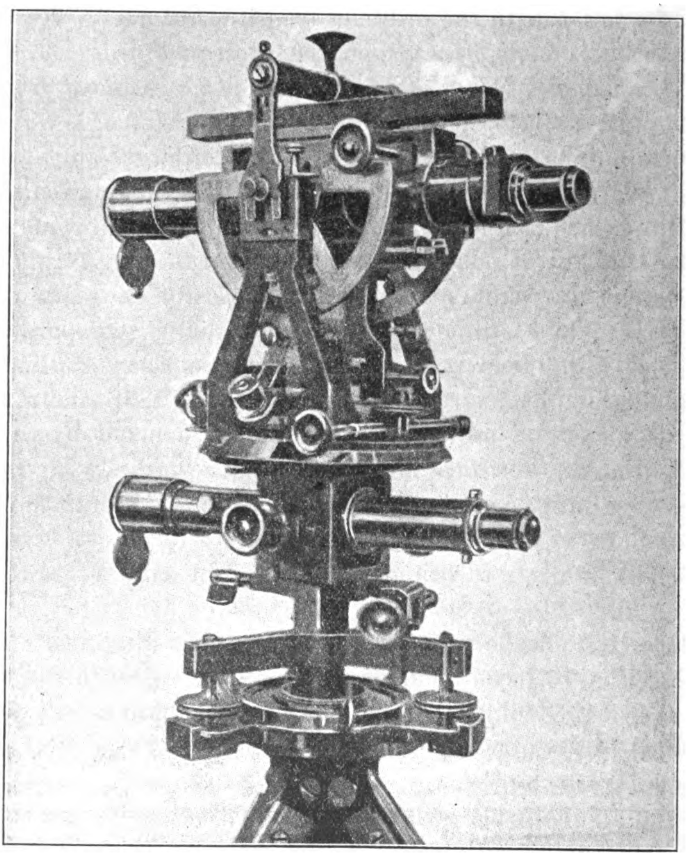
* Page 147. † Page 98. ‡ Page 100. § Page 97.

However, if there are persons who cannot be convinced, or are not able to appreciate the construction and use of any other instrument than a transit-theodolite, Fig. 75 may be converted to that form by making the standards a little higher than they are at present, shortening the object-end of the telescope,

FIG. 147.

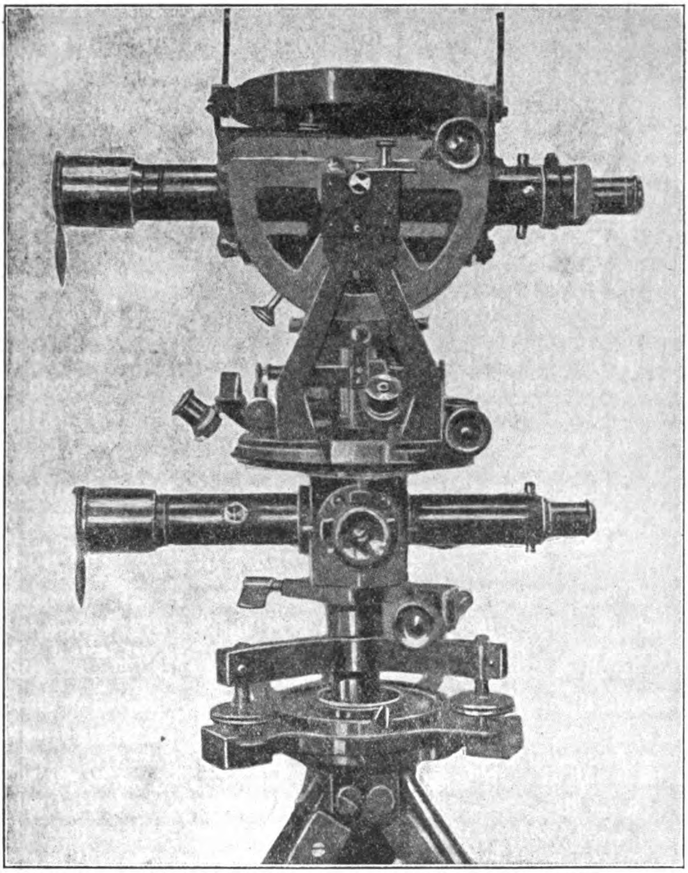


Hoskold's Engineer's Theodolite, Improved.

lengthening its eye-end, and making the object-glass and eye-glass interchangeable; so that the instrument may be used to sight objects in the zenith. In this way, and others to be pointed out, may be obtained a very effective and excellent transit-form of instrument, with the advantage that all the other parts may remain as at present. Nevertheless, the only advantage to be gained by such a change would be the means of measuring greater angles of elevation and depression, with a double transit-effect for the instrument.

A general description of the writer's Engineer's Theodolite, Fig. 75, has already been given, but the diagram illustrating

FIG. 148.

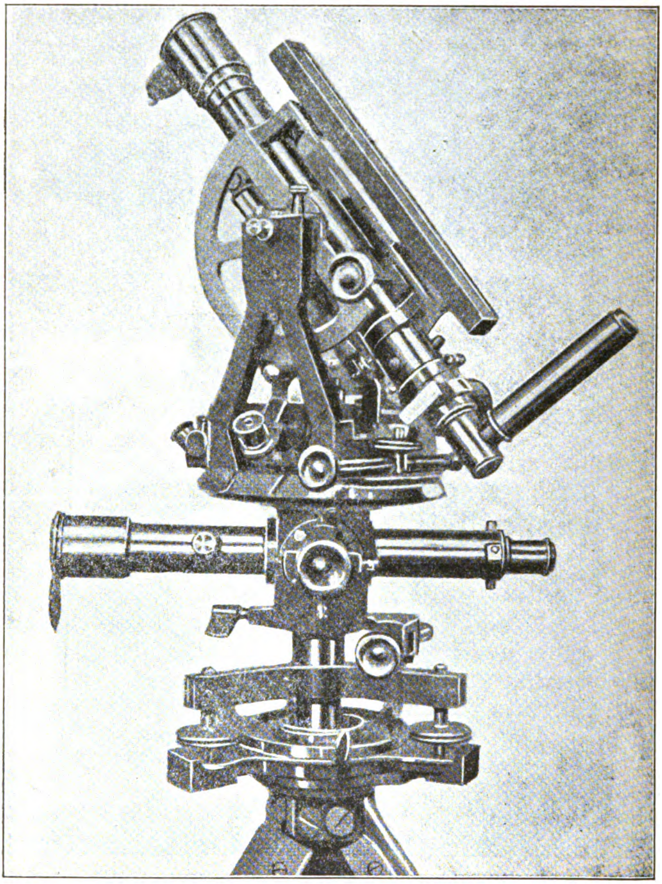


Hoskold's Engineer's Theodolite, Improved, with Circular Compass.

that description does not represent the instrument as now introduced with the ultimate alterations and improvements. Nevertheless, the same general type has been preserved. The four new diagrams, Figs. 147, 148, 149 and 150, exhibit the instrument in different positions, and present all the details of the exterior construction. A very important alteration shown in

Fig. 147 is the tubular or cylindrical bearings, with circular flanges screwed to each exterior side of the lower vertical axis. This arrangement enables the ends of the lower horizontal axis to be suspended in collars between adjusting screws, further from the center of the optical axis of the telescope; and so ef-

Fig. 149.

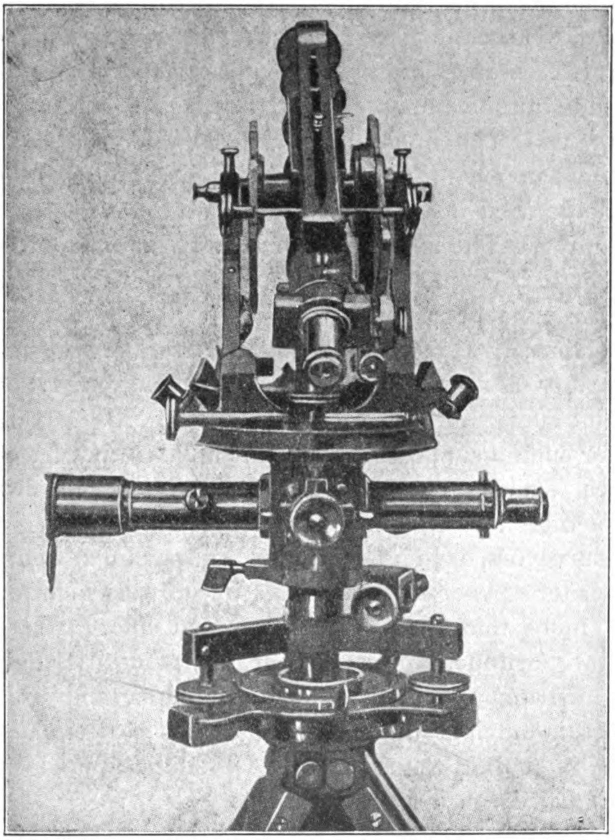


Hoskold's Engineer's Theodolite, Improved.

fectually prevents any possible lateral springing or vibrating effects.

Another important addition is the micrometer, the divided circle or head of which is seen at the eye-end of the upper telescope, Fig. 150. This divided head is attached to a finely-cut screw working in a metal frame which carries the spider's line index, over the divided comb, placed in the micrometer-box and in the focus of the telescope. There is nothing new in this appendage; still, it is exceedingly useful and important in measuring small angles down to single seconds, and by estimation to the

FIG. 150.



Hoskold's Engineer's Theodolite, Improved.

half of that quantity, and consequently any distance within the range of the telescope may be measured with the greatest facility and accuracy. The simple trigonometrical formula required to effect the calculation of the distance has already been given.* Fig. 148 shows the manner of mounting the circular

* Page 116.

magnetic compass on top of the telescope. When not so required it may be replaced by the long-trough magnetic compass, the needle of which has an arc of only a few degrees—as seen in Fig. 150; or a long spirit-bubble may be inserted in place of the trough-compass, if required.

The circular compass, Fig. 148, contains a magnetic needle with a vernier mounted at each end reading to 15″ of arc. When a magnetic bearing is not required so fine, a plain needle is provided to take the place of the one with verniers. The plain sights of this compass are made very short and in pairs, placed at each side of the compass-box; that is to say, a fine sight and an open one. The open sight is filled with glass, and cross-lines are cut upon it. The sights are hinged on a pin or axis, and can be turned down.

Angleometer.—The instrument of Fig. 76* is one of the most convenient and efficient for measuring angles of elevation to the zenith or depression to the nadir; and consequently, as previously noted,† it is well adapted for general mine-surveying.

Precision of Mine-Theodolites.—Mr. Stanley says:‡ "I do not think mine-surveying so exact as surface." He advances no reason for such a supposition, but possibly is thinking of trigonometrical surveys; neither is it clear whether he attributes the inexactness to systematic carelessness on the part of underground surveyors, or to inferiority of the instruments employed. As the writer's paper on this subject has already mentioned, he proved§ more than thirty years ago that when underground surveys are conducted in a proper manner, with the use of modern instruments of the theodolite class and good line measurers, as much accuracy can be obtained in an underground survey as in similar, though much less difficult and inconvenient, operations on the surface.

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* Page 105. † Page 107. ‡ Page 76.

§ *A Practical Treatise on Mining, Land and Railway Surveying, Engineering*, etc., H. D. Hoskold, London, 1863.

Notes on Mine-Surveying Instruments, with Special Reference to Mr. Dunbar D. Scott's Paper on their Evolution, and its Discussion.

BY BENJAMIN SMITH LYMAN, PHILADELPHIA, PA.

(Canadian Meeting, August, 1900.)

SYNOPSIS.

SURVEYORS are much indebted to Mr. Scott for so vigorously attacking the subject of the origin and history of mine-surveying instruments, the compass, the telescope, the transit and other apparatus. He is not afraid of the dark, nor yet foolishly bashful in broad daylight. He does not recoil from the obscurities of the earliest times and the most difficult historical points; and, with commendable public spirit, he makes his own invention known to his fellow-workers, and challenges their criticism. He has, moreover, elicited the praiseworthy emulation of Mr. Hoskold. They both quote from rare old books, two or three of which are to be found in our great Philadelphia and New York libraries, enabling us to ascertain yet a few facts that bear in an interesting way on the origin of the instruments and of some of their essential parts.

I. Ancient History.

Accepted Fables.—Mr. Scott and Mr. Hoskold dip into early Oriental history, but cite only authorities that are antiquated without being ancient. Our few, but very learned Philadelphia Assyriologists and Egyptologists declare they have little faith in the existence of any Assyrian or Egyptian surveying instruments. Proclus, about A.D. 450, in his history of geometry before the time of Euclid, begins with what Prof. A. de Morgan* justly characterizes as "absurd stories:" how the Egyptians invented geometry, or surveying, as a means of recovering landmarks destroyed by the annual Nile floods, and Thales (say 600 B.C.) brought the knowledge to Greece. The oft-repeated tale has so little internal evidence to give it any probability in the eyes of a practical surveyor, that it is surprising to see it approvingly cited from Alfarabius, the famous Arabian scholar of the 10th century, by Jakob Koebel in his *Geometrey von Künstlichem Feldmessen*, the book referred to by Mr. Brough (see the New York Astor Library copy of 1593). When we consider that the doubtless far more highly enlightened Japanese did little or nothing in the way of precise surveying until about 100 years ago, and then with some knowledge of European methods, and even much later were mostly contented with mere sketch maps of the roughest kind; and that it has been the same with the decidedly more advanced Chinese, except for the mapping introduced by the Jesuit missionaries; we may well doubt whether those early ancients accomplished anything better, or used for the purpose any instruments of precision.

Babylonian Mapping.—That doubt is fully confirmed by Fig. 151,† a photographic copy of the best Babylonian map that has yet been discovered, a map of the world, not newer than about 650 B.C., a very rude affair indeed, that could have required no

* Smith's *Dictionary of Greek and Roman Biography*, under *Eucleides*.

† Copied from Prof. Paul Haupt's paper in *Ueber Land und Meer*, Dec., 1895, vol. lxxiii., No. 15, p. 348.

instruments of precision beyond the blunt-pointed dividers with which the outside concentric circles, representing the ocean, were drawn on the clay tablet.

Prof. Haupt explains that the points or triangles projecting from the outer circles are marked as islands, and appear to have been originally seven in number. To the left of each island its distance is exactly given, and to the northeastern one is added: "Six hours the sun is not seen." The smaller circles indicate cities of the Euphrates region. The two long parallel curved lines from above downwards are for the Euphrates; and the long parallelogram crossing it is Babylon, on both banks.

FIG. 151.

Babylonian Map-Tablet, about ½ Full-size.

Plainly, no great cartographic skill is here displayed; and it is hard to believe that even rude angle-measuring surveying-instruments could at that time have been in use in that country.

First Surveying.—Undoubtedly, however, land was much earlier measured by rods or cords; and that must have been the beginning of land-surveying. Perhaps the earliest allusion to land-surveying in any language is where Homer, about 900 B.C.,* compares the zeal and vigor of the Greek and Trojan critical battle at the rampart near the ships to the eagerness of a contest between two men, measures in hand, over the boundary that

* *Iliad*, xii., 421–426.

is to divide land that had been held in common. He makes it very evident that the rude surveying of those days left much to mere opinion as to the equitable division of a piece of ground, and that there was nothing like an authoritative county surveyor at hand to settle the dispute. Closely rendered, the passage says:

> As two men over bounds will stiffly strive
> With rood in hand upon a common field,
> And in a narrow plot claim each his share:
> So battlements part these; but they, atop,
> Smite hard before each other's breast the targe
> Well-orbed of oxhide, or the buckler light.

II. Compass.

Chinese Invention.—The invention of the compass has been claimed for the very early Chinese; but von Moellendorff, an excellent authority, declares* that the wet compass has not been proved to exist in China before our 12th century; and that the dry compass was introduced there from Japan, and to Japan from Europe.

Marco Polo.—As for the introduction of the compass into Europe by Marco Polo, mentioned by Mr. Scott, it is not necessary to do more than quote a single sentence from Yule, the highest authority in regard to Polo. He says†: "Respecting the mariner's compass and gunpowder I shall say nothing, as no one now, I believe, imagines Marco to have had anything to do with their introduction."

First European Compasses.—The use of the compass, if really first invented in China, appears, then, to have quickly spread through Europe, according to the early history of the compass in Europe as given pretty thoroughly in *Nature*, by "K.,"‡ and by Wm. Chappell.§ Chappell shows that the earliest European mention of the compass is by Alexander Neckham, an English monk and writer of elegant Latin in the 12th century, who was born about 1150 and died in 1227. Neckham speaks of the compass in his treatise *De Utensilibus*, and yet more clearly, as a thing already in common use, in another treatise, *De Naturis Rerum*. He describes it, not as floating in water, but as turning

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* *Zeitschrift der Morgenlaendischen Gesellschaft*, 1881, vol. xxv., p. 76.

† *The Book of Ser Marco Polo*, vol. i., Introduction, p. clvi., 1871.

‡ Vol. xiii., Apr. 27, 1876, p. 523.

§ Vol. xiv., June 15, 1876, p. 147.

on a pivot without any special box for it. That seems to show that it was not introduced from China; and, rather, the floating form, soon after common in Europe, was perhaps first carried thence to China. The earliest previously known European mention of the magnetic needle was in the poem called the *Bible of Guiot de Provins*, composed in the 13th century, where a rude floating compass is clearly indicated. The *Encyclopœdia Britannica* also cites Cardinal Jacques de Vitry's *History*, written about 1218, as speaking of the magnetic needle as "most necessary for such as sail the sea." A little later, frequent allusions to it occur, and before the middle of the 13th century, as a generally well-known implement. Already, about 1597, Wm. Barlowe denounced "the lame tale" that Flavio Gioja of Amalfi about 1302 invented the compass as "of very slender probabilitie." But the tale persisted until the present century; and, against the claims of the French to the invention of the compass, based on the fleur-de-lis upon it, the answer is made that Gioja "decorated the north end of the needle with that flower in compliment to his own sovereign, who bore it in his arms, as being descended from the royal house of France."

Early Knowledge of Variation.—According to "K.," a Latin letter ascribed to Peter Adsiger, 1269, speaks plainly of the variation of the compass, or magnetic declination. The dip of the needle was, according to "K.," first discovered as early as 1576 by Robert Norman, a nautical-instrument maker at Wapping, near London; and in the early part of the next century the variation of the declination was clearly ascertained, and by Bond, a teacher of navigation in London, attributed to the motion of two magnetic poles of the earth.

Plotting with the Compass.—The ordinary and occasional extent of the diurnal changes of the declination seems hardly to be familiarly known to those geometers who imagine that it is exquisite nicety to plot compass-notes with the help of the very compass used in the field-work, instead of simply using a protractor. Aside from the delay required by the vibrating needle and the possible influence of the friction at the centerpin of a compass not in the very best condition, the daily change of the declination is very notable. The declination was found by Burt in July, 1839,* to change within seven hours and a half

* See his *Key to the Solar Compass*, 1858, p. 27.

sometimes as much as 20 minutes, sometimes only two minutes; but the average of his 18 consecutive days of three observations daily is 14 minutes of change in the same 7½ hours. A. Beyer,* as cited by Combes,† found the needle to vary 30 minutes between noon and midnight, June 4, 1736. I have myself seen a change of about 30 minutes in 14 hours, in Cape Breton. Plainly, if the plotting of a note should not happen to be at a moment when the variation was the same as it was at the time of making the field observation, the plotting would have an error that might be important. On the other hand, in using the simple protractor, there should be no occasion for notable error, leaving merely the original and necessarily inherent errors of the compass in the field, that more or less balance one another.

