VII. *The description of a floating Collimator. By Captain* Henry Kater, *F. R. S.*

Read January 13, 1825.

The line of collimation of a telescope is a line which passes through the centre of the object glass and the intersection of the cross wires placed in its focus. The apparatus which I am about to describe is intended to determine the situation of this line with respect to the horizon or the zenith, in some one position of an astronomical circle to which the telescope is attached.

A plumb line, a level, and an image reflected from the surface of a fluid, are the means which have hitherto been employed for this purpose. The defects and inconveniences of each of these have been felt, and the subject has for some years past engaged much of my attention, principally with a view of bringing instruments of portable dimensions into competition with those of a larger size.

Since a plumb line even of six feet in length would be subject to a deviation of only about three ten thousandths of an inch with an angular variation of one second, the application of the plumb line to small instruments becomes useless when great precision is required.

The difficulty of procuring a good and sensible level is well known, and though a very valuable instrument when

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carefully fitted up, it is liable to so many errors from a variety of causes, that a single observation with the best level is little to be depended upon.

The method of observing by reflection, is perhaps by far the most perfect of any that has yet been practised; but it requires a union of favourable circumstances which rarely occurs. The fluid generally employed is mercury, which reflects a sufficient quantity of light to give a brilliant image, but is so easily deranged, that the slightest breath of air, not otherwise perceptible, or the distant passing of a carriage, the sound of which is scarcely heard, is sufficient to disturb its surface, and to render an observation either impracticable, or so erroneous as to be perfectly useless.

Nevertheless, by taking extreme care to protect the surface from wind, observations by reflection from mercury have been made with great success at the Royal Observatory at Greenwich, by means of the mural circle. But there are other objections besides those I have mentioned to all these methods. When an instrument with a plumb line is used, the observations may be conducted in two ways. In the first, the instrument being placed in the meridian, the plumb line is brought over a mark which is generally attached to the frame work carrying the microscopes. The star is taken as many nights in succession as may be thought necessary, and the instrument is then turned half round in azimuth, the plumb line brought over the same mark, and the star again taken, when the mean of the results of the readings in both positions of the instrument gives the altitude or zenith distance.

Here it is presumed, that the refraction remains the same

from night to night, and that the relative positions of the different parts of the instrument suffer no change, suppositions which are too gratuitous to be readily received.

In the second method, the plumb line being adjusted as before, the star is taken several times when very near the meridian, the time at each observation being noted. The instrument is then immediately turned half round in azimuth, readjusted if necessary, and the observations repeated, noting the time as before. The mean of the results of the readings in both positions of the instrument will be the altitude or zenith distance of the star at the mean of the observed times.

The time at which the star comes to the meridian being known, the difference between this and the mean of the times of observation gives the horary angle of the star with the meridian; whence the correction is computed which it is necessary to apply to the observed zenith distance in order to obtain the meridional zenith distance.

I know of no objection to this method except the length of time required for observing each star, the labour of computing the corrections, and the possibility of the instrument suffering a strain from being turned half round in azimuth.

The manner of using an instrument furnished with a level, is nearly the same as when it is constructed with a plumb lime; but as the level has a scale, the divisions indicated by the ends of the bubble are usually read off at the conclusion of each observation, and the resulting corrections applied to the observed zenith distance. This presupposes the value of the divisions of the scale to be well ascertained, and that they are equal, which last is not always the case.

In observing by reflection, the error which might arise

from turning the instrument in azimuth is avoided. The star is taken, and the telescope being afterwards directed to the reflected image, the very small movement in azimuth required to follow the star cannot well be supposed to occasion any strain; but the same observations of the time, and the same reductions to the meridian are necessary in this as in the preceding method.

If the instrument is fixed in the meridian, as is the case with the mural circle, the observation by reflection cannot be made on the same night as that by direct vision; and it may be supposed that unfavourable weather might occur for several nights and prevent the completion of the observation, during which interval a change in refraction, or in the relative positions of the circle and microscopes might take place, impossible to be detected, and which would vitiate the result. This inconvenience has been felt at Greenwich, and a second mural circle is nearly ready at the Royal Observatory, for the purpose of simultaneously observing the same star by reflection and by direct vision.

From the slight description that has been given of the different methods of observing, it must be evident, that the important desiderata are to keep the circle constantly fixed in the meridian, using no other motion than that of the telescope, and to possess the means of instantly determining and verifying at pleasure the place of the horizontal or zenith point with a degree of accuracy, limited only by the powers of vision assisted by the telescope.

