The Solar Transit.

B. H. Smith

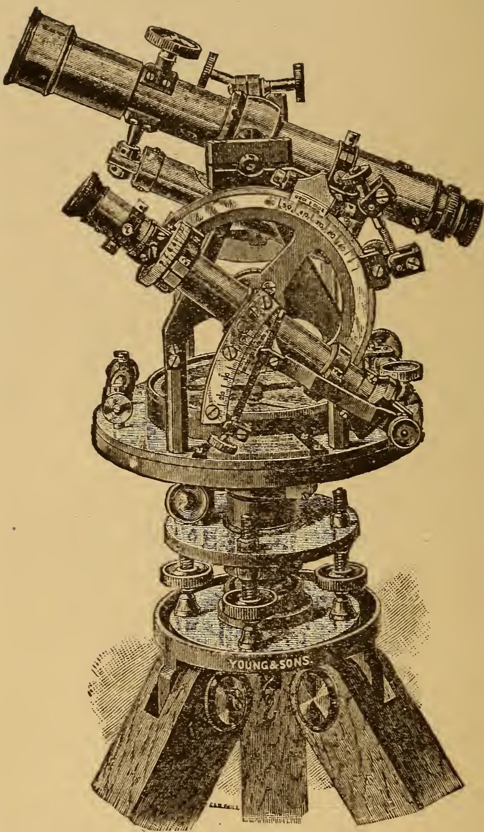
THE

SOLAR TRANSIT

THIS ACCOUNT OF THE SOLAR COMPASS, AND THE MERIDIAN ATTACHMENT FOR TRANSIT INSTRUMENTS, WAS WRITTEN FOR YOUNG & SONS, BY BENJ. H. SMITH, OF DENVER, COLORADO.

PRICE 25 CENTS.

PHILADELPHIA:
YOUNG & SONS, NO. 43 NORTH SEVENTH STREET.



YOUNG & SONS'

No. 10, or MOUNTAIN TRANSIT,

With B. H. Smith's Meridian Attachment.

(*Patented September 14, 1880.*)

Meridian Attachment

for

Transit Instruments.

Although the Solar Compass has been in constant use for more than thirty years, and, with its modern improvements has become one of the most useful instruments known to the surveying profession ; yet, it is a remarkable fact, that its existence has been almost entirely ignored by the authors of all the modern text-books on surveying commonly used in schools and colleges.

As a consequence, the young surveyor who soon finds the use of the solar apparatus attached to his transit indispensable in his practice, is obliged to resort to his own ingenuity to master the principles upon which the instrument is based, or depend upon the imperfect and often incorrect account to be found in the catalogue of the instrument maker he may happen to have on hand.

To attempt to adjust and use any instrument without thoroughly understanding its principles, can only result in unreliable work, which fact has been notably demonstrated in the use, or rather abuse of the Solar Transit.

It is the design of this paper to supply a clear and concise account of the instrument and its modifications, for the use of surveyors, and especially of those who may not be familiar with the astronomical problems involved in its construction, a brief explanation of which will first be given.

The Diurnal Motion.

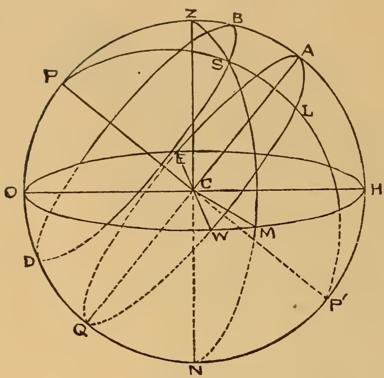


Fig. 1.

For our purpose, the earth, so infinitely small in comparison with celestial magnitudes, may be supposed to be a fixed point C in space around which revolves the celestial sphere O N H Z, Fig. 1, in which Z represents the ZENITH and N the NADIR of the observer; P C P′ the POLAR AXIS, about which the diurnal motion is apparently performed; O E H W the celestial HORIZON whose poles are Z and N, and A E Q W the celestial EQUATOR whose poles are P and P′. All circles passing through Z and N are called VERTICALS, and those through P and P′ are MERIDIANS or hour circles, the one passing also through Z being the meridian of the place, or simply THE MERIDIAN.