Hanging-Compass.—It is not a little surprising to learn from Messrs. Hungerford's and Johnson's contributions to the discussion that the hanging-compass has been found on the whole not only practicable, but the most convenient instrument for surveying tortuous, steep, narrow underground workings in Virginia. One would have thought that a compass on a sufficiently small tripod would be not only more satisfactory in result, but more expeditious in use, than apparatus that requires so much circumstance as driving in nails, stretching a cord, hanging up the compass and waiting for the cord vibrations to diminish enough to make it safe to loosen the needle. We have been accustomed to smile, perhaps too superciliously, at this old-world method, and to think its users, even the professors at Paris and Freiberg forty years ago, were one or two hundred years behind the times; with their *gradbogen*, too, and with their square compass (*boussole carrée*), with its telescope at one side and their consequent ingenious elaborate computations to obviate the difficulty of the eccentricity of the sight, instead of using simply a lop-sided target.

Supposed Gravitational Error.—Mr. Hoskold argues‡ that the compass is inexact because the plumb-line in India and elsewhere has been found to be affected by the gravitational attraction of neighboring mountain masses or of especially dense

* *Gründlicher Unterricht vom Bergbau nach Anleitung der Markscheidekunst.* Altenburg, 1785. † *Annales des Mines*, 1836, Troisième Série, vol. ix., p. 98.

‡ Page 222.

neighboring portions of the earth's crust; and that the probable effect was in advance estimated for the extreme case of the Himalayas as likely to be as much as almost half a minute, though it turned out after all to be "much smaller" than the estimate, and in some places quite reversed in direction. He infers that, as the needle hangs upon the top of a centerpin, it should be affected in the same way as the plumb-line. Even admitting that it were so, it is obvious that the very short length from the ends of the needle up to the level of its point of suspension, say a sixteenth of an inch, would make the arc through which the needle swings extremely short, in fact completely invisible, even if its angular amount were half a minute, and even if its direction were at right angles to the length of the needle.

Of course, as the needle is balanced upon the centerpin, one end would be attracted by the gravity of the mountain or dense mass of rock as much as the other end, so that there would be no effect in that way upon the indication of the needle. On one-half of the needle, however, there is a small bit of brass wire to counteract the dip that is different in different latitudes. That minute additional weight would be attracted towards the mountain or dense rocks; but even supposing that the very feeble or infinitesimal attraction is enough to overcome the at best slight friction at the centerpin, and resist the probably far stronger magnetic directive force of the earth (perhaps as much stronger as the weight of a plumb-bob would be compared to the sidewise pull), and that the attraction works at right angles to the longitudinal axis of the needle and to the highest computed amount of nearly half a minute, even Mr. Hoskold's vernier on the needle for reading quarter-minutes could scarcely in any single reading appreciate the difference caused.

As mountain masses like the Himalayas are extremely rare, and as their observed effect upon the plumb-line proved to be "much smaller" than half a minute, the error from gravitational attraction upon the needle in any ordinary survey would clearly be quite inappreciable, even if the needle were perfectly precise in its indications. When we consider the well-known fact that the needle for magnetic reasons is liable to vary two or three minutes in one hour, it is evident that in using the needle at all, the consideration of the at most altogether invisible and unmeasurable, and moreover wholly doubtful and certainly incalculable, gravitational effect would be like straining out the gnat while ready to swallow the camel. The same may be said, too, of Mr. Hoskold's other idea of undertaking to read the needle to a quarter of a minute with a vernier!

Merit of the Compass.—The merit of the needle is not the extreme precision of its indication in any single reading; but that it refers at each reading independently, within a very few minutes of arc, to an invariable meridian, so that any errors, whether inherent in the compass, or coming from insufficient care in reading or noting, do not, like the errors of vernier-plate running, swing all the subsequent courses of the survey around. The secular variation can be allowed for, and the diurnal changes, if not roughly corrected by the Coast Survey table,* still tend to balance one another. Indeed, the five-inch compass compares reasonably well for accuracy with excellent ordinary chaining, or even with the yet more exact telescopically read stadia-measurement, or with plotting mechanically on a scale of, say, 400 feet to an inch (not by latitudes and departures computed with five-place or larger logarithms). It is not an instrument capable of the utmost precision for geodetic purposes, for city surveying, for tunnel-driving and the like; but it is extremely useful for other much more numerous, in the aggregate far more extensive, and perhaps, on the whole, more important surveys, where the very nicest precision is unnecessary and would require extravagant expense.

III. Telescope.

Origin.—The common accounts of the origin of the telescope are mostly copied one from another, without the least attempt at any independent critical judgment. There is, however, an easily accessible, very thorough discussion in Dr. Robert Grant's *History of Physical Astronomy*, London, 1852; and a later discriminating one by Dr. David Gill, Astronomer Royal, Cape of Good Hope, in the *Encyclopædia Britannica*, 9th edition (1888), and a briefer notice in *Chambers' Encyclopædia* (1892).

The first discovery of the telescope has been variously attributed to Roger Bacon, before 1294, Giambattista della Porta,

* Given in Heller & Brightly's *Remarks on Surveying Instruments*, 1882, p. 13.

1561, Leonard Digges before 1570, three Dutchmen in 1608, and Galileo in 1609. A careful fresh revision of the evidence will make it clear that Bacon and Porta knew nothing of the telescope, that Digges really did invent and use a reflecting telescope, but that Lippershey, one of the three Dutchmen, was the first to make a refracting telescope, and that Galileo reinvented it.

Roger Bacon.—Two citations in particular from Friar Roger Bacon, "the Admirable Doctor," who died about 1294, have been claimed to show clearly that he had at least a theoretical knowledge of the telescope; but they seem really to apply at best merely to single lenses, and nothing that he says necessarily indicates any combination of lenses.

All the passages have been carefully examined by a very competent critic, Robert Smith, LL.D., in his *Compleat System of Opticks*, Cambridge, 1738. He says that Bacon, in his *Opus Majus*, having described several canons of refraction through a plane and a spherical surface, applies them to the explanation of several appearances (doubtless familiar from the earliest times); such as, why an oar partly in the water appears crooked, and why a coin in the bottom of a basin, hidden from the eye by the side of the basin, becomes visible on pouring in water; and that Bacon then adds a passage which Smith cites in full with its diagrams, essentially to the following effect:

"If a man should look at letters or any minute objects through the medium of a crystal, or glass, or other transparent body placed upon the letters; and it should be the segment of a sphere of which the convexity is towards the eye, and the eye should be in the air, he will see the letters better and they will appear larger to him; . . . and therefore this instrument is useful to old men and to those that have weak eyes. . . . But if it be the larger segment of a sphere, or but half of one, then, by the sixth canon, there will be an enlargement of the visual angle and an enlargement of the image, but nearness will be lacking, because the place of the image is beyond the object. And therefore this instrument is not so effective (*non ita valet*) as the lesser segment of a sphere."

It is noticeable that the segment rests immediately, flatwise, upon the letters, and there is nothing said of a refraction at both the surfaces. Smith translates "*non ita valet*" by "not so powerful in magnifying," and argues that Bacon showed thereby his ignorance of the real effect of the lens, and consequently never could actually have used one; and adds:

"As to his theory and applications abovementioned, they are all taken from *Alhazen*, whom he frequently mentions upon other occasions. *Alhazen* is reckoned to have lived about the year of our Lord 1100 [born at Bassora, and died at Cairo about 1038]. Among his experiments made to confirm his theorems, he expressly mentions that if an object be applied close to the base of a larger segment of a sphere of glass, it will appear magnified; which, as I observed, was fitter for Bacon's purpose than his own lesser segment. He also treats about the appearance of an object through a globe; and says he is the first that found out the refraction of rays into the eye."

The magnifying effect of a glass globe on near objects could, however, scarcely have failed to be noticed long before Alhazen. Indeed, a passage in Aristophanes (*Clouds*, Act II., Scene 1) clearly indicates a common knowledge of burning-glass lenses among the ancient Greeks, 423 B.C., 150 years before the time of Archimedes' mythical exploit of ship-burning with a glass.

But when Bacon uses the words "*non ita valet*," he has just distinctly acknowledged the greater size of the image, and with those words he explains that, after all, owing to the greater distance of the image, the instrument is less effective, meaning apparently not in magnifying power, but in definition, and therefore less useful in the general result. The increased thickness of the glass would add to the spherical and chromatic aberrations, and with the impure glass of the 12th century (when "uncolored" glass was greenish, with many bubbles), the greater thickness would to some extent bedim the view; and the obscure result might conceivably have been attributed to the greater distance of the image. It looks, then, rather as if Bacon did really try such lenses, large segments of glass spheres of some size.

The practice of laying such a lens flatwise immediately upon letters, for the convenience of old or weaksighted men, may well have been the first step towards the invention of spectacles, a discovery destined to be of such immense importance to elderly people, and almost equivalent to a prolongation of their lives by many years. Indeed, Smith, although regarding Bacon's words as mere theoretic speculations, and incorrect ones, considers, possibly with some patriotic feeling, that they gave the first hint towards the invention; and in corroboration makes certain citations in other quarters, showing that spectacle-glasses were invented between 1285 and 1300. For instance, Friar Jordan de Rivalto, who died at Pisa in 1311, is said to have written, in a book of sermons in 1305, that it was not twenty years since the art of making spectacles was found out;

and an Italian manuscript of 1299 in Redi's library says they had lately been invented for the convenience of poor old men with failing power to read. Friar Alexander de Spina, who died at his native city of Pisa in 1313, is said by a Latin chronicle there to have first published spectacle-glasses between 1280 and 1311, not as his own invention, but the discovery of somebody else who would not make them public. Smith not unreasonably conjectures that other "close man" to have been a friar; "and that these monkish men, and Jordan amongst the rest, had this invention whispered amongst themselves, before it was publick; and that they all had the first hint thereof from our country-man *Frier* Roger Bacon."

The passage in the *Opus Majus* specially used to support the claim that Roger Bacon combined lenses into a telescope says:

"We can give such figures to transparent bodies, and dispose them in such order with respect to the eye and the object that the rays shall be refracted and bent towards any place we please. So that we shall see the object near at hand or under any angle we please. And thus from an incredible distance we may read the smallest letters, and may number the smallest particles of dust and sand, by reason of the greatness of the angle under which we see them."

Smith argues that the passage indicates that Bacon

"did not think of performing these problems by a single portable instrument like a telescope, but by fixing up several glasses in proper places at large intervals from one another [much as he had in the foregoing chapter explained that mirrors might be arranged so as to multiply a single soldier into an army in appearance]; which would certainly prove ineffectual. . . . Mr. *Molyneux* says it is manifest he knew what a concave and a convex glass was. But this does not appear from the passage there cited, nor from any other that I have yet met with. . . . In short, the author speaks only hypothetically, saying that glasses may be figured, and objects may be magnified so and so; but never asserts one single trial or observation upon the sun or moon (or anything else) though he mentions them both. On the other hand he conceives some effects of telescopes that cannot possibly be performed by them."

It seems that the passage just quoted from Bacon might refer merely to the possible or conceivable change of direction in rays by means of a prism, or perhaps of a combination of prisms (though the words do not clearly indicate that any combination is meant), and to the enlargement possible by means of the segment of a sphere, or rude lens, whose use had been already described, and whose effect, then so novel, may naturally have been set forth in language that would now seem exaggerated. The words do not necessarily imply a combination of more than one glass at a time. There is, then, no sufficient reason to believe that Roger Bacon ever used a telescope, or even any nearer approach to a spectacle-lens than a very thick spherical segment of impure glass applied close to the letters read.

Porta.—A citation from Giambattista della Porta's *Magia Naturalis*, printed in 1558–89, in the XVIIth Book, apparently published in 1561, contains expressions that have been taken to prove that he used a telescope; but it has also been said that grave doubts have been thrown upon Porta's knowledge and originality by such high authorities as Kepler and Poggendorff. All Porta's claims to the invention of the telescope have, to be sure, their foundation in what Kepler says and quotes of Porta in a charming, generously appreciative letter to Galileo, published in 1610, and written after receiving in Galileo's *Nuncius Sidereus* the account of the re-invention of the telescope and the first astounding telescopic astronomical discoveries, the four moons of Jupiter, the diversified appearance of the moon's surface, the distinctly orbicular shape of the planets, the tenfold increase of visible stars, the resolution of nebulæ in the milky way into stars, and the like.

The common short notices give so imperfect and inconclusive and apparently so inaccurate an account of Porta's statements and of Kepler's comments on them, and even Kepler himself so seems to misinterpret Porta, and the original is so difficultly accessible to most of our members, that it is probably worth while to give here the whole passage from Kepler's letter; the more so, as it shows in a striking light how far even the ablest astronomers and physicists of those times had been from realizing the possibility of anything like a telescope, simple and natural as such an application of the well-known laws of optics seems nowadays. Kepler appears to say, in pretty literal translation (and for greater certainty the more essential part of the original Latin is given below):*

"Incredible to many seems the undertaking of so effective a spyglass; but impossible or new by no means is it; nor did it lately first proceed from the Dutch,

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* *Opere di Galileo*, Florence, 1892, vol. iii., p. 108:

"Incredibile multis videtur epichirema tam efficacis perspicilli, at impossibile but already a number of years ago it was published by Io. Baptista Porta in Natural Magic, Book XVII, Chap. X, On the Properties of the Crystal Lens. And that it may appear that not even the arrangement of a concave and a convex lens is new, come, let us bring forward the words of Porta. He writes thus:

"*With the eye placed in the center, behind the lens, whatever was remote you will see so near that you would seem to touch it with the hand, or that you will recognize friends that are very distant: letters of an epistle placed at a due distance you will see so large that you can clearly read: if you incline the lens, so as to look at the epistle obliquely, you will see the letters sufficiently large to read them even at a distance of twenty paces:* and if you know how to multiply the lenses, I doubt not but that you would see the smallest letter at a hundred paces, *so that from one into another the characters may be rendered larger. Let defective sight use glasses according to the quality of the sight. Whoever should understand how to make that adaptation rightly will get a secret that is not small. Concave lenses make whatever is distant to be seen very clearly, convex ones what is near, wherefore you can enjoy them according to their adaptation to your vision. With a concave lens you see small things at a distance, but distinctly; with a convex one, you see near things larger, but indistinctly:* if you know how to arrange each rightly, *you will see both distant and near things larger and clearly. Not a little aid have I given to many friends who saw both distant things dimly and near ones indistinctly, so that they saw everything most perfectly.* So much from Chap. X.

"In Chapter XI he makes a new title on glasses with which beyond all thought any one can see very far; but he so involves the demonstration (which he even admits), that you would not know what he says, whether he is speaking of transparent lenses, as hitherto, or indeed adds an opaque smooth mirror: of which even I myself have one in mind, which shows remote things, with no difference of distance, in very great size, and therefore near and moreover proportionally enlarged, with as much clearness as can be hoped for from a mirror (which necessarily gives a dim color).

"When to this part of Porta's book I saw the complaint prefixed at the beginning of Chapter X, that *of concave and convex lenses and glasses, so greatly necessary for human uses, no one had yet brought forward the effect or the explanations,* I undertook that work six years ago in the Optical part of my Astronomy, so as to set forth with a clear geometrical demonstration what occurs in simple lenses.

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aut novum nequaquam est; nec nuper a Belgis prodiit, sed tot iam annis antea proditum a Io. Baptista Porta, Magiae naturalis libro XVII, Cap. X, De Crystallinae lentis affectibus. Utque appareat, ne compositionem quidem cavae et convexae lentis esse novam, age verba Portae producamus. Sic ille:

"*Posito oculo in centro, retro lentem, quae remota fuerint adeo propinqua videbis, ut quasi manu ea tangere videaris, ut valde remotos cognoscas amicos: literas epistolae in debita distantia collocatae, adeo magnas videbis, ut perspicere legas: si lentem inclinabis ut per obliquum epistolam inspicias, literas satis maiusculas videbis, ut etiam per viginti passus remotas legas:* et si lentes multiplicare noveris, non vereor quin per centum passus minimam literam conspiceris, *ut ex una in alteram maiores reddantur characteres. Debilis visus, ex visus qualitate specillis utatur. Qui id recte sciverit accommodare, non parvum nanciscetur secretum. Concavae lentes, quae longe sunt clarissime cernere faciunt, convexa propinqua, unde ex visus commoditate his frui poteris. Concavo, longe parva vides, sed perspicua; convexo, propinqua maiora, sed turbida:* si utrumque recte componere noveris, *et longinqua et proxima maiora et clara videbis. Non parum multis amicis auxilii praestitimus, qui et longinqua obsoleta, proxima turbida conspiciebant, ut omnia perfectissimo contuerentur.* Haec Capite X." Etc.

"There are to be seen there in Chapter V, where I demonstrate what pertains to the manner of seeing, on fol. 202, representations of a concave and convex lens united in a diagram, plainly in the same way that they are customarily joined together to-day in the common tubes [telescopes]. If the reading of Porta's Magic did not give occasion to this contrivance, or if some Dutchman with instruction from Porta himself did not, when the injunctions of silence had been dissolved by the death of Porta, multiply the manufactured instrument to numerous specimens, in order to make merchandise for sale, certainly this very figure at folio 202 of my book could suggest the construction to a curious reader, especially if he joined the reading of my demonstrations with Porta's text.

"Still, it is not incredible that clever gravers among an industrious people, who use lenses for looking at the minute details of engraving, should by chance, too, fall upon this device, in variously associating convex lenses with concave, in order to select the combination that best suits their eyes.

"I do not say that to lessen the praise of the inventor, whoever he was. I know how great the difference is between theoretical conjectures and ocular experience; between Ptolemy's discussion about the Antipodes and Columbus's discovery of the new world: so, too, between the commonly circulated two-lensed tubes and, Galileo, your contrivance, with which you have bored through the very sky: but I am striving here to create for the incredulous a belief in your instrument.

"Confession should be made, that at the time I attacked the Optics, when the Emperor repeatedly asked me about the above-written artifices of Porta's, I derogated faith in them as much as possible. Nor is it wonderful: for he manifestly mixes incredible things with probable ones; and the title of Chapter XI, with the words *To look forth extremely far, beyond all thought*, seemed to involve an optical absurdity: as if vision were made by emission, and lenses sharpened the rays of the eye, so that they could penetrate more remotely than if no lenses were used: or if, as Porta acknowledges, vision were made by receiving; as if then the glasses conciliated or increased the light for seeing things: while this rather was true, those things that did not send any light far enough to reach our eyes and so be seen would never be detected by any glass.

"Besides, I not only believed that the air was thick and of a blue color, so as at a distance to cover up and confuse the minute parts of visible things; and, as that was certain, I saw it was vain to expect from a spyglass that it should strip off this substance of the intermediate air from visible objects; but also, in regard to the celestial essence itself, I suspected it was such a thing that it could hinder us, if we should very greatly increase the body of the moon into something immense, from being able so well to recognize the small particles of the moon in their purity apart from the extremely deep celestial matter.

"For those reasons, then, I abstained from undertaking any contrivance, and besides there were other things that hindered.

"But now, as you deserve, most accomplished Galileo, I commend your activity; for you, setting aside all mistrust, have applied yourself to direct ocular experiments; and now that the Sun of truth has by means of your discoveries risen, you have dispelled all those hobgoblins of waverings along with the night their mother; and have shown by deeds what could be done."

It may be overboldness to undertake to question Kepler's interpretation of Porta's words; but it does clearly appear that he misunderstood Porta's application of the word *componere.*

Even Homer sometimes nods. Porta is speaking throughout only of the use of simple lenses, or spectacle-glasses, concave and convex, and their use for near and far sight, with perhaps some exaggeration; and when he says "*si utrumque recte componere noveris*," he means: if you know how to put together, or join, or arrange each kind, not (as Kepler imagines) with the other kind, but with its appropriate defect of vision; a suitable concave lens with short sight and a proper convex lens with far sight. That understanding is corroborated by what he immediately goes on to say, of aiding many nearsighted and far-sighted friends, so that they saw both distant and near things distinctly. Obviously, each friend could have had only one of the two defects of sight, nearsightedness or farsightedness, and so must have used only one kind of lens for it. Porta at first certainly speaks of the use of a single lens, and when he mentions, perhaps only hypothetically, the greater effect from multiplying lenses, he seems to mean increasing the number of lenses of one kind, with power thereby enhanced. All the rest appears to be about single lenses or spectacle-glasses.