If a telescope furnished with cross wires be adjusted to distinct vision upon a fixed star, the parallel rays proceeding from the object are converged to a focus, and an image of

the star is formed upon the cross wires. Conversely, if when the telescope is so adjusted, rays be supposed to pass from the cross wires through the object glass, they will emerge parallel, as if they had come from an object at an infinite distance. The cross wires are therefore similarly circumstanced with respect to vision, as a fixed star; and if another telescope, adjusted by a star, be employed to view these cross wires through the object glass of the former instrument, they will be seen with perfect distinctness, however near to each other the telescopes may be placed.

Professor GAUSS first published an account of this beautiful property, and he availed himself of it to measure the angular distance of the wires of a transit instrument by means of a theodolite placed near the object glass.

In the *Astronomische Nachricten*, *No.* 61, Professor BESSEL has given a "new method of determining the flexure of the telescope of astronomical instruments," which for elegance of invention can scarcely be surpassed. This he effected by means of the property described by Professor GAUSS; and at the end of his communication, M. BESSEL proposes a method of finding the zenith point of an instrument, of which the following is a translation.

"I may here be permitted further to remark, that the zenith point of an instrument may also be found without turning it in azimuth by a similar contrivance. For this purpose nothing more is required than a telescope, furnished with a sensible level, which may be placed on either side with respect to the axis. If this be placed alternately towards the north and the south, so that the bubble of the level may be similarly situated in both positions, then the mean of the

readings on the circle at each position of the telescope is the zenith point. This may be obtained in a manner most independant of all other corrections, if the level be fixed nearly at right angles to the axis of the telescope, suspending it in the zenith, and then repeating the observation after the telescope has been turned on its axis. This method, which presupposes only an arrangement very easily made in the slit of the observatory, or upon the pillars, will give a very exact result, since the cross wires appear at all times well defined and without motion, which is not always the case in the comparative observations of stars by a zenith sector and the circle itself."

By this method, the necessity of observing out of the meridian, or of waiting till another night for the completion of the observation is obviated, and the zenith point may be immediately determined with as much accuracy as can be attained by means of a level. But though this is by far the best mode of employing a level that has ever yet been devised, it is still subject to the objections which have been urged against that instrument.

It would require a level of very great delicacy and extent of scale to indicate the fraction of a second; and such a one would be readily deranged by a small inequality of temperature, or by the unavoidable elastieity of the parts necessary for its adjustment.

In the course of some former enquiries, I made many experiments to ascertain the degree of reliance that might be placed on the position of a body floating upon the surface of mercury, and fully satisfied myself that it might be so contrived as to have always when at rest the same

inclination to the horizon. I had thus a floating support to which I could attach a telescope, a support requiring no adjustment, offering the ready means of extreme accuracy, and precluding all fear of those errors which might arise from the use of a level.

For a preliminary experiment I procured a piece of oak, seven inches and a half long, four inches and a half wide, and one inch thick. Upon this, two wooden uprights in the form of Y s, were pinned and glued at the distance of five inches. Half way between these a small ring was screwed into the oak, and the telescope being laid upon the Y's, was firmly secured in its place by a string passing several times round it and through the ring.

In the middle of the longer sides of the oak support, and at right angles to its horizontal surface were inserted two pieces of brass, in which very smooth grooves were made, about one-tenth of an inch wide.

A deal box eight inches long, five inches wide, and an inch and a half deep, having its bottom just covered with mercury, received the float, which was kept in its situation in the middle of the box, and prevented from turning horizontally by two smooth iron pins passing through the sides of the box into the grooves. These were carefully regulated so as to allow the float to adapt itself with perfect freedom to the surface of the mercury.

The whole of the telescope was above the edges of the box, and a screen of black pasteboard, with an aperture equal to that of the object glass, was fixed to the end of the box. This is indispensably necessary, in order to exclude false light.

A fine achromatic telescope by DOLLOND, of thirty inches

focus, and two inches and three-quarters aperture, furnished with a wire micrometer, was placed upon a deal support with three legs. This support rested upon a flat stone laid upon sand which filled a pit of seven feet in depth, and afforded a perfectly steady foundation. The moveable wire of the micrometer was carefully placed in a horizontal position.

The floating collimator was put upon a table attached to the wall of the observatory, and was placed in the proper direction by looking through its telescope, and moving the box till the cross wires appeared upon the wire of the micrometer. The cross wires,* which formed an angle of about 15 degrees, were illuminated by a small lanthorn placed upon the table with a piece of oiled paper interposed.

My first trials were made with the telescope of a sextant, but as the object glass was not sufficiently perfect,† I did not conceive it worth while to register them, and I shall merely remark, that after deranging the float by moving it in a variety of ways, the cross wires returned, as nearly as the imperfection of the image would permit me to judge, to the same situation.