All the circles mentioned are GREAT circles, that is, circles whose planes pass through C the center of the sphere. The circle B S D, described by the star at S in its diurnal motion, is a LESS circle. The distance from P or P′ to any object on a meridian is called its POLAR DISTANCE, and the remainder of the quadrant measured from the equator is called its DECLINATION. The distance from the zenith to any object on a vertical is its ZENITH DISTANCE, and the remainder of the quadrant to the horizon is called its ALTITUDE. Thus, P S is the polar distance, L S the declination, Z S the zenith distance, and M S the altitude of the star S. O and H are the north and south points, and E and W the east and west points of the horizon. The direction of an object, whether terrestrial or celestial, with reference to the plane of the meridian, is called its AZIMUTH or BEARING. O M or the angle P Z S is the azimuth of any object, S or M, in the vertical P S M reckoned from the north point. The angle Z P S, which the circle P S P′ makes with the meridian, is called the HOUR ANGLE of the star S.

Careful observations of the motions of the stars, if continued for a sufficient period, will show that although their relative positions, and, therefore, polar distances and declinations, remain unchanged, they all seem to revolve with a uniform motion from east to west as though attached to the internal surface of a vast hollow sphere, having the observer in its centre and turning round the axis P C P′, inclined to the horizon at an angle equal to the latitude of the place. This apparent rotation of the heavens is called the DIURNAL MOTION.

All bearings in land surveys being referred to the line H O, the correct determination of the direction of that line for any particular place is of utmost importance to the engineer and surveyor. The pole star whose polar distance is less than one degree and a half is a very convenient object for this purpose; and, also, at the same time, for determining the arc P O or latitude of the place.

The Engineer's Transit being an altitude and azimuth instrument, can be used to take equal altitudes of the sun or of a star from which the meridian is readily determined, or the latitude and declination being known, the azimuth and hour angle may be computed from a single altitude of the sun or a star as follows: In the spherical triangle P Z S are given the three sides, P Z the complement of the latitude, P S the polar distance or complement of the declination, and Z S the zenith distance or complement of the altitude, whence P Z S (= O C M) the azimuth, Z P S the hour angle, and Z S P the parallactic angle may be calculated.

These methods all result in a sure determination of the meridian, but the time involved in taking and reducing the observations is not always available to the engineer. Hence, the great value of a Meridian Attachment which will mechanically and instantly solve the problem above mentioned from a single observation of the sun, the apparent motion of which will be next considered.

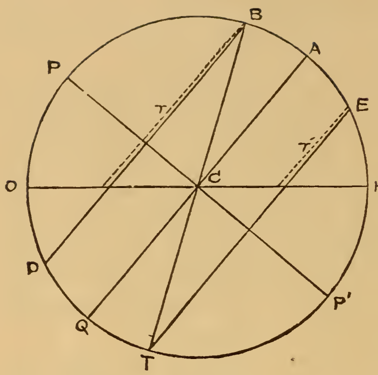


Fig. 2.

If observations be taken at C, Fig. 2, during a whole year, it will be found that independently of the diurnal motion which the sun has in common with the stars, it has also a motion in declination causing it to appear to describe annually the great circle B T called the ecliptic, the plane of which forms an angle of about 23° 28′ with the celestial equator A Q. The sun will appear to describe the circle B D at its greatest north declination on the 21st of June, and the circle E T at its greatest south declination on the 22d of December. Its declination will be zero when crossing the equator on the 21st of March and 23d of September, respectively.

The Meridian Attachment is simply an instrument made to imitate, on a small scale, the motion of the celestial vault as above described, consisting of a Solar Telescope revolving about its polar axis, which corresponds with P C P′, in such a manner, that the line of collimation will follow the sun or any star in its apparent diurnal motion round the earth. Conversely when the transit is turned on its vertical axis to a position where the Solar Telescope when revolved on its axis will follow the sun or star, its axis must be in the line P C P′, and, therefore, in the meridian of the place. This principle was first utilized, but for a different purpose, in the construction of the Universal Ring Dial, more than a century ago, and a description of that simple instrument, will best illustrate the subject for the reason, that all the many forms of solar attachments are constructed upon the same principles, and may be said to be mere modifications of the Ring Dial.

The Ring Dial.