Kepler's citations from Porta, however, apparently convinced both the friends and opponents of Galileo at that time that Porta, and not the Dutchman, had been the first inventor of the telescope; and the accounts of Porta down to the present day seem to be based simply upon Kepler. Even Grant and more clearly the *Encyclopædia Britannica* quote Porta as speaking distinctly of joining together concave and convex glasses; whereas his words, as we have seen, do not by any means justify that interpretation, though Kepler may be excusable for so misunderstanding them at the subsequent first announcement of the refracting telescope.

That Porta was not incapable of exaggeration is now evident from a citation that Franciscus Sitius, a contemptuous opponent of Galileo, makes from Porta's book, arguing the obvious absurdity of the idea that such a man as Galileo should discover what the great Ptolemy with equal opportunity had not seen. The passage occurs in Sitius's essay printed with Galileo's works, Florence edition, 1892, p. 238. Porta there tells how Ptolemy had a spyglass that enabled him on the Pharos tower at Alexandria to see a ship at sea 500 stadia off (about 60 miles —not 600, as Smith has it). The curvature of the earth's surface would alone require the tower to be about 2000 feet high to see a ship sixty miles off. Hence it is equally plain that not only were the inventors of the telescope forestalled by nearly 2000 years, but Eiffel himself was immensely outdone.

Furthermore, it is now perfectly plain from the European experience at the time of the Dutch invention, scarcely fifty years later than Porta, that a refracting telescope used by many friends, and evidently made no secret, would not have escaped rapid transmission through Europe. Beyond question, then, Porta knew absolutely nothing of the telescope.

Digges.—The next supposed, and really much more circumstantial mention of the telescope is in the book published in 1571 under the title: *A Geometrical Practise named Pantometria . . . framed by* Leonard Digges *Gentleman, lately finished by Thomas Digges his sonne.* There is a copy of the book in the Philadelphia Library. The book is 7½ inches by 5½ and ¾ inch thick besides the leather covers. It is unpaged, and printed mostly in black letter, with interspersed italics and letters like our modern so-called antique letters. There are a number of illustrations. At the end of the volume the son speaks of himself as in his twenty-fifth year. The father is supposed to have died about 1570. An epistle dedicating the work to "Sir Nicolas Bacon, Knight, Lord keper of the great seale of England," speaks of the father's "untimely death" and of the book as one of "certaine volumes that he in his youthe time long sithens had compiled in the English tongue." The preface among other things says:

"Archimedes also (as some suppose) with a glasse framed by revolution of a section Parabolicall, fired the Romane nauie in the sea comming to the siege of *Syracusa.* But to leave these celestiall causes and things doone of antiquitie long ago, my father by his continual paynfull practises, assisted with demonstrations *Mathematicall* was able, and sundrie times hath by proportionall Glasses duely situate in conuenient angles, not only discouered things farre off, read letters, numbered peeces of money with the very coyne and superscription thereof, cast by some of his freends of purpose vppon Downes in open fieldes, but also seuen myles of declared what hath been doon at that instante in priuate places: He hath also sundrie times by the Sunne beames fired Powder, and dischargde Ordinance half a mile and more distante, whiche things I am the boulder to reporte, for that there are yet liuing diuerse (of these his doings) *Oculati testes*, and many other matters farre more straunge and rare which I omitte as impertinente to this place."

Evidently Archimedes's "glasse" was a mirror; and the word "glasse" is used in the same way in the 21st Chapter, where it is described

"How ye may most pleasantly and exactly with a playne glasse from an highe cliffe, measure the distance of any shippe or shippes on the sea as followeth. The best kinde of glasse for this purpose is of steele finely pullished, so that the Superficies thereof be smoothe, neyther convexe nor concave, but flatte and playne as may be possible," etc.

At the end of the same 21st Chapter is the principal account of what has been taken to be the telescope. The whole passage is as follows, and in it the same use of the word "glasse" for mirror, and of the word "playne" in distinction from convex and concave is to be observed:

"Thus muche I thought good to open concerning the effects of a playne Glasse, very pleasant to practise, yea most exactlye seruing for the description of a playne champion countrey. But marveylouse are the conclusions that may be perfourmed by glasses concave and convex of circulare and parabolicall fourmes, vsing for multiplication of beames sometime the ayde of glasses transparent, whiche by fraction should vnite or dissipate the images or figures presented by the reflection of other. By these kinde of glasses or rather frames of them, placed in due angles, ye may not onely set out the proportion of an whole region, yea represent before your eye the liuely ymage of euery towne, village, &c., and that in as little or great space or place as ye will prescribe, but also augment and dilate any parcell thereof, so that whereas at the firste apparance an whole towne shall present it selfe so small and compacte together that ye shall not discerne any difference of streates, ye may by applycation of glasses in due proportion cause any peculiare house, or roume thereof dilate and shew it self in as ample fourme as the whole towne firste appeared, so that ye shall discerne any trifle, or reade any letter lying there open, especially if the sonne beames may come vnto it, as playnly as if you wer corporally present, although it be distante from you as farre as eye can discrye: But of these conclusions I minde not here more to intreate, hauing at large in a volume by it selfe opened the miraculous effectes of perspectiue glasses. And that not onely in matters of discouerie, but also by the sunne beames to fire, pouder, or any other combustible matter, whiche Archimedes is recorded to haue done at *Syracusa* in Sicilie, when the Romane Nauy approched that Towne. Some haue fondly surmised he did it with a portion of a section Parabolical artificially made to reflect and vnite the sonne beames a great distance of, and for the construction of this glasse take great paynes with highe curiositie to write large and many intricate demonstrations, but it is a meere fansie and vtterly impossible, with any one glasse whatsoeuer it be to fire any thing, onely one thousand pase off, no though it were a 100 foote over, marry true it is, the Parabola for his small distance, most perfectly doth vnite beames, and most vehemently burneth of all other reflecting glasses. But how by application of mo glasses to extende this vnitie or concourse of beames in his full force, yea to augment and multiply the same, that the farder it is caried the more violently it shall pearse and burne. *Hoc opus hic labor est*, wherein God sparing lyfe, and the tyme with opportunitie seruing, I minde to imparte with my countrey men some such secretes, as hath I suppose in this our age ben revealed to very fewe, no lesse seruing for the securitie and defence of our naturall countrey, than surely to be mervailed at of straungers."

It is evident that he writes of a reflecting telescope, and not of a refracting one. The "ayde of glasses transparent" there-with is mentioned as only "sometime useful," apparently for the eye-piece, or, as he says, for "multiplication of beames," because, merely, the "fraction should unite or dissipate the images or figures presented by the reflection of the other" glass, or mirror—that is, cause the rays to converge or diverge.

One difficulty in believing that a telescope existed in England before 1571, nearly forty years before the first Dutch telescope, has been to account for its not becoming in all that time widely known and used, whereas the fame and use of the Dutch telescopes ran through all Europe within a few months. The reason may well be that Digges's telescope was a reflecting one, comparatively difficult and costly of construction. Even in Friar Bacon's time, in the depth of the dark ages, a refracting telescope really in use could hardly fail to have been copied, as the spectacle-glasses were, and to have spread through Europe. The last sentence of Digges's account seems also to intimate that the value of even a reflecting telescope for military purposes was fully appreciated, or perhaps over-estimated, and that consequently its use had "ben revealed to very fewe, no lesse seruing for the securitie and defence of our naturall countrey, than surely to be mervailed at of straungers." Digges appears to have had the friendship of very high officials, and the dedicatory epistle to Queen Elizabeth's celebrated Lord Keeper of the Great Seal, Sir Nicholas Bacon, father of the famous Lord Bacon, mentions "the great fauour your lordship bare my father in his lifetime and the conference it pleased your honor to vse with him." It is not impossible that the government may have discouraged the general promulgation of the method of constructing the telescope; just as the first idea in regard to the Dutch telescope was to keep it secret for military uses. At any rate, the younger Digges in his several later books never published the full description of the telescope, according to what he says of "having at large in a volume by it selfe opened the miraculous effectes of perspectiue glasses." The word "perspective" here does not appear to imply transparency, but to be used rather in place of "prospective" or "optical."

In his book called *Stratioticos*, published in 1579, is said to occur, at p. 359, the statement that his father, "among other curious practices had a method of discovering by perspective glasses set at due angles all objects pretty far distant that the sun shone upon, which lay in the country round about," and that this was by the help of a manuscript book of Roger Bacon of Oxford. The repeated mention of the "due angles" at which the glasses must be set seems to indicate the necessary observance of the angles of incidence and reflection of mirrors, and to be quite inapplicable to the description of the refracting telescope.

We may then safely conclude that Leonard Digges did really use a reflecting telescope; but that the refracting telescope was not yet invented.

Lippershey.—The next telescope was the Dutch refracting telescope of 1608. Its origin was fully set forth so long ago as 1831, in Vol. I. of the *Journal of the Royal Institution*, by Dr. G. Moll, of Utrecht, in his account of the already deceased Professor Van Swinden's researches into the government archives at the Hague. They fully established the fact that the spectacle maker, Hans Lippershey, of Middelburg, was the maker of the first refracting telescope, previous to Oct. 2, 1608 (in the midst of the 80 years' war); for the government on that day considered his petition for a patent on the instrument, or an annual pension, in case the government should require the exclusive use of the invention. Less accurate investigations in 1655 gave the credit to another spectacle-maker named Zacharias Jansen, in 1610; who, according to those investigations, would appear to have invented the compound microscope about 1590; though Fontana claims to have invented it in 1618, and Huygens's investigations make it probable that it was first invented by Drebel, a Dutchman, in London, about 1620. Jacob Adrianzoon, a learned mathematician, also called James Metius (called Metius from a student-nickname that clung to a brother of his through life), applied to the government on October 17, 1608, for a patent on a telescope of his invention as powerful as the one lately offered to the government by a spectacle-maker of Middelburg—that is, evidently by Lippershey. Adrianzoon claimed to have made his discovery independently, partly by theory and partly by accident, within the previous two years. He was not encouraged by the government, and, apparently in disgust, he never made his method public. The government, oddly enough, was not at first fully appreciative of Lippershey's wonderful, epoch-making discovery, or at least not satisfied; and, on October 6, 1608, required of him a spy-glass made of rock-crystal that could be used with both eyes, at the price of 300 florins, instead of the 1000 florins he had at first demanded; and exacted a promise from him to make no such instruments without the consent of the States. He accordingly supplied them with such a binocular on the 15th of the next December; and they ordered two more like it, and paid him 900 florins, or about $360, for the three (not for one, as some say); but they refused the patent, because the invention had already become known to many.

Lippershey's first discovery happened by accident, as the common story goes; that is, he had the intelligence to perceive the bearings of an accidental observation. It is said that he chanced to look through two spectacle lenses, one in each hand, towards a neighboring steeple, and was astonished to find how near and distinct the weathercock became. It has been urged against the story that it also mentions that the weathercock became inverted, as it would be if seen through two convex lenses; whereas the Dutch telescope was not inverting, but was made with a convex and a concave lens. It is, however, more probable that the two lenses in his hands should be alike, and not in the least improbable that they should both be convex. Indeed, the effect of two concave lenses would scarcely be particularly noticeable, as being merely of double the power and suited to doubly nearsighted eyes. It is the remarkable difference in the effect of two convex lenses at an accidentally suitable distance apart that would have been especially striking. He evidently was a very intelligent, ingenious man, and doubtless was as ready, either by theoretical or by experimental investigations, to obviate the inconvenience of the inversion as he later was to prepare a binocular for the exacting legislators. The inverting telescope accordingly remained in abeyance until Kepler suggested its advantages in 1611, and Scheiner constructed one in 1617, and published it in 1630.

Lippershey's first telescope was, on the 2d of October, 1608, in the possession of Maurice, Prince of Orange and Count of Nassau, the head of the Dutch government. At first it was thought to keep the invention secret for military purposes; but it soon got abroad, and within a few months its fame (mainly as a curious toy, to be sure) had gone all over Europe.

Galileo.—The account of Galileo's reinvention of the telescope, as related by Moll from Galileo's own writings, and essentially repeated by Grant and other writers, shows they had never seen one or two letters of Galileo that were not published until 1847, and that throw a little additional light on the matter.

The date of the reinvention has never been exactly fixed, but was long taken to be in May, or even in April, 1609; owing to Galileo's first public mention of it, in his *Nuncius Sidereus*, published early in March, 1610, as having occurred "nearly ten months ago" (*mensibus abhinc decem fere*). In his rough draft he had written "eight months," as may be seen in the *fac simile* in the recent, yet unfinished, Florentine edition of his works (1892, vol. iii.); and the change was perhaps due to delay in printing, or to imperfect recollection, or to a desire to use a round number, or to a combination of more than one of these causes. But in his letter of August 29, 1609, to B. Landucci, first published in the Florentine edition of Galileo's works, of 1847, vol. vi., p. 75, he gives the time as "about two months ago" (*sono circa a due mesi*); showing it clearly to be not earlier than June, 1609.

That letter and the *Nuncius Sidereus* and Galileo's *Il Saggiatore*, published in 1623, relate the circumstances in a sufficiently concordant manner, each account giving some points omitted by the others. He says, then, that about June, 1609, while he was professor of mathematics at Padua, but on a visit to Venice, rumors came that a spyglass made by a Dutchman had been presented to Count Maurice which made very distant things seem very near, so that a man two miles off could be distinctly seen; "and nothing more was added" (*nè più fu aggiunto*). The rumors were believed by some, and not by others; but in a few days were confirmed by a letter to Galileo from a French noble, James Badovere, at Paris. On Galileo's return from Venice to Padua these rumors set him to trying to think out the method that could accomplish such results. With his knowledge of optics, feeling sure it could not be with a single lens, nor with two similar lenses, he that same night concluded it must be with a convex and a concave lens. The next day he took a piece of leaden pipe and put two such lenses into it and found he had a magnifying power of three times linear. The same day, he sent word of his success to his friends at Venice, with whom he had been discussing the rumors the day before. He then set to work upon another more perfect telescope, with a magnifying power of nine times linear; and six days later, in compliance with the government's request, he took it to Venice, where it was seen with wonder by the whole senate and all the principal gentlemen of the republic for more than a month together, much to his own fatigue. They climbed up eagerly, even old men, more than once to the top of the highest towers of the city, and descried vessels more than two hours before under full sail they became visible to the naked eye. At length, by the advice of one of his most affectionate patrons, and seeing how useful a thing the telescope would be on sea and land, he freely made a present of it to the Doge in full assembly, on the 25th of August, 1609. The telescope was received with such admiration, that Galileo's professorship was made an appointment for life, and his yearly salary nearly doubled, increased to 1000 florins (about $900), three times what any previous incumbent had received. This warm appreciation of the merits of his discovery among his numerous Venetian friends is of itself full confirmation of his otherwise undoubted statement, that the rumors of the Dutch telescope had been a very insufficient guide to the method of its construction. In his *Il Saggiatore* he argues against the detractions of one of his opponents that, although he claims no great credit for the discovery, yet it is more meritorious to work out by reasoning the method of attaining a result known to be possible, than to hit upon the method and result by accident. To be sure, he might not have thought of making a telescope, had it not been for the rumors of the Dutch one, but merely on the suggestion of those rumored results he worked out the method with nobody's help. He deprecates his opponent's attempt to take away the little merit there might be in his performance.

He made more and more powerful telescopes, up to a magnifying power of not more than thirty-two or thirty-three times linear, about the limit for telescopes of the Galilean kind without achromatic correction, and about a yard in length. But his chief merit was the immediate application of the telescope to astronomical discoveries that startled the world, especially theologians.

IMPROVEMENTS.

Micrometer and Cross-Hairs.—With the Keplerian telescope first came the possibility of the micrometer, invented by Gascoigne perhaps as early as 1638, when he was only about eighteen years old; and it was seen by Crabtree in 1639, as mentioned in a letter of his to Horrocks.* Flamsteed's *Historia Cœlestis*, Vol. I., records the mutual distances of the Pleiades as given by Gascoigne to seconds in a letter of 22 May, 1639, to Crabtree, distances apparently measured with the micrometer. Twenty years later it was reinvented on the Continent. The micrometer had two straight edges of metal that were by a screw made to approach each other at the focus of the telescope. Hooke suggested using human hairs instead of the metallic edges. Silver wires and silk fibers were used in the early continental micrometers; and Mr. Brough points out that a century later lines on glass or mica were used at the focus. Spider-webs were not applied until David Rittenhouse's invention in 1785, unless Mr. Brough can substantiate his date of 1775.† For in November, 1785, a letter from Rittenhouse was read before the American Philosophical Society, with the following postscript (*A. P. S. Trans.*, 1786, Old Series, Vol. II., p. 183):

"P. S. The great improvement of object glasses by Dolland [*sic*] has enabled us to apply eye-glasses of so short a focus, that it is difficult to find any substance proper for the cross-hairs of fixed instruments. For some years past I have used a single filament of silk, without knowing that the same was made use of by the European astronomers, as I have lately found it is by Mr. Hirschell [*sic*]. But this substance, though far better than wires or hairs of any kind, is still much too coarse for some observations. A single filament of silk will totally obscure a small star, and that for several seconds of time, if the star be near the pole. I have lately with no small difficulty placed the thread of a spider in some of my instruments; it has a beautiful effect; it is not one-tenth of the size of the thread of the silkworm, and is rounder and more evenly of a thickness. I have hitherto found no inconvenience from the use of it, and believe it will be lasting, it being more than four months since I first put it in my transit telescope, and it continues fully extended and free from knobs or particles of dust."

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* Cited by Grant (p. 452) from Sherburne's translation of the *Sphere of Manilius*, 1675, p. 92.

† Page 70.

This distinct statement seems to put at rest Mr. Scott's assertion,* apparently taken from the *Encyclopædia Britannica* (under *Micrometer*), that Troughton was the first to put spider-webs to practical use, on Rittenhouse's suggestion. The *Encyclopædia* also says that they were first suggested, though not used, by Prof. Fontana, of Florence, in 1755.

Rittenhouse's First Telescope.—Mr. Scott adds that Rittenhouse at the time of his invention was "constructing the first American telescope." A diligent search through several biographies and notices of Rittenhouse at Philadelphia, his home, and through papers in the *Transactions of the American Philosophical Society*, Vols. I. and II., has failed to be rewarded by the discovery of the least allusion to any such priority of construction by him; though already at the time of the transit of Venus in 1769 he had shown himself not only a learned theorist but "mechanic enough to make with his own hands an equal altitude instrument, a transit telescope and a timepiece." He appears to have made his own first telescope about 1756, when he was twenty-four years old.

Platinum Cross-Wires.—In 1871 Messrs. Heller & Brightly, of Philadelphia, introduced and published the use of platinum cross-wires $\frac{1}{1000}$ of an inch in thickness, or as thin as ordinary spiders' webs, in the telescopes of engineering transits. The platinum wires obviate the sagging which dampness causes in spiders' webs; and, not being transparent, can easily be seen when the sight is towards a light, say the sun, the north star, or a lamp. (See the Report of the Franklin Institute Committee, December 18, 1871.)

Telescopic Sights.—The possibility of using a telescope for ascertaining with precision the direction of sight, and consequently the application of telescopes to graduated instruments, depend, of course, on the use of two convex lenses, the Keplerian arrangement; for with the Galilean method there is no means of marking a definite and invariable optical axis of the telescope. Here, too, the young Gascoigne, who died at Marston Moor, 1644, in his twenty-fourth year, was the leader, and, already by 1640, he used for the purpose a hair or thread at the focus. It was even claimed in 1675 that he had been the

* Page 20.

first to use a telescope of two convex lenses. At any rate, he was evidently the first to use telescopic sights.