The telescope subsequently employed had an achromatic object glass of one inch and a quarter aperture, and seven inches and a half focus, and this gave a sufficiently good image.

In the experiments I am about to detail, every method I could think of was used that could fairly introduce error.

* The material which after numerous trials I found to answer best for cross wires, was the steel spring used in the balance of a watch.

† I may here observe, that I find this mode of examination to be a most severe test of the goodness of an object glass employed as a collimator.

The end of the box next the object glass of the telescope was raised so that the mercury ran from beneath the float to the other end of the box; it was then restored to its former position; this for the sake of brevity I shall designate by *O raised.*

The eye end of the box was elevated and restored to its place in like manner; this I have called *E raised.*

One side of the box elevated and replaced, *S raised.*

The other side of the box treated in like manner, *S s raised.*

The object end of the box raised, and the box carried in that position to the other side of the observatory, brought back and replaced, *O raised and carried.*

The eye end raised, and the box carried and replaced, *E raised and carried.*

S raised and carried, and *S s raised and carried,* signify similar operations, previously elevating one side or other of the box.

Out and replaced O first, signifies that the float was lifted quite out of the mercury and the box replaced, the end of the float next the object glass being brought first into contact with the mercury.

Out and replaced, E first, the same, with the eye end of the float first brought in contact with the mercury.

Out and replaced S first, the same with one side brought first into contact.

Out and replaced S s first, the same with the other side brought first into contact.

As soon as the cross wires appeared to be perfectly at rest, the angle was carefully bisected by the micrometer

wire, and the mean of seldom less than three readings registered.

The stability of the micrometer was severely proved by pressing upon the end of the telescope, and it was found that upon removing the finger, the micrometer wire always returned precisely to the same situation. The value of each division of the micrometer head is six-tenths of a second.

In the following tables, the first column contains the readings of the micrometer when the angle of the cross wires was bisected. The second column contains the difference between every two consecutive observations, and indicates the derangement of the position of the float from its having been moved between such observations. The third column contains the error in seconds, which would affect the determination of the horizontal point in consequence of the derangement of the float, and is equal to the half of that derangement.

Wooden Float.

	1st Set.	Divisions of Microm.	Difference.	Error in Secs. affecting the Horiz. point.
Dec. 5	Previously to moving - - -	83,9		
			+ 1,5	+ 0,45″
	O raised - - -	85,4		
			— 2,8	— 0,84
	E raised - - -	82,6		
			— 1,7	— 0,51
	S raised - - -	80,9		
			— 1,6	— 0,48
	S s raised - - -	79,3		
			+ 0,2	+ 0,06
	O raised and carried - -	79,5		
			— 8,6	— 2,58
	E raised and carried - -	70,9		
			+ 1,0	+ 0,30
	S raised and carried - -	71,9		
			— 1,6	— 0,48
	S s raised and carried - -	70,3		

The image of the cross wires not being perfectly distinct, I limited the aperture to three-quarters of an inch, and thus

obtained a much better image. These observations were made in extremely damp weather, and the support had been kept for a few days in a very dry place.

	2d Set.	Divisions of Microm.	Difference.	Error in Secs. affecting the Horiz. point.
Dec. 8	O raised - - - -	31,6		
	After an hour's interval - -	16,6		
	Lanthorn close to wires - -	19,9	+ 3,3	+ 0,99″
	After an hour - - -	8,8		
	Out and replaced, S first - -	13,7	+ 4,9	+ 1,47
	Ditto, - E first - -	13,1	− 0,6	− 0,18
	Ditto, - O first - -	13,1	0,0	− 0,00
	O raised and carried - - -	11,5	− 1,6	− 0,48
	S raised and carried - -	11,7	+ 0,2	+ 0,06
	Ditto, read again - - -	10,7	− 1,0	− 0,30
	Carried box, kept as level as possible	5,2	− 5,5	− 1,65
	S raised and carried - - -	3,5	− 1,7	− 0,51
	Out and replaced, S first - -	0,5	− 3,0	− 0,90

The wooden float being designed merely for preliminary experiments, and it not being my intention to introduce any errors but such as might arise from moving the float or agitating the mercury, I had a float made of cast iron eight inches long, four wide, 0,2 thick, and weighing 2 lb. 5 oz. troy. The telesccope was tied firmly to the Y s.

Experiments with the Iron Float.