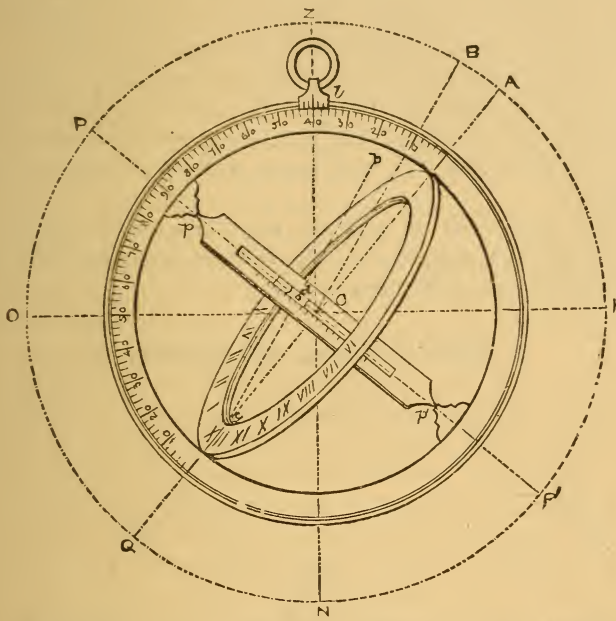


FIG. 3.—Ring Dial. H O, Horizon; P P, Polar Axis; A Q, Equator; A C Z = P C O, Latitude; A *c b* = A *c* B, North Declination.

The Ring Dial, Fig. 3, consisted of two rings of brass or other metal, which being turned at right angles with each other, corresponded with the equatorial and meridian circles A E Q W and O Z H N, Fig. 1, and a plate turning on pivots at *p* and *p′* represented the polar axis P C P′. In an opening in this plate moved a brass block *d* through a small aperture in which the sun's image was projected on a line engraved on the inner edge of the equatorial circle. The block *d* could be set to any required declination A C B, by means of graduations along the opening in which it moved. The meridian circle was utilized as a latitude arc. The dial was suspended from a ring attached to the vernier *l* which was set to the latitude of the place, A Z

(= P O). The axis of the instrument then corresponded with the line Z N and was revolved slowly thereon, until the sun's image crossed the equatorial line, the hour being indicated by graduations upon the lower half of the equatorial circle.

With the instrument firmly fixed in this position, the sun's image would follow the equatorial line, and, hence, its axis of motion would correspond with $p p'$, which would then coincide with the polar axis P P′, and, hence, with the direction of the meridian.

The Ring Dial, if properly mounted, would, therefore, answer all the purposes of a Solar Compass in determining the meridian as well as the time of day.

Burt's Solar Compass.

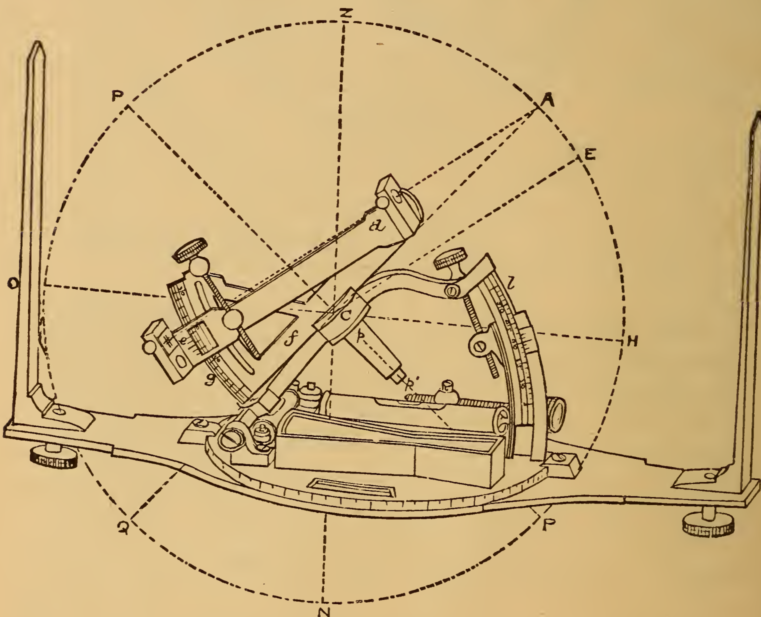


FIG. 4.—Burt's Solar Compass. H O, Horizon; P P, Polar Axis; A Q, Equator; A C Z = P C O, Latitude; C A e = A C E, South Declination.

The first practical application of these principles to the art of surveying, was made by William A. Burt, of Michigan, in his invention of the Solar Compass, the prominent features of which are represented in Fig. 4. The bar *f* revolves in the plane of the equator A Q about the polar axis $p p'$, carrying the declination arc *g* and bar *d e*. The sun's image is brought to a focus at the intersection of lines engraved on a silver plate at *e* by means of a lens in the opposite end of the bar. To find the meridian, the latitude P C O is set off on the latitude arc *l*, and the declination A C E on the declination arc *g*. The Compass is then revolved about its vertical axis Z N, and the Solar apparatus about its polar axis until the image of the sun is brought accurately within the lines at *e*, when the axis $p p'$ must, necessarily, correspond with the plane of the meridian.