Reflecting Telescope.—Keplerian telescopes, with two convex lenses, were used, then, for astronomical purposes; and were made of enormous length by Huygens, Cassini and others, even up to 300 feet long, and without tubes, and called therefore aerial telescopes. But the spherical aberration, already understood, and especially the chromatic aberration, then unknown, prevented satisfactory definition; and in 1663 James Gregory proposed the reflecting telescope, since called by his name, and was the first to explain completely its construction, though the idea had long been known in a general way. Newton, after his discovering the reason of chromatic aberration, made the first reflecting telescope, except, as we now have reason to believe, Digges's of a hundred years before. Newton made his invention public in 1671.

Achromatic Lens.—Achromatic lenses were first made, it seems, in 1733 by Chester Moor Hall, an English lawyer and mathematician, but he was in independent circumstances and took no special pains to publish his invention or get a patent; and in 1758 John Dollond, of London, made public his successful construction of an achromatic lens, and he obtained a patent on it. The patent was legally maintained notwithstanding the earlier invention by Hall, whose neglect expressly to publish it was severely animadverted upon by the judge.

The difficulty of making satisfactory flint glass was still an obstacle to the construction of large astronomical achromatic lenses, until Guinand, a humble Swiss watchmaker, after seven years of experiments succeeded in 1790 in producing by secret methods large masses of flint glass free from striæ. Fraunhofer induced him to remove with the secret to Munich in 1805. Curiously enough, throughout the world, producers of large disks of glass trace their success to information obtained more or less directly from Guinand.

Dr. Blair, whose success Mr. Scott, on the authority of the Rev. Dr. Dick, cites with approval,* contrived (*Edin. Trans.*, Vol. III., p. 53) a partly fluid achromatic object glass, with hydrochloric acid filling the space between the convex sur-

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* Page 19.

faces of a meniscus and a plano-convex lens; but, as pointed out in the *Encyclopædia Britannica* (under *Telescope*, p. 143), such combinations are practically useless, not only from unavoidable leakage, but also because in fluid lenses changes of temperature set up currents equivalent in effect to want of homogeneity in the flint lens.

Kellner Lens in Erecting Telescopes.—In 1873 the Kellner achromatic compound lens eye-piece was, by means of two suitable additional lenses, first made applicable by Heller & Brightly to the erecting telescopes that American engineers commonly prefer. The result is excellent definition from the completeness of the achromatism, greatly increased light from the much enlarged opening of the diaphragm between the object lens of the eye-piece and the accumulative lens, and at the same time the spherical aberration is so completely overcome as to leave the field flat, and make stadia measurements very much more satisfactory.

Inverting Telescope.—In spite of the better magnifying power, better definition, better light and larger field of the inverting telescope for the same size and weight of telescope, and notwithstanding the remarkable ease of accustoming one's self to the inversion, American engineers generally demand that the telescope shall not invert. It seems to be a wholly unaccountable prejudice, considering the instrument's greatly increased lightness and convenience obtained with an inverting telescope of equal precision.

IV. Theodolite.

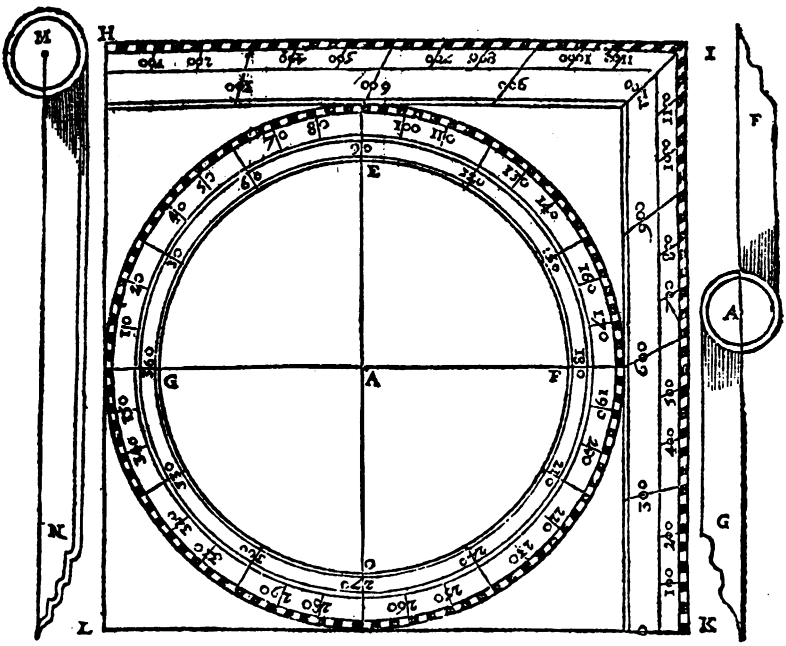
Origin.—The evident origin of the theodolite has been strangely overlooked by Mr. Scott, Mr. Hoskold and others in their examination of Digges's *Pantometria.* Obviously, not his *theodelitus*, but his "Topographicall instrument" is essentially the modern theodolite, with the yet unknown refracting telescope replaced by sights, and with the support for them and for the vertical semicircle reduced to a mere central pillar. His 29th chapter describes the instrument as follows:

"The Construction of an instrument Topographicall seruing most commodiously for all manner mensurations.

"Having alreadie plainly declared the making of the Quadrant Geometricall with his scale therein contayned, whose vse is chiefly for altitudes and profundities: the composition also of the square and planisphere or circle named *Theo-*

delitus for measuring lengthes breadthes and distances. Yt may seeme superfluous more to write of these matters, yet to finishe this treatise, I thinke it not amisse to shew how you may ioyne these three in one, whereby you shall frame an instrument of such perfection, that no mãner altitude, latitude, longitude, or profunditie can offer it selfe, howsoeuer it be situate, which you may not both readely and most exactly measure. You shall therefore first prepare some large foure square pullished plate of Latin, wherein you may describe your Geometrical square, his sides divided in 1200 parts at the left, with index and sightes as was before shewed : describing also within the same square the *Planisphere* or circle called *Theodelitus*, then must you vppon an other fine pullished plate, drawe your Quadrant, or rather a semicircle diuided iustly into 180 grades, and within the

FIG. 152.



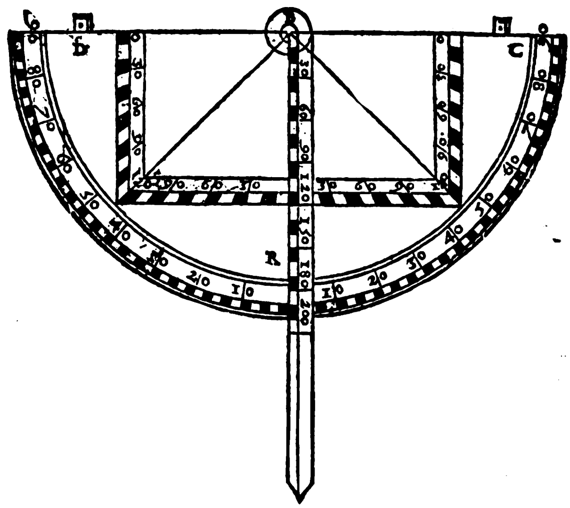
Digges's Square Geometricall, Index, Theodelitus and Alhidada.

same a double scale: every side contayning at the leste an 120 partes, finally, fixing on the dimetient thereof two sightes perpendicularly reared, and equedistantly persed, so as the line visuall may pass parallele to that diameter. You haue a double Quadrant Geometricall with a double scale, whiche you muste by the ayde of some skilfull Artificer, so place over the other plate wherein youre square Geometricall and *Theodelitus* was described, that his centre maye exactly reste in a Perpendicular line from the centre of the planisphere or circle named *Theodelitus*, his circũference depending dounwarde. And this double Quadrant or semicircle, must in such sorte be connexed to the Perpendiculare erected from the centre of the planisphere, and *alhidada* at the foote thereof, that what way so euer the Diameter with sightes be turned, the *Alhidada* maye alway remayne exactly underneath it, directing bothe to one verticall circle or pointe of the

Horizon: this perpendiculare wherevnto the semicircle's centre is fastened, ought also to be marked with 200 partes equall to the diuisions of the scale beginning at the centre, so proceeding dounward til you come to the end of those 200 portions: more I neede not say of this instrument, considering the construction, if every parte hath ben seuerally declared sufficiently before, for the placing and conioyning them, behold the Figures [Figs. 152 and 153].

"I K L H the square Geometricall, M N his index with sightes, G E F O *Theodelitus*, G F his *Alhidada* or index with sightes A B the line perpendiculare from B dounward noted with 200 partes, equall to the diuisions of the scale, D R C the semicircle hauing on his Diameter two sightes fixed as was to fore declared. This is also to be noted, that the double scale is compound of two Geometricall squares, the one seruing for altitudes, the other for profundities. The square which the line perpendicular cutteth when the Diameter is directed to any markes lying lower than your station, I call the scale of profundities, the other shall for

FIG. 153.



Digges's Semicircle.

distinction be named the scale of altitudes. This semicircle ought so to be placed that the centre B hang directly over the centre A, and that the diameter D C with his sightes may be moued vp and downe, and also sidewise whither you list, alwayes carying G F about directly under it. You must also prepare a staffe pyked at the ende, to pitche on the ground with a flat plate on the toppe to set this instrument vpon. It is also requisite that within *Theodelitus* you haue a needle or fly so rectified, that being brought to his due place the crosse diameters of the *Planisphere* may demonstrate the foure principall quarters of the Horizon, East, Weste, North and Southe: And this may you do by drawing a right line making an angle (with that one diameter of youre instrument representing the meridiane) equall to the variation of the cōpasse in your region: which in England is 11¼ grades or neere therabout, and may be redely observed in all places sundrie wayes. But thereof I mind not here to entreate, forasmuch as it appertayneth to *Cosmographie* & navigatiō, whereof I haue cōpiled a treatise by itself, touching the fabricatiō this may suffise."

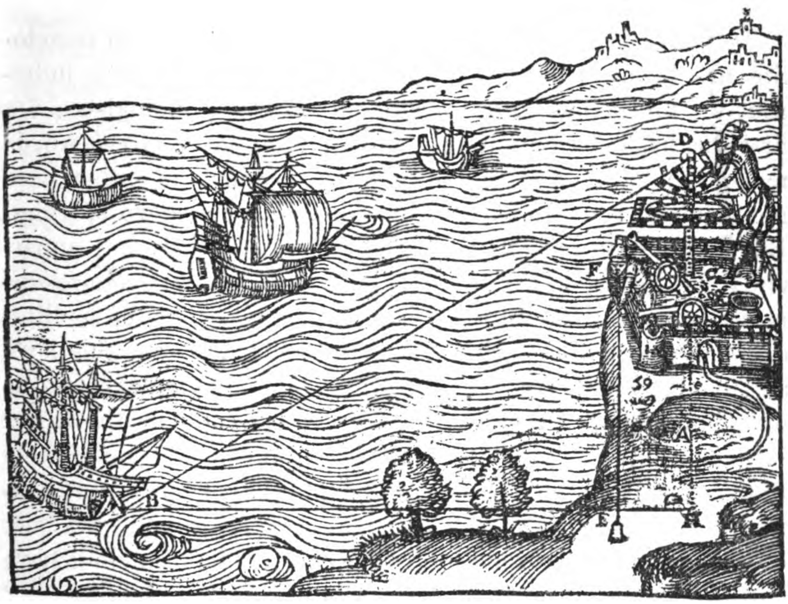
His 30th chapter begins:

"*By this instrument to knowe how many myles or pase any shippe is distante from you, your selfe standing vpon an highe cliffe or platforme by the sea coaste.*

"Your Topographicall instrument equedistantly situate to the Horizon, (as was before declared) turne the diameter of the semicircle towards the ship," etc.

It is perfectly clear from the figure (Fig. 154), as well as the text, that the instrument is nothing but the modern theodolite; except that it is rudely made, and that it has sights for the

FIG. 154.



Digges's Topographicall Instrument in Use.

naked eye in place of the refracting telescope not then invented. The vertical semicircle is joined to the sights just as it is in the modern theodolite to the telescope, but is supported by a pillar from the center of the horizontal plate, instead of by two standards or vees; and the pillar is joined to the alidade instead of to a vernier plate. To see the essential identity, it is only necessary to compare the figure with Figs. 16 and 17, pp. 696 and 698, vol. xxviii. of the *Transactions*. To be sure, the "square geometricall" has been disused in the modern form, and the graduated plate is round.

Digges expressly mentions the application of his instrument to underground use, meaning particularly military mines, at the end of the 35th chapter and of the "fyrst Booke," as follows:

"*A Note for Mines.*

"**Most commodiously also serueth this instrument to conducte Mynes vnder the earth, for noting the Angles of position in the Planisphere or *Theodelitus*, and also Angles of Altitude or profunditie in the semicircle or scales appropriate therevnto, measuring the distances from Angle to Angle, you may make by the former preceptes most certeine plattes of your iorneis, and thereby always knowe vnder what place you are, and which way to directe your Myne to approche any other place you liste.**"

Derivation of the Name.—The derivation of the word theodolite has been variously explained, and generally quite ludicrously; for it has been a sore puzzle to philologists. Its first part has been imagined to come perhaps from Greek words meaning "to see a road" or to "run a road;" in either case requiring an *o* after the *d*, as in the ordinary modern spelling. But it is very noticeable that Digges, the first user, and apparently the inventor of the word, invariably spells it *theodelitus*, notwithstanding his extremely varied irregularity in the spelling of most other words. Now Mr. Scott brings to notice Stanley's and Bauernfeind's two other derivations, both as amusing as the old explanations, but not requiring either the *o* or the *e*, nor indeed hardly any of the other letters. It seems inconceivable that anybody could have formed the name of such an instrument from Stanley's *theodicaea*, divine right, aside from the lack of resemblance in form; or, according to Bauernfeind, have corrupted into *theodelitus* such familiar words as "the alidade," or, as Digges himself repeatedly calls it, "the Alhidada," one part of his instrument considered by him quite distinct from his *theodelitus*. Bauernfeind, in objecting to the derivation of the termination *lite* from *lithos*, stone, seems to overlook the fact that hundreds of mineralogical names are so formed in English; though, it is true, not so long as 300 years ago. But in any case, what in the world has the instrument to do with stones?

Perhaps the word was never quite correctly formed, but Digges's idea is probably indicated by his spelling,—at any rate not more absurdly than the previous derivations would appear. It looks as if his intention had been to combine the Greek words *θέα*, or *θεάομαι*, viewing or observing, *δῆλος*, clear, or *δηλόω*, to make clear, and *ἴτυς*, the rim of a round body; meaning: a distinctly marked rim (or disk) for viewing, or for observation. If so, the second vowel should strictly have been *a*; but even the Greeks in like cases seem to have slipped into *o*, especially in later times; for example, Theogenes for Theagenes, and several compounds of *σκιά*, as in the English sciomachy and sciomancy. But possibly the first syllable is from *θέω*, to run or revolve; so as to mean a revolving, clear-making rim or disk. In use, however, the *theodelitus* was mainly stationary, while the alidade moved round. It may be objected that by the ordinary later methods of transliterating, the last vowel should be *y* instead of *u* (*theodelitys*); but until nearly or quite Cicero's time *u* would have been the letter to use, as in *cubus*, cube. It is said, too, that the learned Gladstone, of our days, so transliterated with *u*. It is nothing violent, then, to suppose that Digges did likewise; especially, seeing that he clung so closely to the Greek form as to give *Stratioticos*, instead of *Stratioticus*, for the title of one of his books.

V. TRANSIT.

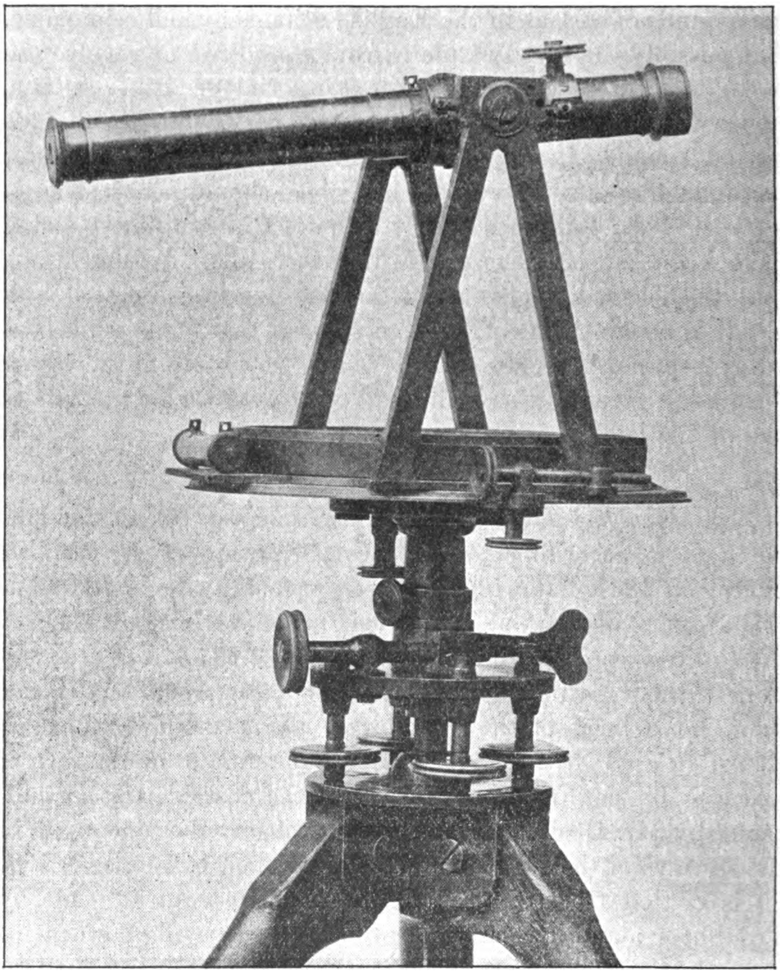
First Surveying Transit.—The first American transit for surveying was, according to Mr. Scott,* introduced by Wm. J. Young in 1831, following, however, probably after "Ramsden (1803), who introduced the transit principle in small English theodolites at that time." Also on page 697 Mr. Scott mentions "the transit-principle of Ramsden in 1803." It must, then, have been of the "*sic transit gloria mundi*" type; for Ramsden died Nov. 5, 1800. Mr. Scott refers to no authority; and was he not perhaps thinking of the portable transit indicated by Mr. Hoskold, Fig. 80,† as probably the one used in the surveys of the Box Tunnel, as mentioned by Bourns? Fig. 80 is copied from Simms's figure of an instrument made by Troughton; and is clearly not properly a surveying instrument at all, but merely a portable astronomical instrument, used in this case extraordinarily for a single sight or two in a tunnel survey. It seems clear, indeed, that the transit surveying-instrument was first invented and used in America.

But who was really the American inventor of the transit?

* Page 25. † Page 111.

Mr. Scott gives no authority for his statement that it was Young in 1831. Others before Mr. Scott have made the same statement, and much color has been given it by Mr. Young's justly high reputation as an instrument maker; but did Mr. Young

FIG. 155.



Draper's Early Transit.

himself ever lay claim to the invention? There appears to be no evidence whatever that he did so.

Fig. 155 shows a transit by Edmund Draper, apparently of earlier date than 1831, and supposed by its owner, Mr. S. G.

Frey, of Watsontown, Pa., to date from 1821. But, as Draper died Dec. 24, 1882, "in the 77th year of his age," according to the advertisement of his death in the usually very accurate Philadelphia *Public Ledger*, he would have been only in his 16th year in 1821, and could hardly have invented and constructed a transit at that early age. Mr. Frey took the instrument to Mr. Draper in 1874, for repairs; and says that Mr. Draper, then an old man, after carefully looking it over, said: "Yes, I made that transit many years ago. It was among the first I put out when I commenced business, and it works as nicely now as it did when first made. But I cannot remember to whom it was sold, as I have not my old record at hand." It has latterly been announced that Draper begun business in 1815, but at that time he must have been no more than in his tenth year, and could have held only a very subordinate position in any business. Mr. Frey has had the transit ever since 1863, and the next preceding owner told him that he had had it since 1834. According to tradition, it was made by Draper in 1821, presumably to be used in surveying the Pennsylvania State canals and the Reading Railroad.