	3d Set.	Divisions of Microm.	Difference.	Error in Sec^s. affceting the Horiz. point.
Dec. 9	Previously to moving - -	57,7		
	O raised - - - -	51,5		
	Not sufficient mercury; added more.			
	Out and replaced S first - -	47,1		
	O raised and carried - -	43,3	− 3,8	″ − 1,14
	S raised and carried, escaped from the grooves - - -	44,3	+ 1,0	+ 0,30
	Out and replaced, the surface at once in contact - - -	46,6	+ 2,3	+ 0,69
	Out and replaced, O first - -	46,5	− 0,1	+ 0,03
	Out and replaced, E first - -	44,2	− 2,3	− 0,69
	Out and replaced, S first - -	43,8	− 0,4	− 0,12
	Out and wiped the mercury, S first -	43,1	− 0,7	− 0,21
	Out and replaced, E first - -	42,1	− 1,0	− 0,30
	Out and replaced, S first - -	41,9	− 0,2	− 0,06
	Out and carried, S first - -	37,5	− 4,4	− 1,32
	Out and wiped, S first - -	37,4	− 0,1	− 0,03
	On returning after an hour's interval	42,4		
	Out and carried, S first - -	40,7	− 1,7	− 0,51
	Out and carried, S first - -	42,7	+ 2,0	+ 0,60
	Out and carried, S first - -	43,1	+ 0,4	+ 0,12
	Out and carried, S first - - -	42,1	− 1,0	− 0,30
	O raised and carried - -	39,1	− 3,0	− 0,90
	Agitated by raising and depressing the end of the box - -	No Var.		
	Out and carried, S first - -	38,0	− 1,1	− 0,33
	Left the lanthorn close to the wires for three quarters of an hour and returned	39,3		
	Out and agitated mercury, S first -	38,6	− 0,7	− 0,21
	O raised and carried - -	41,3	+ 2,7	+ 0,81
	Out and wiped mercury, S first -	39,1	− 2,2	− 0,66
	Lanthorn taken away and returned in an hour and a half - -	45,0		
	Lanthorn left close to the wires, returned in an hour - - -	50,8		
	Agitated by tapping the box - -	51,6		
	Returned in an hour - -	No Var.		
	Out and wiped mercury, S first -	55,8	+ 4,2	+ 1,26

Experiments with the Iron Float.

	4th Set.	Divisions of Microm.	Difference	Error in Sec^s. affecting the Horiz. point.
Dec. 10	Out and replaced, S first - - -	84,5		
	Ditto, and agitated the mercury, S first	90,3	+ 5,8	+ 1,74″
	Ditto - - - ditto	89,8	— 0,5	— 0,15
	Ditto - - - ditto	88,7	— 1,1	— 0,33
	Ditto - - - ditto	87,3	— 1,4	— 0,42
	Ditto - - - ditto	84,9	— 2,4	— 0,72
	5th Set.			
	Out and agitated mercury, O first -	84,3		
	Ditto - - ditto -	83,9	— 0,4	— 0,12″
	Ditto - - ditto -	82,9	— 1,0	— 0,30
	Ditto - - ditto -	83,2	+ 0.3	+ 0,09
	Ditto - - ditto -	85,0	+ 1,8	+ 0,54
	Ditto - - ditto -	79,2	— 5,8	— 1,74
	An acccident suspected			

The surface of the mercury being very dirty, it was carefully strained through a paper funnel.

	6th Set.			
	Out and replaced S first - -	81,0		
	Ditto - - ditto - -	80,9	— 0,1	— 0,03″
	Ditto - - ditto . -	78,9	— 2,0	— 0,60
	Ditto - - ditto - -	78,5	— 0,4	— 0,12
	Ditto - - ditto - -	78,0	— 0,5	— 0,15
	Ditto - - ditto - -	77,0	— 1,0	— 0,30

The mercury carefully strained through a paper funnel, and the support oiled and rubbed dry.

Experiments with the Iron Float.

	7th Set.	Divisions of Microm.	Difference.	Error in Secs. affecting the Horiz. point.
Dec. 11	Out and replaced, S first - -	17,3		
	Ditto - - ditto - -	12,4	— 4,9	— 1,47″
	Ditto - - ditto - -	15,8	+ 3,4	+ 1,02
	Ditto - - ditto - -	16,7	+ 0,9	+ 0,27
	Ditto - - ditto - -	10,7	— 6,0	— 1,80
	Ditto - - ditto - -	15,8	+ 5,1	+ 1,53

Experiments to show the effect of turning the box round.