This invention was originally designed, and was admirably adapted for use in connection with the open sight compass for work on the public land surveys, but when the Engineer's Transit came into more general use, and a higher order of land surveying was demanded, various attempts were made to attach the Burt apparatus to the Transit, but never with satisfactory results. It has been mounted over the needle box, under the main plate, on the end of the axis, on top, and even on the object end of the Telescope, but in every case at the expense of the usefulness of the Transit.

The Meridian Attachment.

With a view of meeting these objections, the writer, a few years ago, designed a form of Meridian Attachment, especially for use in connection with the Engineer's Transit, which has since been manufactured by Messrs. Young & Sons, to whom belongs the credit due to skillful workmanship and good judgment in the arrangement of the details of construction. After six years' trial in the field, it is found that the following advantages over the old form have been secured:

(a) Compactness of form, especially adapting it for attachment to the Engineer's Transit. The instrument being complete in itself, the Transit Telescope and vertical arc are not required to do double duty. The view of the needle box and verniers is unobstructed.

(b) The sun being observed through a telescope, its image can be brought sharp and clear between the equatorial wires with greater exactness than can be attained by the old plan of focussing upon a silver plate; and, hence, the meridional result is more accurate.

(c) The polar axis, which from the preceding remarks will be recognized as the vital part of a Solar Attachment, is longer than in any other form.

(d) The sun's image can be clearly defined in hazy weather when the old forms cannot be used at all.

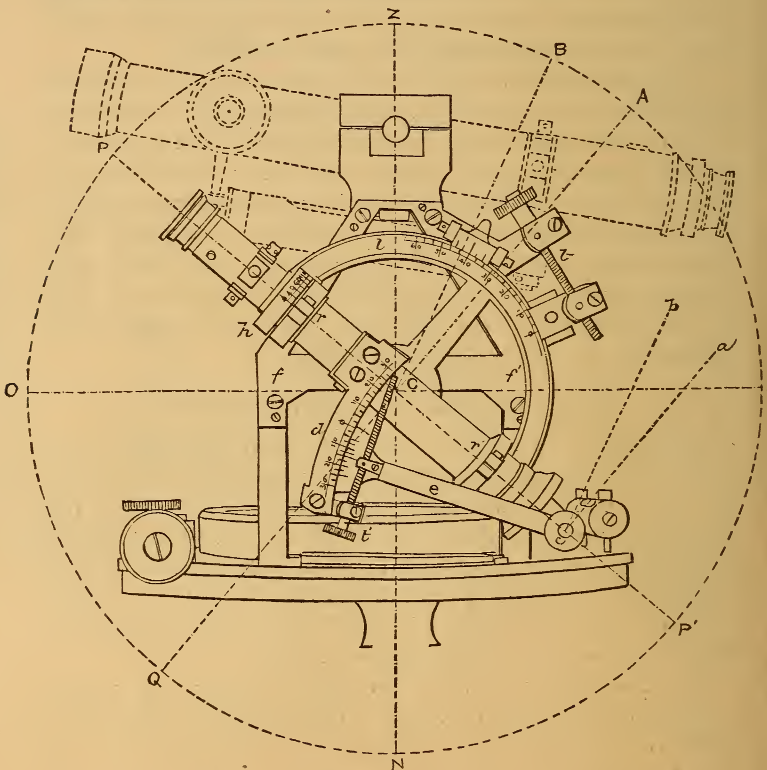


FIG. 5.—Smith's Meridian Attachment. H O, Horizon; P P, Polar Axis; A Q, Equator · A C Z = P C O, Latitude; *a c b* = A C B, North Declination.

The Meridian Attachment is represented in Fig. 5, C is the Solar Telescope revolving in collars *r* and *r′*, whose line of collimation and axis of revolution coincide with the polar axis P P′. The declination arc *d* is fixed to the side of the Telescope, the vernier being attached to the arm *e* which turns on its axis a reflector at *c* in front of the object-glass of the Telescope. The collars in which the Telescope revolves are firmly attached to the latitude arc *l*, having a horizontal axis, the whole being mounted on the frame *ff′* which is attached to the standards of the Transit. Tangent screws *t* and *t′* give slow motions to the declination arm and latitude arc.