At all events, the instrument itself bears strong evidence of age, and has a decidedly more antique appearance than Young's; yet Draper was certainly never behind the times, and even in this early piece of work shows his superiority in the elegance of the proportions of the vees and other parts. One of the details, however, that give the more antique look is the greater height of the transit-plates above the tripod; for in the lapse of years, they have been gradually lowered towards the tripod, to secure more satisfactory steadiness. The telescope of the Draper transit is an erecting one of very weak power, compared with the inverting telescope of the Young transit, which appears, in fact, to belong to a much more advanced stage of optical development. Both instruments have the old arrangements for adjusting the telescope by shifting one end of the axle so as to make the cross-wires cut the same object that the sights of a compass cut when reading the same magnetic bearing from the same point. It was the early method for surveying transits, but was soon abandoned for the present much more accurate one of reversals, for adjusting the vertical cross-hair, or line of collimation—the method which had already been used with the astronomical transit-telescope (though, in that case, with reversal of the telescope-axle in its wyes, end for end). On looking closely at the Draper instrument, small indentations may be seen in the lower parallel leveling-plate, which have been made by the leveling-screws; showing that the important device of placing a ring or disk of sole-leather beneath the screws, as a washer, upon the plate had not yet been adopted, as it may be perceived to have been in the Young transit. For the same purpose, flat-bottomed metal cups below the screws have been used, but are apt to get lost; and, as the bottom of the screws is not spherical, they are liable to bind at times. Heller & Brightly, in 1871, very satisfactorily gained the desired end by introducing a truly spherical cup and ball inseparably attached at the bottom of the screws. Draper's transit has straight spirit-levels, instead of the round one seen in Young's; for Draper never would use the round level, because it is sometimes impossible to seal it perfectly and permanently, and the difficulty of giving its interior a perfect curvature is greater.

Edmund Draper.—Draper, although he made no bluster and noise about his accomplishments, took great pride in his excellent skill and knowledge of his art, and is said to have earnestly declared that he would never have any "successor" in his business to diminish even indirectly his fair professional fame. Accordingly, after his death, in 1882, the business carried on from 1883 to 1892 with some of his old tools, but not even at the old stand, by Mr. Robert Wareham, who had been one of his workmen, was never made an excuse for assuming the title of Draper's successor. Later, after Mr. Wareham's death, a young man who had never worked with either Draper or Wareham, continued business at Wareham's place, with possibly some of Draper's apparatus; and now advertises himself as "Draper's successor." It must be done on the ground merely of being subsequent to him, without any idea that Draper or others would consider it an impropriety so to use his name, as an indication presumably of an authorized continuance of his skill and reputation.

VI. Instrument-Parts.

Ramsden's Dividing-Engine.—Mr. Scott says* "Jesse Ramsden had already (1760) constructed a circular dividing-en-

* Page 16.

gine," and is apparently corroborated by Mr. Hoskold.* In 1760 Ramsden was in the midst of the four† years' apprenticeship which he had begun in 1758,‡ after coming, at the age of twenty, to London in 1755. It was only in 1777 that he published a description of his celebrated dividing-engine, presumably just completed; and he was thereupon rewarded by the Board of Longitude.

Fineness of Graduation.—Mr. Hoskold is quite right in his conclusion§ that, as regards precision of the graduation, "there is a medium course," and that "it is necessary to determine the fineness of the divisions . . . according to the nature of the work and the degree of accuracy sought to be attained." But his illustration of the inaccuracy of coarser divisions is not very convincing. He arbitrarily supposes certain observed angles with a graduation to minutes, and shows the result of a whole minute of error in the sum of an angle and its supplementary angle. But a reading to the nearest minute (which is probable) and consistently with the two other suppositions would have shown no such error, and according to his reasoning would have proved complete accuracy; although the true angle might have differed by twenty seconds from the observation. Indeed, if his three supposed cases, with graduations to one minute, twenty seconds and fifteen seconds, were made consistent with each other and with the graduations, and the readings made to the nearest graduation, the result in each case would show complete accuracy in the sum of the angles, and consequently, according to him, complete accuracy in the observations, as follows:

Angle, ...	164° 32′ 0″	164° 31′ 40″	164° 31′ 45″
Supplementary angle, .	195° 28′ 0″	195° 28′ 20″	195° 28′ 15″
	360° 0′ 0″	360° 0′ 0″	360° 0′ 0″

The true angles may be near either of the pairs observed with the two more precise graduations, or may be between them. Clearly, the angle and its supplementary angle, if both were read correctly to the nearest graduation, will always sum up 360°; except that an error might occur when the truth is

* Page 96.
† Grant, p. 490.
‡ *Dict. Nat. Biog.*
§ Page 114.

exactly half-way between two graduations, so that a reading might be made in one case or the other that would cause an error to the extent of one graduation in the sum.

Conical Graduation.—Mr. Hoskold says* that graduations upon a conical or bevel-edge form are more easily read than those upon a flat surface. They are, indeed, slightly easier to read; because the eye is placed a little more conveniently in a line at right angles with the slope of the bevel-edge, instead of vertically over a horizontal plate. But the sloping graduations are disliked by instrument-makers, because more troublesome from the increased difficulty of correcting the centering and of getting the vernier precise; and therefore repairs are much more expensive.

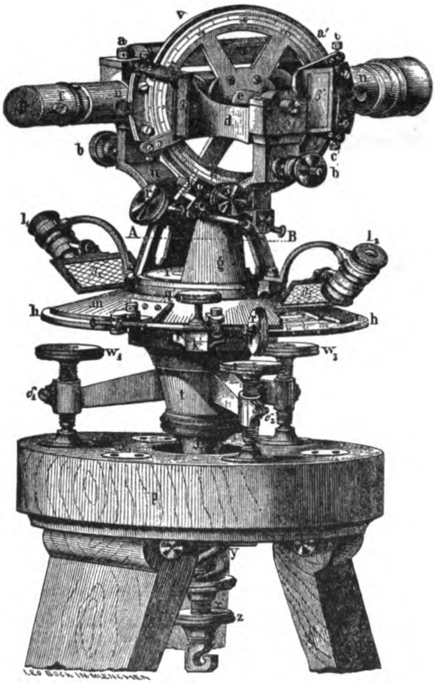
Full Vertical Circle.—Mr. Hoskold says,† against Mr. Stanley's using a full vertical circle with only one vernier, that the only advantage of the full circle is thereby lost. But the full circle has the very important additional advantage that it enables the constructor to test the placing of the vernier so thoroughly as to make it trustworthy. A second vernier would give the same reading as the first, and would therefore be rarely used, if at all.

Leveling-Screws.—Mr. Hoskold says‡ that, "by preference, a triangular leveling and centering frame of light weight, with three leveling-screws, is attached to the theodolite;" and Mr. W. F. Stanley says§ that "the growing sentiment in England is greatly in favor of three leveling-screws." In America, four leveling-screws are constantly preferred to three, and apparently with good reason. Not only is the leveling effected more conveniently and speedily with four screws than with three, because both hands work at the same time, and consequently only one-half the time that one screw would require in bringing each level-bubble to its proper place; but also the construction of the tripod-head necessitated by the three screws is decidedly less satisfactory than when there are four. With four screws, the transit simply moves about a ball-and-socket joint in the tripod-head; but, with three screws, that arrangement is impossible, and the transit either rests by its own

* Page 113. † Page 210.
‡ Page 103. § Page 76.

weight, without any binding attachment, upon a roughly horizontal plate at the top of the tripod, or, more usually and more securely, is united to the tripod by a central vertical shaft that is surrounded by a very strong spiral spring some five inches long, against which the leveling-screws pull. (See Figs. 156 and 157, copied from Bauernfeind, pp. 188 and 340.) The spring, after being in one position for some time, "takes a set," or relaxes slightly, and the transit ceases to be in perfect level,

FIG. 156.

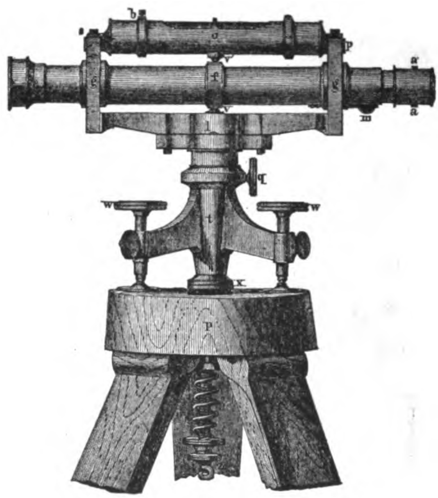


Three Leveling-Screw Method.

and needs to be leveled up anew. At each removal of the instrument from the tripod, the shaft must be unscrewed by a milled-head at its lower end from the socket of the instrument center above; and on replacing the instrument, must be screwed on again, and another milled-head nut must be turned to adjust the spring. For packing the instrument a specially arranged box is necessary that is less convenient than the arrangement that is possible with four leveling-screws, and cannot be made safely to protect the instrument from injury, as it can with the four screws. Four leveling-screws, then, are decidedly preferable to three on the ground both of greater ease in operation, and of the still more important exigencies of accuracy in use and of safety and convenience in carrying.

In general the English tripod-heads with four leveling-screws give a very narrow base for the leveling-screws and for the top of the tripod legs, and are consequently unsteady compared with the American form. But the three leveling-screws requiring a wider base are more steady than the English four-

FIG. 157.



Three Leveling-Screw Method.

screw form, though too cumbersome to suit American engineers. That advantage of the three leveling-screws may explain the preference for them that Mr. Hoskold and Mr. Stanley say now exists in England.

Shifting Tripod-Heads.—Mr. Hoskold describes and illustrates* Troughton & Simms's shifting tripod-head, and says it is their invention. It is, however, essentially Edmund Draper's shifting tripod-head, with the addition of a clamping-plate to adapt it to use with three leveling-screws. Within a year after Young in 1858 patented the shifting tripod-head now claimed by Hulbert as his own suggestion to Young, Draper, to attain the

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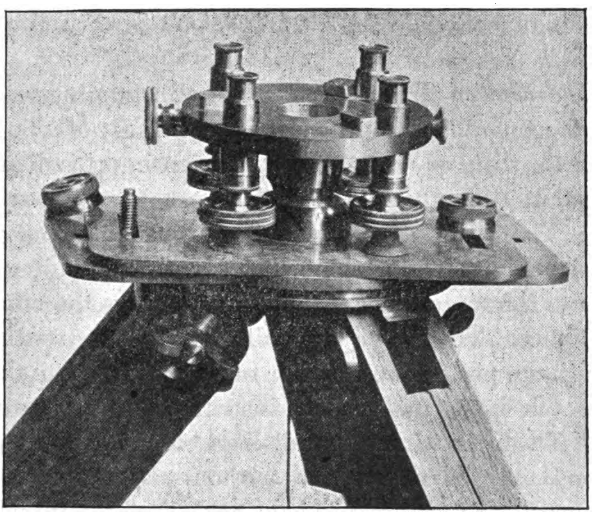
* Page 212.

highly important object of the device and yet to avoid infringing upon Young's patent, very ingeniously contrived his own method, but did not have it patented. It is shown in Fig. 158.* There are two horizontal brass plates, about 4 in. by 8 in., large enough to give great stability, the lower plate fixed upon the top of the tripod, and the upper or shifting-plate capable of moving in any direction upon the lower one, within a radius of about an inch, but restrained from wider movement by a small pin in a narrow slot near each end of each plate, the slots of one plate at right angles to those of the other. The

Fig. 158.



Draper's Shifting Tripod-Head, with One Nut Removed.

pins have a shoulder at the bottom and a screw-thread on their upper part, and the plates may be clamped together by a milled-head nut on each pin. The ball-socket is a part of the upper plate at its center. Upon the upper or shifting-plate rest the four leveling-screws. Draper's tripod-head has a larger movement than Young's, and in spite of its bulkier form is still preferred by some engineers, and is still manufactured. Its main objections are that the clamping-screws are liable to get lost in the field, and the large plates to get slightly bent and consequently useless.

* See also Fig. 35, p. 39, with a brief reference to the device.

About 1864, Mr. Chas. S. Heller (now of Heller & Brightly) contrived a shifting tripod-head, still in use, that is readily applicable to any old instrument, and precisely similar in principle to Mr. Hoskold's tripod-head of 1866.* A 4 in.-broad annular plate, or flat ring, of brass, with a wide hole in the middle for the shank of the instrument, and for the four leveling-screws, and with a screw-thread cut inside of a down-hanging flange at the rim, screws down upon the tripod-top, clamping the shifting-plate between it and the tripod-top. The four leveling-screws rest upon the shifting-plate. When the transit with the leveling-head is carried from one station to another, the clamping-plate hangs loose, making a little racket; and that small objection is the principal one against the arrangement.

Hoffman-Harden Tripod-Head.—Notwithstanding the ingenuity and the theoretically probable effectiveness of the Hoffman tripod-head, with or without the Harden improvement, apparently certain difficulties in practical use have caused dissatisfaction. The least dust upon the upper half-ball prevents smooth working; and a somewhat larger grain of grit there plows into the metal, and completely destroys the efficiency of the appliance. The upper half-ball unduly increases the height of the instrument. The number of joints between the tripod and the telescope makes the instrument comparatively unsteady. The approximate parallelism of the parallel plates of the tripod may be maintained without the device by merely careful setting of the tripod-legs, without or with extensible legs; as intimated by Mr. Hoskold.†

Heller & Brightly's Improvements.—In 1871, Messrs. Heller & Brightly introduced several important improvements in the construction of the transit. See the report on them by the remarkably able committee of the Franklin Institute. The weight of the transit was diminished about one-half by using cast bronze, cast under great hydrostatic pressure—with a "high gate"—instead of hammered sheet brass, and by ribbing and bracing the plates, with the removal of superfluous metal. An experience of almost thirty years has now amply proved the wisdom of the change of metal, though the excessively conservative

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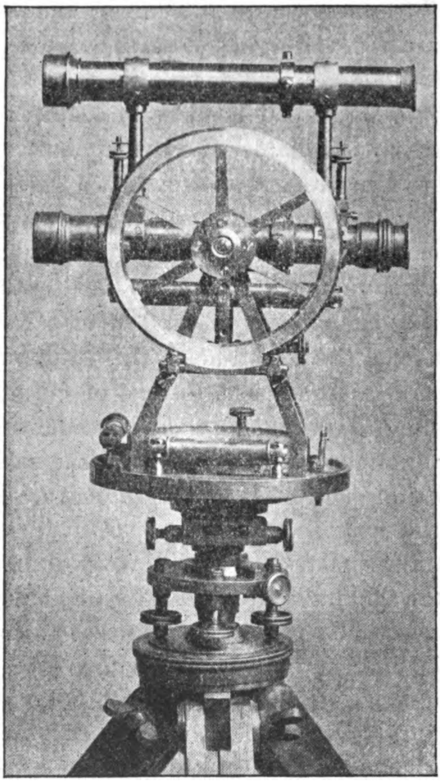
* Page 214. † Page 211.

long maintained their doubts about so radical a departure from old practice. The method of attaching and detaching the instrument on the tripod was also improved by means of three lugs on the upper parallel plate of the tripod-head, all corresponding to recesses in a flange around the exterior of the socket enclosing the compound center, and one of the lugs being movable, so as to clamp the socket after turning the instrument until the lugs are away from the recesses in the flange. The tripod leveling-head was separately detached from the tripod. So detaching the transit proper, or level, with its long center from the tripod leveling-head, and this head separately from the tripod, enables the instrument to rest securely in its packing-box in precisely the same way as it does upon the tripod-head. Though more difficult, it is a securer plan than the ordinary one, and makes it possible to carry the instrument safely to distant countries. Owing to the great reduction in the weight and to the readier method of attaching and detaching the transit from the tripod-head, the compound center became feasible for ordinary use, instead of being virtually confined to the most accurate city- and tunnel-surveying. By degrees other makers have now adopted the same methods, so that the compound center has at length become common everywhere; and the "flat center" comparatively rare, with its friction between the plates, the quick wearing of the graduated plate around the shallow center, and the consequent inaccuracy of work, and with the exposure of the spindle, or turning-center of the entire instrument, whenever the transit is detached from the tripod-head.

Heller & Brightly also used a tangent-screw that overcame all lost motion, by means of a spiral spring that constantly presses the screw away from its supporting nut, not with the spring opening and closing to the extent of the whole motion of the screw, but merely to the extent of the backlash, by pressing against a detached follower within the nut. They extended the slits in the clamps on the axis of the telescope downwards almost to the bottom of the clamps, and made sighting-holes in the slits; so that an accurate sight at right angles to the telescope can be made. They made the tripod legs of semicircular cylinders sliding on one another's plane surface and clamping in any position; so as to give a play of from three to five feet in length of legs. The tripod-head and the cheeks for the legs were made of one piece; so as to prevent the possibility of unsteadiness there; and the top of each leg enclosed a single cheek, instead of being enclosed by two cheeks. Pure plumbago was used as a lubricant for all the screws, preventing hard work in cold weather.

FIG. 159.

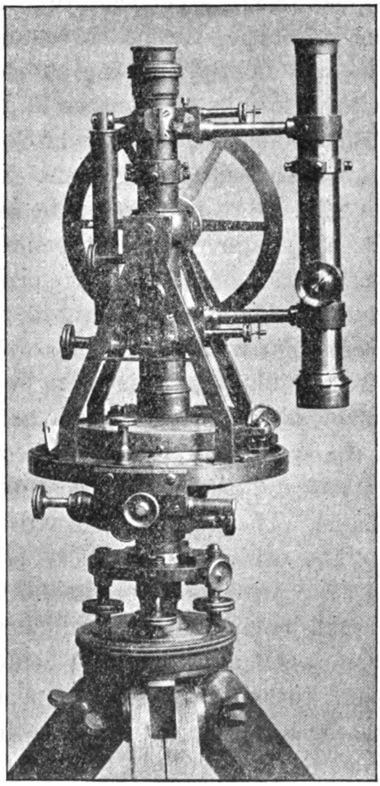


Heller & Brightly's Mining-Transit.

One small device of theirs is a great convenience in setting the transit precisely under a plumb-bob hanging from the top of a mine gangway. For that purpose, a small screw in the center of the top of the axle, or the binding-screw there that fixes the telescope in its axle, has a minute hole, say $\frac{1}{32}$ in., or less, in diameter, by a special apparatus drilled in the top exactly in the center of the axis of rotation of the transit. This form of the device dates back to about 1884; but from 1874, the same object was effected by a small brass plate with adjusting-screws, and with the center marked by two lines crossing at right angles.

Heller & Brightly also constructed a mining-transit (Figs. 159 and 160), described by Dr. Raymond at our meeting of February, 1873 (*Trans.*, Vol. I., p. 375). It was a close copy

FIG. 160.



Heller & Brightly's Mining-Transit.

of their complete engineer's transit, but of reduced dimensions, making it the lightest American transit that had then been made. It had an erecting telescope 7¼ inches long; extreme diameter of plates, 5 inches; plate-graduation circle, 4½ inches in diameter; a three-inch compass-needle; long compound centers; height of the instrument from the tripod legs, 7 inches; weight in all, about 5½ pounds; besides a tripod of 3½ pounds.

At that time, a prism and tube were provided to attach to the eye-piece of the telescope, for sighting vertically upward in shafts; but (as, notwithstanding Mr. Hoskold's argument* that sighting a telescope up a shaft gives the same angular result as sighting down it, the sight cannot be equally satisfactory if water be dripping abundantly upon the upturned object-glass) by 1876 a side-telescope was adjusted so as to be parallel to the central one, and was placed removably at the end of the main telescope axle opposite to the vertical arc. The effect of the eccentricity of the telescope can be corrected either by computation, or, more conveniently, by using a lop-sided or a double target. Mr. Hoskold† speaks of Combes and "the use of his double target." But it does not appear that Combes ever used a double target, or even a lop-sided single one. The double target given by Scott in Fig. 23A‡ appears to be of decidedly later date. Heller & Brightly later replaced the side telescope by an auxiliary top telescope, supported by two pillars, fore and aft, upon the main telescope; for the testing of the adjustment is far more convenient than with a side telescope, and a counterpoise, though quite feasible, yet so liable to be lost by a fallible mortal of a surveyor, is less necessary on account of the less serious effect of the weight of a top telescope, from its not tending to pull itself and the main telescope away from the correct vertical plane. The sights taken with the auxiliary telescope are, of course, comparatively very few, and at other times it is packed away with its pillars in the transit box, or in the surveyor's satchel, leaving the instrument wholly unincumbered and free from uneven wear of the center, even if there be no counterpoise. In using a top telescope, the correction of the observed angle for eccentricity from the center of revolution should not be neglected, especially in short sights; most conveniently by computation or by a small table. A small removable metallic reflector in the shape of a quadrant of a cylinder, to facilitate the reading of angles, was in 1873 applied just behind the vernier opening; also there was a small adjustable lamp-stand easily fastened upon one leg of the tripod, and quickly set so as to illuminate the cross-wires of the verniers. These last attachments are likewise useful in astronomical ob-

* Page 231. † Page 108. ‡ Page 28.

servations with the larger transit, in determining the true meridian.

Such, at that time, revolutionary improvements in transits well deserved the generous encomiums of Prof. J. B. Davis, of the University of Michigan, in describing Heller & Brightly's exhibits at the Centennial World's Fair. He says:

"I think their most valuable contribution to the advancement of their business is the spirit of invention and adaptation which they have awakened amongst their competitors. . . . One is surprised at every point, in examining the work of this Philadelphia firm, to see the extreme care and judgment with which every detail is worked out. One cannot well help referring the work of other makers to theirs as a kind of standard with which to compare it."

Indeed, it is quite incomprehensible how anybody in undertaking to write up "The Evolution of Mine-Surveying Instruments," with special allusions, moreover, to nearly every other surveying instrument directly or indirectly, even very remotely, connected with them, could have wholly failed to discover and mention an American establishment so prolific in important improvements in that line and so eminent in every branch of their business. The firm was established after the death of Wm. J. Young in July, 1870. The head and soul of the firm, Mr. Charles S. Heller, had been fifteen years with Mr. Young, the last five years of Mr. Young's life as his only partner. Mr. Brightly was one of their most skilful workmen. Mr. Brightly retired from the firm in 1889, and died in 1893.

VII. Other Instruments and Appliances.

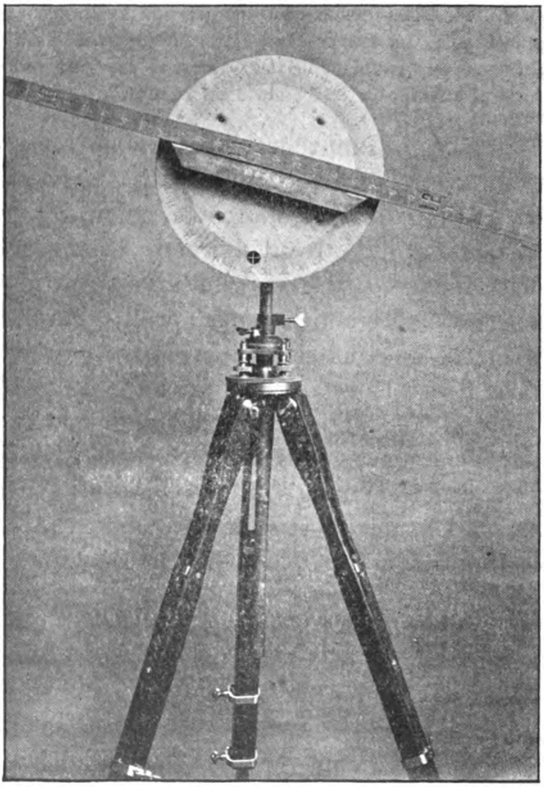
In a general account of "the evolution of mine-surveying instruments" several important improvements should not have been omitted that Mr. Scott seems to have overlooked.

Sunflower.—An instrument that has been found very convenient for measuring the cross-section of tunnels is called the Sunflower (Fig. 161). It was first made by Heller & Brightly from the design of Alfred Craven, a division engineer on the Croton Aqueduct, and was published in 1887.* It is a wooden disk about 15 inches in diameter, graduated to degrees, supported vertically by a tubular rod upon a tripod with extension-legs, and having across the center of the disk a wooden arm,

* *The Sanitary Engineer and Construction Record*, New York, June 11, 1887. See also *Trans. Am. Soc. C. E.*, xxiii., July, 1890, pp. 17-38.

metal-shod at the ends, that revolves on the plane of the disk, and bears a long graduated wooden rod sliding on the upper surface of the arm. There are two small levels for exactly plumbing the rod that supports the disk; and there is a sighting tube with cross-wires for testing the precise adjustment of the center of the disk to the center of the tunnel. One end of the

FIG. 161.

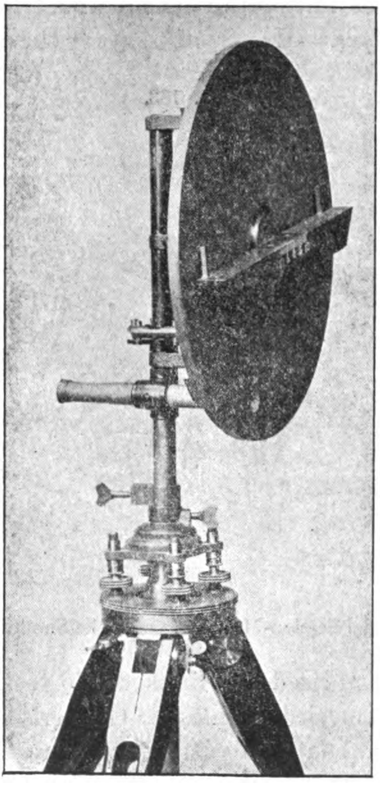


Heller & Brightly's Sunflower, Front View, with an Extension-Tripod.

wooden rod touches the perimeter of the tunnel, while the distance is read with a vernier at the center of the disk. The distances are taken at any desired number of angles around the whole disk, and are plotted conveniently with a protractor. (See Fig. 163.) The time required to measure a section of the tunnel is from six to ten minutes. The weight of the disk including all attachments is 10 pounds, and the tripod-head with an extension-leg tripod weighs 10¼ pounds, making a total weight of 20¼ pounds. There are two measuring-rods, 8 and 14 feet long. The instrument is also useful for testing masonry work after the centers are struck.

Plummet-Lamp.—Eckley B. Coxe's plummet-lamp was described by Dr. Raymond, then President of our Institute, and

FIG. 162.



Heller & Brightly's Sunflower, Side View.

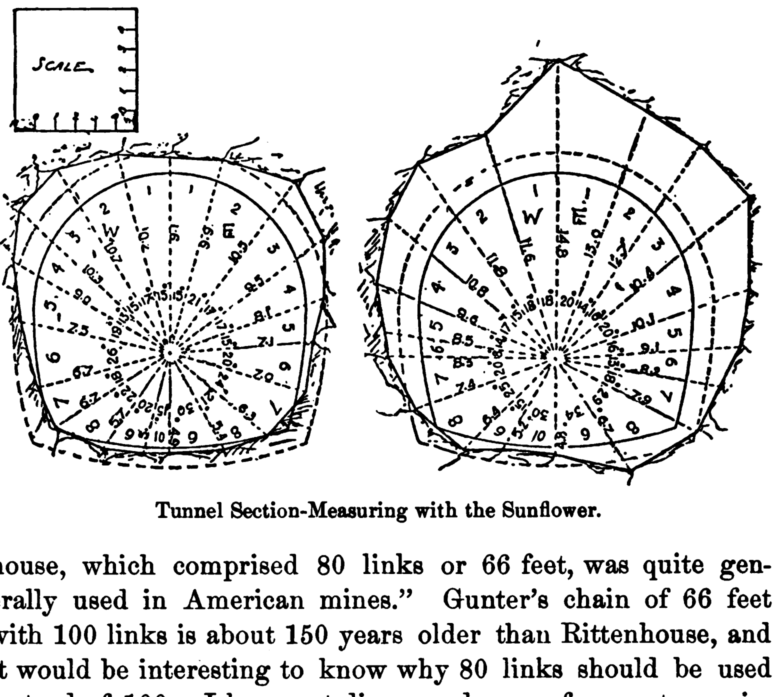
its use explained by Mr. Coxe himself in papers read before the meeting of February, 1873,* and was soon published in several journals. The lamp was made by Heller & Brightly, and was contrived for use in accurate mine-surveying to take the place of the open mine-lamp set (if not, as too often happened, overset) on the ground, or of the mere string of a plumb-bob

* *Trans.*, i., 378.

with or without a light or a white surface behind it. The plummet-lamp, as eventually made, rests by trunnions on a horizontal "compensating" ring, which at points 90° from the trunnions is hung by two light short chains from a cord that depends from a spud (a nail with a hole in the head) driven into the mine timber over a station, or into a wooden plug inserted in a hole drilled in the coal or rock roof. Mr. Coxe found that with the plummet-lamp "two persons can make a very accurate survey as quickly as three can by the old method."

Chains and Tapes.—Mr. Scott* says "the chain of Ritten-

FIG. 163.



Tunnel Section-Measuring with the Sunflower.

house, which comprised 80 links or 66 feet, was quite generally used in American mines." Gunter's chain of 66 feet with 100 links is about 150 years older than Rittenhouse, and it would be interesting to know why 80 links should be used instead of 100. I have not discovered any reference to so singular an arrangement in any of the numerous works on Rittenhouse or by him.

Eckley B. Coxe was also the first to introduce, with Heller & Brightly's aid, the use of the long steel tape, or "chain-tape," at first 500 feet long, afterwards up to 1000 feet, instead of chaining. Formerly the graduation scratched on the tape, or

* Page 32.

marked with rivets, would often occasion breaking; or if etched on the tape, or marked on a thin layer of solder or tin, were not very legible or easy to find, and were easy to efface; the steel ribbon was soft, not tempered, and was consequently liable to alterations in length; and there was no reel. Heller & Brightly obviated all those difficulties. They soldered a small piece of brass wire with white solder across a tempered steel ribbon, with the solder for greater conspicuousness extending about an inch each side of the wire. The wire had a small notch at the exact end of the foot. They countersunk figures in the solder so that, no matter how dirty the tape, the figures are easily read, from being filled with dirt when the solder is wiped off with the finger. The tape is stronger at the graduations than anywhere else. Only every tenth foot is marked, and a five-foot rod is used for measuring the intermediate feet. The tape has a single wooden reel, with two detachable brass handles for use with the tape. Coxe gives in his paper the details of one out of three equally good surveys with the tape, showing, thanks to the tape, extraordinarily accurate work for that kind of mine surveying.

VIII. Scott's Tachymeter.

In regard to Mr. Scott's own instrument of 1896, which* "he ventures to assert, by its peculiar yet simple construction, embraces the advantages and eliminates the disadvantages of all other types," it may be unpardonable skepticism to doubt in the least degree its surpassing merits. Yet it does seem, after all, to fall in some points a little short of absolute perfection.

He says the auxiliary telescope has instead of cross-hairs a single one that is vertical when that telescope is on top and horizontal when at the side. Apparently, then, no point of observation can be fully fixed, with both horizontal and vertical angles, without taking two sights, with the telescope in both positions,—obviously a serious inconvenience. It does, moreover, seem to an obtuse skeptic that it would be more practical to have the supporting pillar of the auxiliary joined to it (in one piece, if you please—in that case, wholly giving up the

* Page 61.

unsatisfactory side use) and removable with the auxiliary, rather than to have the pillar always sticking up from the main telescope, and much exposed to injury, especially in a mine.

Furthermore, the lack of a compass seems to be a defect of some importance; but P. & R. Wittstock's detachable compass* in the place of the auxiliary above the main telescope, and incapable of use when the telescope is at all inclined, does not seem to be altogether practical, although Mr. Hoskold† has adopted a like situation for the compass, and distinctly recommends that method.‡ The U-shaped standards made possible by dispensing with the compass hardly seem by their grace or any other peculiar merit to make up for the loss of the compass. They are made of aluminum; notwithstanding the late firm of Buff & Berger, makers of this instrument, used to argue strongly and with much reason in their catalogue against the use of aluminum in surveying instruments, because its coefficient of expansion for temperature is so different from that of the other metals with which it must be replaced at the bearings and graduations, that the working results become very unsatisfactory as regards accuracy. But we are told§ the standards "will doubtless come into general use," and, of course, the instrument too. The inventor's charming zeal cannot but make us hope that our "old-time fancies" and doubts may indeed have to melt away before such success in actual practice, the true test.

IX. Nomenclature and Classification.

Names.—The names of surveying-instruments have varied differently from the instruments themselves, and have been used so diversely as to deserve a little elucidation and strict definition. In some cases a new name has been devised without any radically important change in the instrument; but more often the same name has been applied to somewhat radically different instruments, one form having been derived from another by repeated gradual improvements before a change of name was considered necessary.

For example, the name astrolabe, given, as appears from

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* Page 145.
† Page 101.
‡ Page 220.
§ Page 64.

Reinhold, in 1781, to a mere semicircle with two fixed sights and a movable alidade bearing sights, and 150 years earlier* applied to a copper disk for astronomical observations, hung vertically, with such an alidade, but with no fixed sights, was still used by Reinhold, after the addition of various improvements, for an instrument that is essentially a theodolite, with a vertical semicircle below a telescope, with verniers upon the horizontal alidade, with a compass and with an auxiliary side-telescope, Fig. 106. (Page 168.) It seems clear that, instead of calling a theodolite an astrolabe, even though it be plainly developed from the astrolabe, the word astrolabe should at the present day be used only for the simpler forms, the forms to which it belonged before the invention of special names for the improved and essentially altered forms.

The name dial seems to have been derived from the graduation of a disk with the hours of the day; but has been applied, particularly in England, to a compass used in mine-surveying.

Circumferentor is a name that belongs strictly to a compass that is graduated continuously up to 360°.

The *Eisenscheibe*, or iron-disk, of Germany is a graduated brass disk turning horizontally and vertically in any plane by means of a ball-and-socket joint, and with two arms revolving upon the disk about its center, each hooked at the end to receive the measuring cords, and without a compass, and without either sights or a telescope.

The *graphomètre* of Gensanne (1770) appears from Schmidt's description† to have been merely an astrolabe of a simple form. But Komarzewski's *graphomètre* (1795) was an *Eisenscheibe* (iron-disk) with the addition of a vertical arc of 120°, the convexity upwards, upon the horizontal alidade.

The compass has as its principal feature the reference of all horizontal angles to the meridian by means of a magnetic needle and a graduated ring; and may have either sights or a telescope. If there be a special graduated plate for horizontal angles and a telescope and a vertical circle or arc, the instrument becomes either a theodolite or a transit, and the compass becomes a subordinate accessory. In the solar compass the meridian is taken from the position of the sun.

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* *The Art of Navigation*, Martin Cortes, Seville, 1556. Cited in *Encyl. Britan.*, under *Navigation*. See Fig. 105, p. 167.

† Page 85.

The theodolite is capable of measuring both horizontal and vertical angles, with a graduated horizontal plate and a vertical semicircle below the telescope or the sight-bearing alidade. The telescope or sights can move a number of degrees vertically, but cannot revolve completely in the vertical plane. As we have seen, Digges's topographical instrument was essentially the modern theodolite in its most important distinctive principles. His *theodelitus*, however, was merely an astrolabe used for horizontal angles instead of only for vertical ones.

The transit likewise has the horizontal graduated plate; but the telescope is so mounted as to be capable of a complete revolution in the vertical plane. The telescope, to correspond with the astronomical transit-instrument or transit-circle, should be supported by a horizontal axis upon two standards and between them. But an instrument like Combes's of 1836, Figs. 109 and 110*, with its telescope supported only on one side like the telescope of the astronomical mural circle, or the sights of the older mural quadrant, has yet the more essential quality of the transit as distinguished from the theodolite, namely, the power to revolve the telescope completely in the vertical plane. Certain compasses, for example, the French square compass (*boussole carrée*), have such a side telescope; but have still been called simply compasses, because the compass was their principal feature and there was no special horizontal graduated plate. To apply the name mural, analogous to transit, would perhaps seem not wholly appropriate, because there is in a portable instrument no immovably fixed wall, as the very word mural implies. Perhaps the less compact term side-telescope-transit might be used.

The expression transit-theodolite is sometimes used, especially by men who have been more particularly accustomed to the theodolite. Their idea probably is that the distinguishing characteristic of the theodolite is the capacity of measuring both horizontal and vertical angles. But the expression is an inconvenient or clumsy one, and the difference between the transit and the theodolite is so radical and important as to justify the wholly distinct, simple name of transit.

Grouping.—The different instruments might perhaps be usefully classified in the manner of the following table, beginning generally with the simpler and older forms, and mentioning

* Page 171.

some of the principal forms, particularly those that have had special names given to them. Instruments that combine the features of more complicated and simpler forms, as the theodolite and magnetic compass, or transit and solar compass, are well enough called by the more advanced name with the other name prefixed; as, compass-theodolite, solar-transit. The name Infallible is perhaps better suited for its class than Traverser; not only because it is older, but because traversing is done also with the theodolite and transit.

Classification of Surveying-Instruments.

A. Distance-measurers.
  - Pole, cord, chain, steel-tape, odometer, pedometer, gradienter, stadia, barometer, etc.

B. Angle-measurers.
  - I. Ungraduated Instruments.
    - Vertical angles.
      - Level.
    - Horizontal angles.
      - Plane-table, three-legged stool.
        - Without compass.
        - With compass.
      - Infallible.
        - Without compass: Douglas's Infallible, 1727. Zollmann's Scheibe, 1781. Henderson's Rapid Traverser, 1892.
        - With compass: Setz-compass, 1541. Agricola's compass, 1556.
  - II. Graduated Instruments.
    - Quaquaversal:
      - Quadrant, sextant, octant.
    - Vertical angles:
      - Gradbogen. Sunflower. Clinometer.
    - Horizontal angles:
      - Without meridian:
        - Astrolabe. Digges's theodelitus, 1571. Gensanne's graphomètre, 1770. Eisenscheibe.
      - With meridian:
        - Compass:

Magnetic (including: Hang-compass, dial, circumferentor, 1796).
Solar.
Horizontal and vertical angles:
Without sights or telescope:
Komarzewski's graphomètre, 1795. Studer's Eisenscheibe, 1801.
With sights or telescope:
Theodolite:
Without compass (including Digges's Topographical Instrument, 1571. Junge's Goniometer).
With compass (magnetic, or solar, or both).
Transit:
Without compass (including Combes's).
With compass (magnetic, or solar, or both). (Including Morin's Combes's.)

Notes on Tripod-Heads, with Reference to Mr. Dunbar D. Scott's Paper on the Evolution of Mine-Surveying Instruments.

BY JOHN H. HARDEN, PHŒNIXVILLE, PA.

(Richmond Meeting, February, 1901.)

IN the valuable paper of Mr. Dunbar D. Scott and its varied discussion, on the evolution of mine-surveying instruments, the tripod-head has not received the attention it merits. During the last 50 years this very necessary adjunct to the surveyor's instrument has been much improved. The legs are of better construction; and the devices for laterally moving the instrument over the station-point and for quick leveling, without the use of the screws, have given to the instrument fitted with the modern tripod-head the same facilities possessed by the old-fashioned ball-and-socket, with more perfect accuracy, not attainable in the latter, while saving from 30 to 50 per cent. of the time required for setting the instrument over a station.

For the purpose of extending the discussion to this important part of the instrument, the subject is here treated under the two divisions of the tripod-legs and the tripod-head.