The arm *e* is so adjusted that the declination vernier reads zero when the plane of the reflector makes an angle of 45° with the axis of the Telescope, in which position the line of collimation is reflected at right angles, and is caused to coincide with the line *a c* parallel with A C. Hence, if the Telescope be revolved on its polar axis, the line of collimation will describe the celestial equator A E Q W, Fig. 1. In like manner, by setting off on the declination arc any given declination north or south, as A C B or A C E, the image of any celestial object traversing the circles B D or E T, Fig. 2, may be kept in the center of the field of view from rising to setting, by simply revolving the Telescope. The hour arc is attached to the Telescope at *h*, revolving at right angles with the polar axis, and, hence, in the plane of the equator.

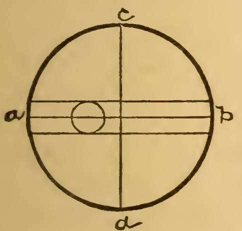


Fig. 6.

The appearance of the sun in the field of view is represented in Fig. 6. The three equatorial wires *a b* correspond with the line of the celestial equator and circles parallel therewith, while the hour wire *c d* corresponds with the hour circle or meridian towards which it may be directed.

The meridian is found in precisely the same manner as with the Ring Dial and Burt Solar Compass. Having set off the latitude and declination, and the hour circle to the approximate time, the sun can generally be brought into the field of view by simply revolving the Transit on its vertical axis. The Transit then being clamped, the sun may be brought accurately between the equatorial wires with the tangent screws, at which time the Solar Telescope and also the Transit Telescope parallel to it, will be in the plane of the meridian.

The same letters and lines have been used in the foregoing figures for purposes of comparison, and to show the reader how the three instruments described are based upon the same principles.

Latitude.

It will be readily understood from the above explanations, that the Meridian Attachment in common with all forms of solar devices for determining the meridian, depends for accuracy of results upon the indispensable condition that the polar axis of the instrument must coincide with the line P P′, Fig. 2, at some time during a revolution of the Transit on its vertical axis. Hence, the most important requirement is a correct determination of the angle P C O or the latitude of the place of observation. Whether ascertained from accurate maps or charts, or from direct observations by some of the well-known methods, the latitude should be known within one minute to ensure a correct meridional result.

Declination and Refraction.

The apparent declinations of the sun at Greenwich mean noon, and the hourly differences may be found in the Nautical Almanac. To calculate the declinations, it requires an approximate knowledge of the longitude of the place, which can be determined from any good map with sufficient accuracy.

The effect of refraction is to apparently increase the altitude of celestial objects. In Fig. 2, if B D and E T represent two diurnal circles described by the sun, one with north and the other with south declination, the dotted lines r and r' will represent the apparent path of the sun as affected by refraction. It will be seen that the effect on the declination will be to apparently increase it when north, and decrease it when south. The correction is, therefore, made by adding the correction for refraction to north, and subtracting it from south declinations.

The tables of refractions being calculated for verticals, cannot be applied to declinations, which are measured on meridians, without special computations. Hence, the necessity of the table of *refractions in declinations*, prepared by Hon. Cortez Fessenden, and published for use with the Solar Transit by Young & Sons. The table is calculated for all hours of the day, and for any latitude from 30° to 55°.

The method of calculating the declinations for a day's work can be best illustrated by an example:

Time, November 1, 1886. Station, Denver, Colorado.

Latitude 39° 45′ N. Longitude 105° 00′ W.

From the Nautical Almanac,

Declination, S. 14° 30′ 19.4″. Difference for 1 hour — 48.0″, the — sign indicating that south declination is increasing.

From table of refractions in declination for nearest latitude 40° and declination — 15°, the corrections are for noon, 1′ 21″, 1 hour 1′ 25″, 2 hours 1′ 35″, 3 hours 2′ 01″, 4 hours 3′ 18″.