Tripod-Legs.—Tripod-legs of wood have been made of different forms and cross-section, designed to suit surface or underground surveying of varied character, including:

1. The round leg, of equal diameter throughout its length, with metallic screw-joints in the middle, reducing the height of the instrument one-half, when required, as in the leg of the "Hedley" dial. This form of leg has no less than 9 joints, wood and metal coming together; it was never a firm, certainly not a durable support, owing to the contraction of the wood within the metal; and the attachment to the head gave an uneven movement to the joint.

2. The round leg, larger in diameter in the middle of its length, fitting between plates in the tripod-head. It is defective at this joint, and its movement is uneven.

3. The angular section leg (120°), in which three legs combined form, when closed, one compact round leg, sectionally larger in the middle of its length, very convenient and easy to handle. The joint with the head is metallic, insuring a uniform movement. The rigid fastening of the metal to the wood with wooden screws is not durable, owing to unequal expansion and contraction of the parts.

4. The lattice or built leg, solid for a short part of the lower length, spread to receive the joint at the head, and with one or all legs adjustable to the height of the mine or contour of the surface. This, the modern form of leg, is more nearly perfect, and gives a firmer support, without being heavier, than any other leg designed. All its parts adjust themselves and clamp together firmly, to make decidedly the best form of tripod-leg for all classes of instrumental work in the field or mine.

The Tripod-Head.—The tripod-head, connecting the instrument with the legs, was, in its earliest inception, a rigid piece of mechanism with ball-and-socket or screws (3 or 4) for leveling the instrument, after the legs had been manipulated to obtain the exact position, as near level as possible, over a station-point—an operation occupying much time and strategy, according to the nature of the ground.

In the year 1858 Mr. William J. Young, of Philadelphia, invented an improvement in tripod-heads, known as the "shifting head." This was a decided improvement; for it enabled the surveyor to dispense, in a large degree, with the process of moving or depressing one or other of the legs to bring the instrument over the station-point exactly. This exactness is attained by moving the instrument laterally on the head, by means of the shifting-plate, within the limits designed—usually about one inch.

In 1877 Mr. Daniel Hoffman, of Philadelphia, introduced his improved tripod-head, with a quick-leveling device, together with the Young shifting-device. We now have a tripod-head with all facilities for adjusting the instrument over a station, approximately leveling it without using the screws, and requiring for the whole operation from 30 to 50 per cent. less time. The two devices mentioned, with the lattice-built legs, make a tripod fully equal to the other parts of a modern surveying-instrument.

Actual practice is the true test. I have used these devices on all my instruments during 20 years, and have proved them to be mechanically correct in principle, and to work well in practice. Never on any occasion has dust affected the smooth working of the upper half-ball, described by Mr. Lyman; and the tripods made by Heller & Brightly in 1879 are as perfect in their movement as they were the day they left the hands of the maker.

It is true that the height of the instrument is somewhat increased, though not to such an extent as to destroy its stability, firmness or usefulness.

It is also true that the approximate parallelism of the parallel plates of the tripod may be maintained, without such a device, by merely careful setting of the tripod, with or without extensible legs, as intimated by Mr. Hoskold. This careful setting of the tripod-legs, and the time required for doing it, is what is avoided in the use of the Hoffman and Young devices, which give to the modern tripod-head its superiority. In proof of this, the devices have had their imitators; the Young shifting-device having been imitated by Draper and others, and the Hoffman quick-leveling device by Young, Gurley and others.

In the suit of Hoffman *vs.* Young for infringement, decided by Judge Butler in favor of Hoffman, such eminent engineers as the late Eckley B. Coxe, Prof. Lewis M. Haupt, D. McN. Stauffer, the late Thomas Shaw, and others, gave evidence in favor of the device as a valuable addition to the tripod-head, before unknown to them. The Hoffman invention, patented in England, has been largely applied to both new and old instruments by John Davis & Son, Derby.

In conclusion, I may refer to my paper, presented to the Institute in 1878, on "Imperfections in Surveying Instruments."*

The Evolution of Mine-Surveying Instruments.

BY DUNBAR D. SCOTT, HOUGHTON, MICH.

(Concluding Discussion.)

MR. SCOTT: So many contributors have appeared recently with commendable arguments that I re-enter the field apologetically, taking the liberty first to supplement Mr. Davis's paper by showing how that clever mechanic, Mr. Berger, has converted the interchangeable auxiliary telescope into a solar of the Saegmuller type.†

The auxiliary is made to revolve about the polar axis and in the declination circle by means of a new appliance called the "equatorial adapter," which is shown attached in Fig. 164, and more in detail in Fig. 165.

It consists of two parallel circular plates, the lower one of which is screwed to the "vertical pillar" of the telescope. The upper carries the polar axis with its peculiar bearing-arm, to which the auxiliary is attached in a position similar to that which it occupies when at the side of the instrument. The polar axis may be adjusted to verticality by means of a permanently attached bubble-tube and two small thumb-screws, which operate against springs between the plates; and the bearing-arm is governed in its revolution about the polar axis by the usual small clamp-and-tangent screw-arrangement.

The solar adapter with the small striding level, used to bring the auxiliary back to a horizontal position after the main telescope has been set for declination, adds only 9 oz. to the weight of the instrument, so that, with a little care, the same counterpoise-weight will answer every purpose.

The diaphragm of the auxiliary, when thus used for solar

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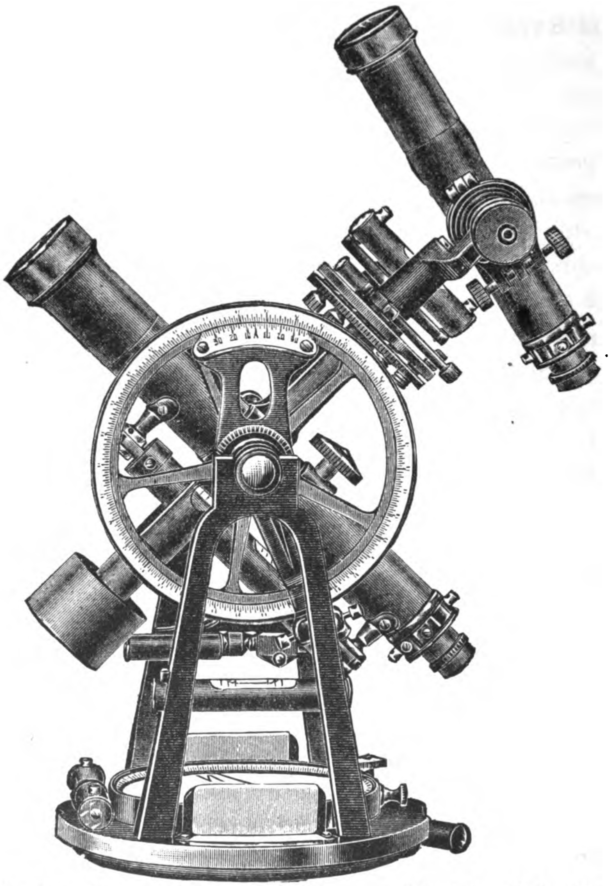
* *Trans.*, vii., 308.

† *Eng. and Min. Jour.*, N. Y., vol. xlviii., No. 24, Dec. 9, 1899; also *Mines and Minerals*, Scranton, Pa., vol. xx., No. 6, Jan., 1900.

purposes, is provided, in addition to the usual cross-webs, with four extra coarse webs, forming a square slightly smaller than the sun's image, as shown in Fig. 166. This arrangement of webs, as Mr. Lyman will see, does not interfere with the successful operation of the auxiliary in mining work; and, indeed, there is no valid objection to the use of cross-webs—though,

FIG. 164.



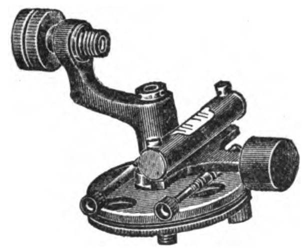
The Interchangeable Auxiliary Telescope Adapted to Solar Work.

for the peculiar exigencies encountered in conducting a mine-survey with an *interchangeable* auxiliary, a single web fulfills every demand and is not a "serious inconvenience," unless the surveyor insists upon doing the very thing I am trying to avoid, namely, observing vertical angles with the auxiliary on top, and computing the correction for eccentricity.

Mr. Lyman is entitled to grateful acknowledgment for the very thorough investigation he has made in response to the last paragraph of my paper,* which was intended to convey more plainly my own estimate of its worth than the presumptuous title would imply. The time available for its preparation in the midst of a busy professional career was so limited as to permit errors and misconceptions to creep in. Of course it is as absurd to suppose that Ramsden had constructed his circular dividing engine at twenty-three, in the second year of his apprenticeship, as that Draper had constructed a transit in the sixteenth year of his age; and the implied assertion that Ramsden had introduced, posthumously, a transit-principle is a self-evident mistake.†

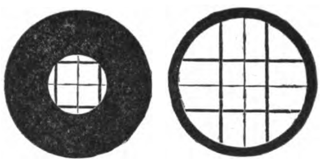
Mr. Hoskold has shown in his second contribution that

FIG. 165.



The Solar Adapter.

FIG. 166.



Diaphragm of the Interchangeable Solar Auxiliary.

Ramsden did not complete his dividing-engine until 1773, instead of 1760, as I had it;‡ and while no less an authority than Mr. Stanley is responsible for the citation concerning the introduction of the transit-principle by Ramsden in 1803,§ he is now unwilling to substantiate any part of it, and, in writing me, seems inclined to forgive us for having detected an inaccuracy in his otherwise studiously prepared and exhaustive work.

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* SECRETARY'S NOTE.—The paragraph here referred to, which formed the conclusion of Mr. Scott's paper in its pamphlet form, was a request for correspondence, corrections, and additional facts. Having served its purpose, it was, for obvious reasons, and in accordance with usual practice, omitted when the paper was printed in permanent form in vol. xxviii.—R. W. R.

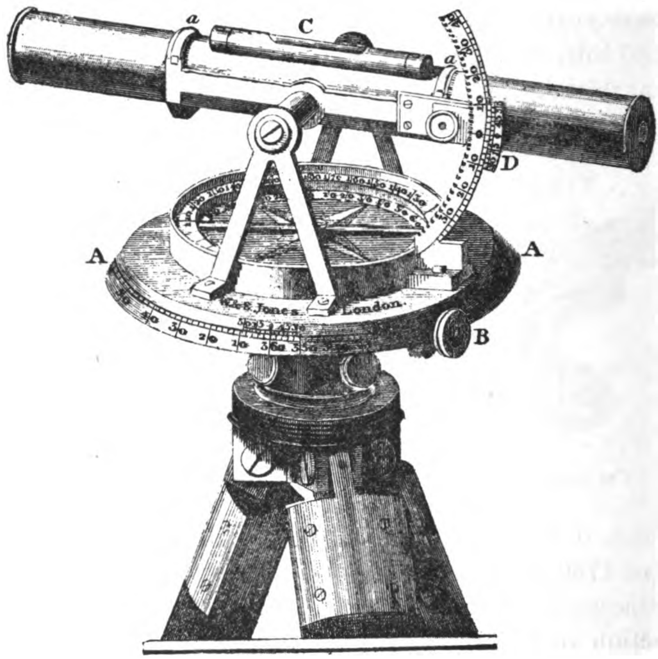
† Mr. Lyman's paper, Canadian meeting, Aug., 1900, pamphlet ed., pp. 33–35.

‡ *Trans.*, xxviii., 694 and 697.

§ *Surveying Instruments*, William Ford Stanley, 2d ed., London, 1895, p. 206.

Much force was given, in my mind, to this citation, when I found in Adams's *Geometrical Essays*, published six years previously (1797), a description and cut of a miniature theodolite, herewith reproduced in Fig. 167. This is a 4-inch model which Adams designed in 1791, and at least suggests the possibility of making a small transit-instrument by slightly increasing the height of the standards as they occur in the contemporaneous instrument shown in Fig. 16, and by substituting a better-proportioned telescope.

FIG. 167.



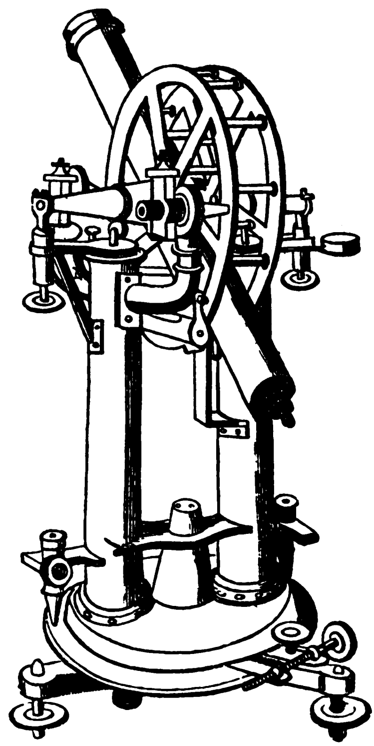
Adams's Miniature Theodolite.

The telescope rested in a sort of cradle, and could be reversed, end for end, by opening the clips, *a*, *a*. The vertical arc was set concentric with the axis of revolution; and while, by the old-fashioned rack-and-pinion screw, the telescope could be made to move through an arc of only from 30° to 40° above and below the horizon, I consider this, in some respects, the most perfect of old English portable instruments.

Dr. Raymond has called attention to the fact that the original astronomical transit-instrument was the invention of Roemer (Olaus Roemer, the Danish astronomer) in 1700, though other authorities place the date as early as 1689; for the instrument was described in 1700 in the third volume of *Miscellanea Berolinensia.* In 1704 Roemer combined with it a vertical or altitude-circle, possibly the first of that type of instrument which the English have since designated "alt-azimuth."

The first of this class for the Greenwich observatory was built by Troughton in 1816; and Mr. W. T. Lynn* informs me that the first of the portable type, to the best of his knowledge, is referred to in the sixth volume of the edition of 1830 of the *Edinburgh Cyclopedia,* where there is illustrated and described a portable transit-instrument which Edward Troughton designed in 1810. In the same place he is credited with having contrived a similar one as far back as 1792.

FIG. 168.



8-inch Alt-Azimuth.

Later, Mr. Lynn says, there was published in the *Dictionary of Arts, Sciences and Literature* (Abram Rees, 1810) another model of Troughton's, which bears a very close resemblance to Young's. The only copy of this rare work known to Mr. Lynn is preserved in the British Museum, where they object to having reproductions of any kind made, though I hope subsequently to prevail upon the Director to extend this courtesy to American students. The transit illustrated by Rees has some points in common with the one I have selected from Simms's work† and presented in Fig. 168. The author does not give the date of its introduction;

* Late of the Royal Observatory; now residing at 26 South Vale, Blackheath, London, S.E.

† *A Treatise on Mathematical Instruments,* F. W. Simms, London; 1st ed., 1834; 5th, 1844.

but Mr. W. Simms (now retired from the firm of Troughton & Simms) testifies that it was a regular model when he entered the business in 1832. The azimuth-axis of this transit-instrument was inverted between the standards, as in one of Mr. Hoskold's instruments; but the pillars were of sufficient height to permit a complete revolution of the telescope—a desirable feature not included in the model just referred to (Fig. 75, p. 99).

It would be hardly fair, from what I know at this writing concerning these instruments, to attempt to show that the designs prevalent in early English models were in any way responsible for that of Young, particularly as these so-called altitude- and azimuth-instruments, with their large circles and reading-microscopes, were intended rather for geodetic work than for civil or railroad-engineering. It is noteworthy that, in another work of Simms,* one E. M. Clark advertises to sell "Young's Railway Transit," and recommends it as possessing many advantages over the theodolite for railroad work.

My remarks upon Young's invention were, in a measure, based upon a long-established popular opinion, sustained by such authorities, among others, as Johnson† and Carhart.‡ I do not think the elder Young would claim what was not rightfully his. His grandson, in contributing to this discussion, has been noticeably generous in the apportionment of honors with a fine sense of charity unknown to some of the phenomenal manufacturing inventors who sit in their shops and anticipate the instrumental embodiment of every scientific principle with which the engineering profession has to deal!

Mr. Lyman's researches concerning Draper are highly appreciated; but any attempt to associate his name with the invention and introduction of the transit in America seems to be permanently defeated by the evidence of Mr. B. Jay Antrim, Draper's oldest apprentice, still residing in Philadelphia, who testifies that he was born in 1819, and, at the age of 15, went to learn his trade of Draper, who, at that time, had been in business two years. If Mr. Antrim's recollection be accurate,

* *A Treatise on Drawing Instruments*, F. W. Simms, London, 3d ed., 1847.

† *Theory and Practice of Surveying*, J. B. Johnson, C.E., New York, 1886, 1889, p. 86.

‡ *A Treatise on Plane-Surveying*, Daniel Carhart, C.E., Boston, 1887–93, p. 396.

Young's transit, as shown in Fig. 60, was on the market a year before Draper became established; and it would further appear that, where I have spoken of Draper's house as founded in 1815,* I am in error, as well as my informant, Mr. Knight, by about 17 years.

Mr. Lyman's heroism in the defence of Mr. Heller (p. 281) is characteristic and commendable; but I do not deserve the imputation of being partial or malicious. I made repeated efforts to obtain information from Mr. Heller in correspondence, and even went to the patient expedient of inducing an acquaintance to call at his office for that purpose, but was not, I regret to say, indulged with the solicited consideration. If, however, after the lapse of two years, he has delivered the desired facts to Mr. Lyman, I am obliged to both for thus enriching the technical value of this investigation.

At first glance, Figs. 159 and 160 in Mr. Lyman's paper seem to contradict my somewhat sweeping statement at the top of p. 40; but it appears that the small structures at the side of the pillars are not intended for the adjustment of parallelism, being only clamping-screws, with unusually long shanks, into which are inserted "safety-pins" to prevent loss. My statement is none the less to be qualified by the fact that the first side-auxiliary which Heller & Brightly introduced in 1871 was capable of being tested for parallelism by four clamping- and four adjusting-screws, in much the same manner, I understand, as that adopted by Saegmuller in 1881 for his solar attachment.

Perhaps that statement ought to be further corrected by a claim of the F. E. Brandis, Sons & Co.,† who introduced in 1890 the instrument shown in Fig. 169.

The top-telescope of this instrument was attached to the main telescope by the usual small upright pillars and locking-nuts; but in addition to these there was supplied a round capstan-screw base, intended to either increase or diminish slightly the length of the pillars, and so to adjust the telescopes for parallelism. The position of the hubs, as fixed by the makers, was supposed always to insure the adjustment for

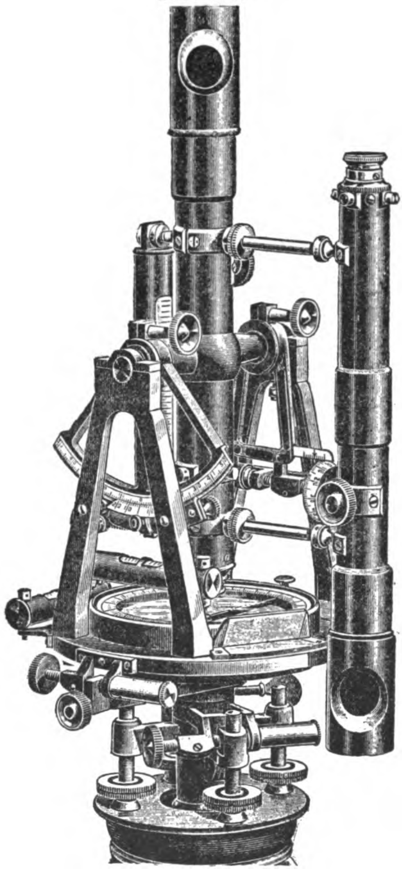
* *Trans.*, xxviii., 704.

† Mathematical instrument-makers, 814 Gates Ave., Brooklyn, N. Y.

alignment; but later, in 1894, they made it possible to test this by mounting the pillars on annular straps, which were movable in azimuth.

In 1891 this firm made also, upon the order of Barry Searle, E.M., then of Montrose, Pa., an instrument which he intended should meet all the requirements of solar, mining and railroad-work. In a letter to me, Mr. Searle describes it as provided with a detachable side-telescope and a Saegmuller solar attachment. The side-telescope was provided with a small longitudinal bubble, according to the practice instituted by the Brandis Co. in 1888 for the purpose of insuring a correct replacement of the auxiliary to correspond with the zero of the vertical circle. Mr. Searle's instrument was furnished with an adjustable 120° vertical arc, similar to that in Fig. 169, together with a prismatic eye-piece and stadia-wires. In my original paper* I quoted from Prof. Baker the statement that "stadia-hairs were not introduced in America until after the Civil War." This is incorrect, as the following passage from an American author shows:

FIG. 169.



Brandis Mine Transit.

"The credit of having first introduced this method of measurement in this country would seem to belong to Mr. John R. Mayer, a French-Swiss. It was used by him as early as 1850, and subsequently during his connection with the U. S.

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* *Trans.*, xxviii., 721.

Lake Survey. . . . An essay by him in the *Journal of the Franklin Institute*, Jan., 1865, contains a short historical sketch of the development of topographical surveying, and a brief discussion of the principles of stadia-measurement."*

I am not, nor does Mr. Lyman seem to be, convinced by any evidence yet developed that the micrometer of Gascoigne involved the principle of stretching hairs or filaments across the diaphragm, as used by Watt (1771) and Green (1778). Townley says nothing of hairs in mentioning Gascoigne's micrometer; and the citation from Mackenzie, even if it may be considered as authoritative, is not sufficient to prove this point. Mr. Lyman writes me that Grant, in his *History of Physical Astronomy*, says, at p. 452:

"Mr. Townley's micrometer was actually produced before the meeting held on the 25th of July, 1667; and a detailed description of it was subsequently given in No. 29 of the *Philos. Trans.* In principle it exactly resembles the micrometer of Auzout. Two straight edges of metal are made to approach each other at the focus of the telescope by means of a screw, the mechanism being so contrived that the optical axis of the telescope is always situate midway between the two edges. . . . . Hooke suggested an improvement upon this micrometer by substituting human hairs for the solid edges."

My observation at the top of p. 43 has yet, I believe, to be disproved, even though, at the time, I had overlooked James Watt. More recently there has come to my notice other literature on the subject,† introducing a new claimant who, with respect to the stadiametric principle, will at least supersede both Watt and Green. At p. 619 of his work on surveying,‡ Dr. Jordan says, as one would translate:

"Concerning the history of the stadia, it is reported in *Études théoriques et pratiques sur les levers topométriques et sur tachéométrie*, by C. M. Goulier, Paris, 1892, that the stadiametric measurement was commonly supposed to have been invented in 1778, by Wm. Green, an optician of London, and has been used since 1812, in Holland, by French army officers, and since 1816 in mapping the borders of Savoy. The Italians date the invention still further back to 1674, at which date Geminiano Montanari introduced the practice of placing upon the diaphragm many equidistant threads; and the number of these intervals, for a rod of a fixed length, determined the distance at which it was placed. As an authority for

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* *Stadia-Surveying*, Arthur Winslow, New York, 1884, p. 5.

† Prof. E. Hammer in *Zeitschrift fur Vermessungswesen*, xx. Band, Heft 11, 1891; also, the same with addenda in *Zeit. für Instrumentenkunde*, May, 1892. See also Prof. M. Schmidt on "Mensula Prætoriana," in *Zeit. fur Verm.*, xxii. Band, Heft 9, 1893.

‡ *Handbuch der Vermessungskunde*, Dr. W. Jordan, Stuttgart, 5th ed., 1897.

these facts is cited *La livella diottrica* of Dr. G. Montanari, Venezia, 1680, p. 28; and one should also compare *Instrumenti e metodi moderni di geometria applicata*, A. Salmoiraghi, Milano, 1884, pp. 278–279."

The conception of the idea of subtense measurement, with a constant length of rod, plainly belongs, then, to Montanari, while Watt and Green seem entitled to only the credit of having introduced the improved method as we use it to-day.

I am reminded here to touch briefly upon the subject of platinum wires. While I have no authority or inclination to dispute the fact that Heller & Brightly were first to introduce these in America, their original introduction as a substitute for spider-webs on the diaphragms of telescopes certainly belongs to Dr. Wm. Hyde Wollaston, a celebrated English scientist, who died in 1828. He received a medal of the Royal Society for his process of manufacturing platinum; and his paper on its malleability was published in the *Philos. Trans.* the year following his death. It is now hinted that he acquired the secret of rendering it malleable from one Thomas Cock.

Because Digges incidentally recommended his *theodelitus* for use in mines in a short note, in which his only instructions are to the effect that "the diligent practizioner shall be able of himselfe to invent manifolde meanes to resolve" the problems confronting him, Dr. Raymond omits to give v. Hanstadt the credit of having written the first exclusive treatise on mine-surveying, in which the theodolite is recommended in preference to all other instruments.

At any rate, with respect to the hollow brass cylinders spoken of, I feel impelled to take exception to the foot-note at the bottom of p. 169, in the course of Dr. Raymond's remarks, as confusing. While the *Spreitzen* or gang-plank is the same in each case, the methods of setting-up are very different; and to distinguish these features I submit a cut of Mōhling's *Eisenscheibe* and its support (Fig. 170), with a few extracts taken from his work.*

"The *Eisenscheibe* differs from the astrolabe only that it is provided with a ball-and-socket joint beneath the center, and, in place of the diopters, is supplied with two similarly constructed lineals, having hooks at the outer ends and pivot-joints at the center.

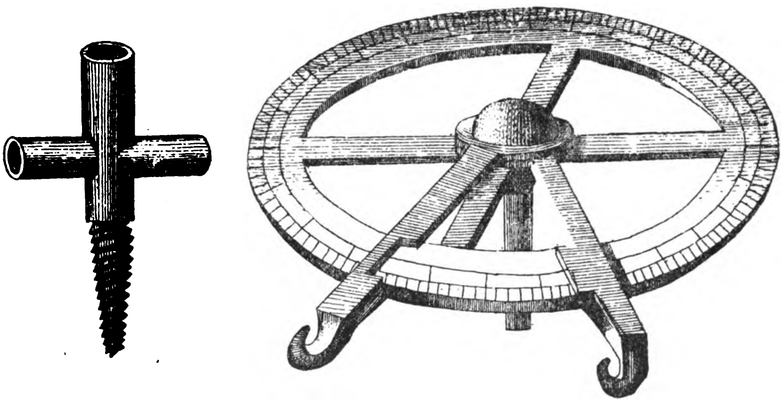
* *Anleitung zur Markscheidekunst*, Johann Möhling, Wien, 1793, p. 155.

"In the beginning of a survey the *Kreutzschraube* (cross-screw) is set firmly into the plank of the second station. After the shank of the instrument has been inserted into the socket of the support, one of the arms is connected by a cord with the first station, and the instrument is swung upon its axis until the zero of the graduations coincides with the index of this arm. The second arm is now connected with a cross-screw placed at the third station in the same manner; and the indicated angle on the plate is the one sought.

"The inclination of the cord is determined by the *Gradbogen*, and the distance by measurement, in the usual way.

"Because the instrument must sit very securely, on account of the tension in the cords, we cannot use a tripod, as with the astrolabe, so that a very solidly wedged plank is necessary, and this is especially true since one must be certain of placing the instrument precisely at the point to which the cord had been previously stretched."

FIG. 170.



Möhling's *Eisenscheibe* and Support.

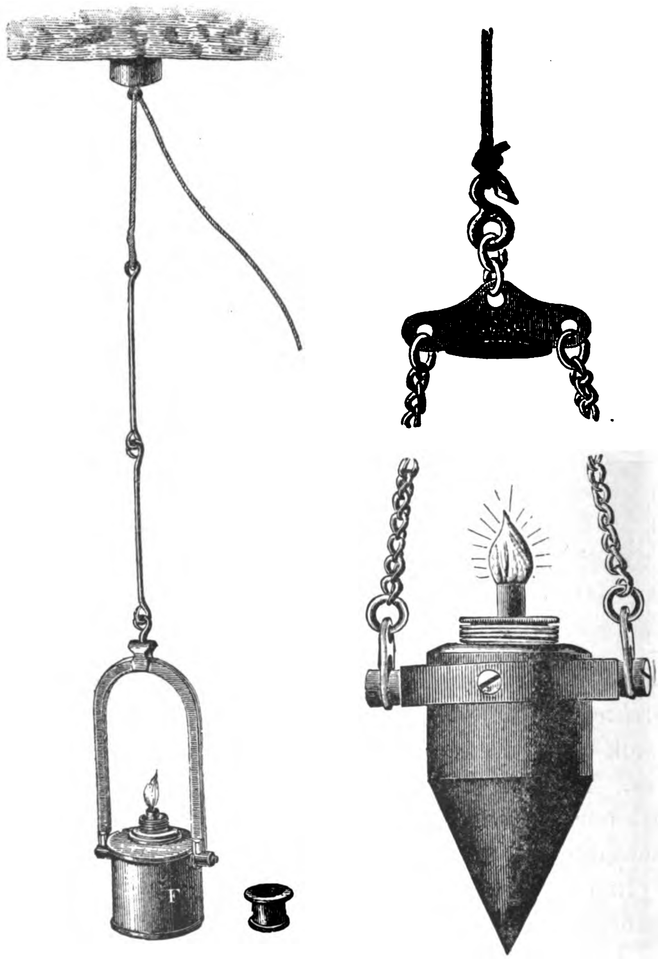
So far as I know, Möhling's form of support is unique; but the *Spreitzen* method of setting-up is very old, and probably dates back to the time when the astrolabe was first employed in mines. Another application of it (Fig. 172), in which no holes are bored, I shall include in the short discussion on the plummet-lamp of Mr. Coxe, which I now beg leave to submit.

The plummet-lamp, as introduced in America by that versatile engineer, Mr. Eckley B. Coxe, I infer, was the more highly civilized resultant of an old German method, taught him while he was a student at Freiberg.

Weisbach's hanging lamp, reproduced here in the first part of Fig. 171, is selected from his work of 1859; and I have no doubt that, being his invention, it also occurs in the first edition (1851). Its construction is so apparent that no special explanation need be given.

He recommended it for surveys where, in open chambers and the like, the instrument had to be mounted upon a tripod, except for sights of less than 3 *Lachter* (fathoms). In that case, he explains, an attempt to bisect the flame is not attended with

FIG. 171.



Weisbach. Coxe.

The Hanging Lamps of Weisbach, 1850, and Coxe, 1870.

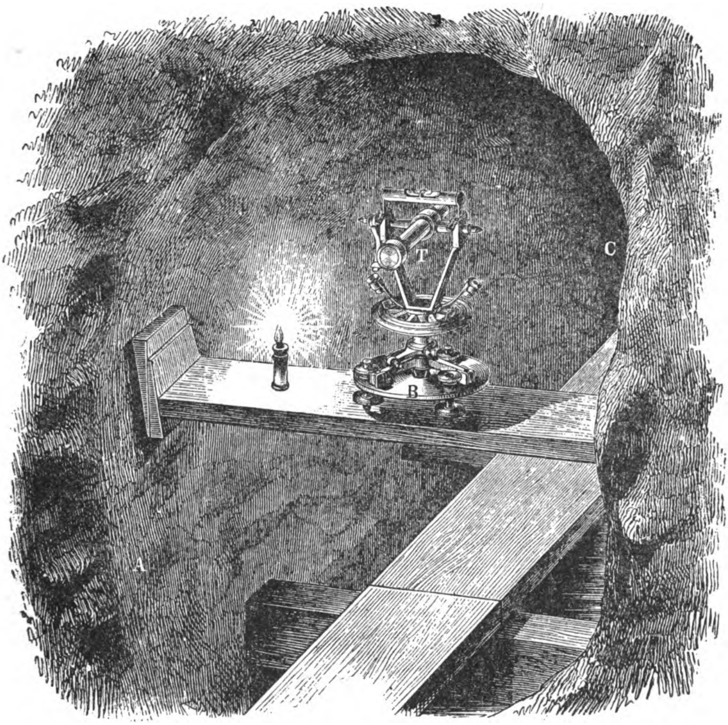
good results; and in such cases the plumb-line only should be sighted.

Weisbach always greatly preferred the *Spreitzen* method of setting-up, as shown again in Fig. 172, and the *Setz-signal-lampe*

(Fig. 173), which, as he contrived it, was, in reality, the base of a theodolite peculiarly designed to carry out this practice. His special argument in favor of the *Spreitzen* system was based on the fact that the plank provided room, not only for the instrument, but also for the hand-lamp and the note-book, as occasion demanded.

The *Setzlampe* was a brass plate with a central circular

FIG. 172.



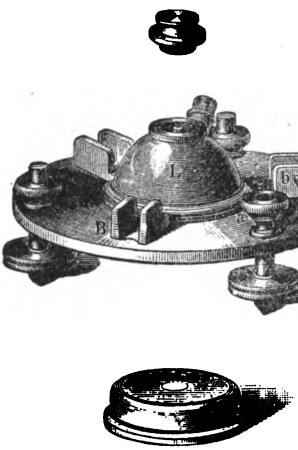
Weisbach's *Spreitzen* and *Setzlampe* System.

socket, into which the box-bubble was first placed, and then, when the plate was perfectly level, the oil-cup and burner. To insure a permanent adjustment in this respect, the small nuts on the upper shank of the leveling-screws were screwed down tightly against the plate.

When a sight had been taken upon the flame, the lamp was removed, the instrument was brought forward, and the legs were clamped into the saddles, B, B, by the little set-screws at the side. The circular base of the theodolite was also designed to fit perfectly into the lamp-cavity of the plate.

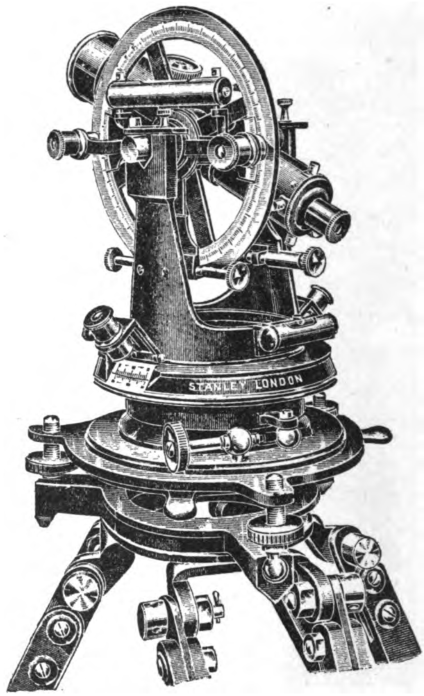
This is another instance of the three-screw leveling-method. Not feeling competent, I shall not attempt to discuss that point further, but will rather leave the exposition of its merits to Mr. Stanley, who I trust will favor us eventually with a more extensive account of his research in England and on the continent of Europe. In 1870 Stanley introduced a special form of theodolite, intended to be universal in its application, which he termed the *geodolite;* but for mining work it was much too tall

FIG. 173.



Weisbach's *Setzlampe.*

FIG. 174.



Stanley's Nadir Mining and Railroad Tunnel Theodolite.

and weak, so that the model was abandoned. Recently he has come out with something novel in the way of a nadir mining theodolite, shown in Fig. 174, which invites special attention to the three-screw argument, as well as the shifting center in connection with this construction.

In the Stanley 4-in. model (Fig. 174), the outside diameter of the vertical axis is $2\frac{3}{4}$ in., the clear central aperture $2\frac{3}{8}$ in., and the range of the telescope on each side of the nadir 5°. The distances between the leveling-screws mark a triangle of

6¾ in. on a side, and the entire weight of the instrument alone is 16 lbs. The horizontal axis of this instrument is pierced to permit the diaphragm to be illuminated by a bracket-lamp; but I regard such lamps as abominable excrescences, and the perforation of the horizontal axis as a reckless novelty, for mining work. The damp atmosphere of a mine should never be allowed to enter a telescope in this way, to film the lenses with moisture and relax the spider-webs by virtue of their hygrometric properties. Even an objective reflector is unnecessary; for by simply flickering the candle-flame a short distance in front of the objective, one can sufficiently discern the cross-webs until he gets them bearing on an illuminated plumb-line or station.

Concerning my own instrument, again I refrain from extended discussion. I have, perhaps pardonably, elevated it to lofty dignity among other mining instruments, because it embraces everything that I consider essential for accuracy, simplicity, rapidity and completeness. That, however, is a purely personal opinion. Others, after studying its features, will accept or reject it as they choose. I have absolutely no pecuniary interest in inciting enthusiasm anywhere.

It is not improbable that this general topic will be pursued indefinitely by other members and outsiders, and even I may ask permission to appear again; but, before I finish this contribution, I wish to make ample acknowledgment of my gratitude for the valuable assistance furnished me by the many gentlemen who have given up their time at my peremptory demand. To make special mention of a few would be an injustice to the rest, and to enumerate all, an imposition upon the space available in these *Transactions*; but I hope each may feel himself repaid by the result of the labors of all, and that the information thus collected may be of service to mining students now and hereafter.

INDEX.

[Note.—In this Index the names of the authors are printed in SMALL CAPITALS, and the titles of papers in *italics*. Casual references, giving but little information, are usually indicated by bracketed page numbers.]

ERRATA.

Page 3, line 2 from bottom. "Munster" should be "Münster."

Page 4, line 5. "Beyern" should be "Beyer."

Page 4, line 17. "2364" should be "2634."

Page 5, lines 3 and 4 from bottom. "Diggs" should be "Digges" and "Leonhard" should be "Leonard."

Page 6, line 1. "*Theodolitus*" should be "*theodelitus.*"

Page 6, line 2 from bottom. "The same year" should be "1579," and "Stratiaticus" should be "Stratioticos."

Page 7, line 15. "1590" should be "1608." The telescope given then to Prince Maurice was made by Lippershey, not Jansen.

Page 7, line 19. "1608" should be "1609."

Page 9, line 1. The reference here made is to *Höhere Markscheidekunst*, by Prof. Albert von Miller-Hauenfels, Wien, 1868, pp. 286–291.

Page 11, line 8 from bottom. "Strum" should be "Sturm." See his *Vier kurze Abhandlungen*, of which the fourth treats of the *Markscheidekunst als ein Anhang dem kurzen Begriff der gesammten Mathesis beizufügen*, Frankfurt a. d. O., 1710.

Page 11, line 4 from bottom. After "J. G. Studer," add: See *Ueber Eisenscheiben. Freiberger gemeinnützige Nachrichten*, No. 50, 1802. *Moll's Annalen*, II., p. 387.

Page 12, line 2 from bottom. "1537" should be "1590."

Page 12, line 2 from bottom. After "Leonhard Zubler," add: See his *Fabrica et Usus Instrumenti Chorographici*, Basel, 1625.

Page 13, line 12 from bottom. After "Dr. Lamont" insert (1840).

Page 16, line 11. "Helvetius" should be "Hevelius."

Page 16, line 6 from bottom. "Guiliani" should be "Giuliani."

Page 19, lines 16 and 17. "Dolland" should be "Dollond."

Page 19, line 4 from bottom. "1669" should be "1667."

Page 20, line 15 from bottom. "Bourne" should be "Bourns."

Page 21, at bottom. "Bohm" should be "Bœhm."

Page 28, line 16. "1845" should be "1836."

Page 43, line 4. "Gascoign" should be "Gascoigne."

Page 45, line 11. "British" should be "Argentine Mining and Metallurgical."

Page 61, line 10 from bottom. "Up" should be "upon."

Page 61, line 5 from bottom. "Steep horizontal angles" should be "horizontal angles measured with the telescope steeply inclined."

Page 62, line 10 from bottom. "Kelner" should be "Kellner."

Page 272, foot note, for "210" read "219."