Reducing the longitude 105° to time by dividing by 15 (15° of arc = 1 hour) gives 7 hours; and, therefore, Greenwich noon corresponds with 5 A. M., at Denver. The declination being south, the corrections for refraction are subtracted, hence, the following results:

Time.	Declination.		Refraction.		Corrected Declination.
5 A. M.	14° 30′ 19.4″				
+ 3 × 48″ =	2 24				
8 A. M.	14 32 43.4	—	3′ 18″	=	14° 29′ 25.4″
+ 48″					
9 A. M.	14 33 31.4	—	2 01	=	14 31 30.4
10 A. M.	14 34 19.4	—	1 35	=	14 32 44.4
11 A. M.	14 35 07.4	—	1 25	=	14 33 42.4
Noon,	14 35 55.4	—	1 21	=	14 34 34.4
1 P. M.	14 36 43.4	—	1 25	=	14 35 18.4
2 P. M.	14 37 31.4	—	1 35	=	14 35 56.4
3 P. M.	14 38 19.4	—	2 01	=	14 36 18.4
4 P. M.	14 39 07.4	—	3 18	=	14 35 49.4

As the declination arc is only graduated to minutes, the results may be transferred to the field book for reference, as follows :

November 1. 1886.

Noon, 14° 34′ 34.4″.

8 A. M., 14° 29′	1 P. M., 14° 35′
9 A. M., 14 31	2 P. M., 14 36
10 A. M., 14 33	3 P. M., 14 36
11 A. M., 14 34	4 P. M., 14 36

Adjustments.

From the foregoing synopsis, it will be apparent that the following conditions must be established in the construction of a theoretically perfect Meridian Attachment :

(a) The Transit to which it is attached should be in perfect adjustment.

(b) When the optical axis of the Solar Telescope is horizontal, the latitude vernier should read zero.

(c) The axis of the reflector should be at right angles with the optical axis of the Telescope, and when its plane is at 45° therewith, the declination vernier should read zero.

(d) The axis of the latitude arc should be horizontal and at right angles with the optical axis of the Transit and Solar Telescopes.

(e) The equatorial wires must coincide with the line of the celestial equator, and the hour wire be at right angles therewith.

It is supposed that the reader is familiar with all the adjustments of the Transit, but it may be worth while to remind him that good solar work cannot be effected unless his Transit is a first-class one, and in perfect adjustment.

The adjustments of the Meridian Attachment are as follows :

The Latitude Vernier. Set the latitude arc at zero, clamp it, and place the striding level upon the Telescope. Bring the bubble to the centre by turning the tangent screw *t*. Then reverse the level, and if the bubble settles in the same position as before, we may conclude that the axis is horizontal ; but, if the bubble moves from its former position, turn the screw so as to move the bubble over half this distance, the other half to be ascribed to error in the level itself. If, when the level is reversed, the bubble occupies a similar position in the opposite direction, the adjustment is complete. The vernier will now indicate the index error, which may be corrected by shifting the vernier by means of the adjusting screws for that purpose.

The Declination Arc. Having set off the latitude, take an observation of the sun on the meridian, and bring its image accurately between the equatorial wires by means of the tangent screw t'. The difference between the observed and calculated declinations corrected for refraction will be the index error, which may be corrected by loosening the three small screws on top of the arc, and moving the arc to the correct reading.

The Plane of the Latitude Arc. The axis of the latitude arc and that of the reflector should be placed by the maker at right angles with the optical axis of the Solar Telescope, and are not liable to derangement. The vertical planes of the latitude arc and the Solar and Transit Telescopes should also be made parallel; but as this condition is sometimes disturbed in detaching and attaching the apparatus to the standards, the following is the adjustment:

Having completed the adjustments above described, take a solar observation at say, 9 A. M., and note the error east or west of the meridian as indicated by the Transit Telescope directed south. Bring Transit Telescope to the meridian with the tangent screws. This will cause the sun's image to leave the equatorial wires diagonally. Then by means of the small butting screws in the plate ff', move the south end of the plate east, if the error was east, or west, if it was west, until the sun is accurately between the wires. A solar observation at 3 P. M. will verify the adjustment; but, if the morning and afternoon observations cannot be made to agree, then a portion of the error must be ascribed to the plane of the reflector not being truly at right angles with the line of collimation. The adjustment of the reflector should be perfected by the maker, and is not liable to get out of order. THE SURVEYOR IS RECOM-

MENDED, THEREFORE, IN SUCH A CASE TO ALLOW FOR THE MERIDIAN ERROR IF SMALL, BUT IF LARGE, TO RETURN THE INSTRUMENT TO THE MANUFACTURER FOR RE-ADJUSTMENT.

The Equatorial and Hour Wires. If the sun in traversing the field of view should appear to depart from the equatorial wires, the correction can be made by loosening the screws and rotating the diaphram carrying the cross wires, until the sun appears to follow the equatorial wires accurately.

All these adjustments are made by the manufacturer, and are not liable with careful usage, to become deranged. They should, however, always be verified before beginning any important work.