	8th Set.			
	Previously to moving - - -	16,7		
	Turned quite round - - -	16,4	— 0,3	— 0,09″
	Back again - - -	19,0	+ 2,6	+ 0,78
	Turned round - - - -	15,8	— 3,2	— 0,96
	Back again - - - - -	13,7	— 2,1	— 0,63

The micrometer wire not being *perfectly* horizontal, the cross was brought precisely to the same part at each experiment.

	9th Set.			
	Previously to moving - - -	11,0		
	Turned round - - - -	10,3	— 0 7	— 0,21″
	Back again - - - - -	10,2	— 0,1	— 0,03
	Turned round - - -	10,5	+ 0,3	+ 0,09
	Back again - - - -	8,4	— 2,1	— 0,63
	Turned round - - -	8,1	— 0,3	— 0.09

The side and subsequently the whole float, whilst replacing, pressed gently upon the mercury.

	10th Set.	Divisions of Microm.	Difference.	Error in Sec[s]. affecting the Horiz. point.
Dec. 11	Out and replaced, S first - -	95,7		″
	Ditto - ditto - -	96,7	+ 1,0	+ 0,30
	Ditto - - ditto - -	99,5	+ 2,8	+ 0,84
	Ditto - - ditto - -	98,2	— 1,3	— 0,39
	Ditto - ditto - -	97,0	— 1,2	— 0,36
	Ditto - - ditto - -	97,7	+ 0,7	+ 0,21

The float pressed upon the mercury as before, and the mean of the readings of both angles of the cross wires taken.

	11th Set.			
	Out and replaced, S first - -	97,4		″
	Ditto - - ditto - - -	98,1	+ 0,7	+ 0,21
	Ditto - - ditto - - -	100,5	+ 2,4	+ 0,72
	Ditto - - ditto - - -	93,8	— 6,7	— 2,01
	Ditto - - ditto - - -	95,0	+ 1,2	+ 0,36
	Ditto - - ditto - - -	94,6	— 0,4	— 0,12

In the preceding experiments it may be seen that by far the greater number of the results are negative, or that the readings of the micrometer for the most part gradually decrease. I felt much at a loss to account for this, and at first supposed it to have been occasioned by the vicinity of the lamp to the Y supporting the cross wires; but I found on trial that this was not the fact; indeed in that case the effect would have been the reverse of what was observed. I can in no other way account for it than by supposing that as the weather was very damp and cold, my approach to the stand which supported the micrometer, caused the legs which were

next me to expand; a supposition which appears to be in some degree corroborated by the micrometer giving an increased reading on my return, after having been absent for some time from the Observatory. Whatever may be the cause, it constantly operates in one direction, and seems to be the principal source of the errors which are observable.

I now wished to ascertain whether by encreasing the length of the float, or by adding to its weight, the length being the same, I should attain greater accurary. I therefore procured two other cast iron floats, the one twelve inches long, four wide, and a quarter of an inch thick, and the other of the same dimensions as that before described, except that its thickness was half an inch, and its weight 4 lb. 8 oz. troy. Iron pins were fixed in the sides of these floats in place of the grooves, and grooves to receive the pins were attached to the sides of the box. The box in which both floats were used was fourteen inches long and six inches wide.

Before I made trial of the new floats, I browned that used in the preceding experiments by rusting it with nitric acid, and then rubbing it with oil; imagining that I might thus diminish any small affinity which the iron might have for the mercury. With the float thus browned, the following experiments were made.

Iron Float browned.

	12th Set.	Division of Microm.	Difference.	Error in Sec^s. affecting the Horiz. point.
Dec. 28	Out and replaced, S first - -	20,0		″
	Ditto - - ditto - -	20,5	+ 0,5	+ 0,15
	Ditto - - ditto - -	19,9	— 0,6	— 0,18
	Ditto - - ditto - -	19,0	— 0,9	— 0,27
	Ditto - - ditto - -	15,9	— 3,1	— 0,93
	Ditso - - dttto - -	20,3	+ 4,4	+ 1,32
	13th Set.			
	Out and replaced, O first - -	22,2		″
	Ditto - - ditto - -	15,8	— 6,4	— 1,92
	Ditto - - ditto - -	17,8	+ 2,0	+ 0,60
	Ditto - - ditto - -	23,5	+ 5,7	+ 1,71
	Ditto - - ditto - -	22,6	— 0,9	— 0,27
	Ditto - - ditto - -	16,4	— 6,2	— 1,86

I now made the following experiments with the long float, the rough surface of which had been made smooth by rubbing it with wax.

Long Float.

	14th Set.			
Dec. 29	Out and replaced, S first - -	31,0		″
	Ditto - - ditto - -	32,0	+ 1,0	+ 0,30
	Ditto - - ditto - -	34,8	+ 2,8	+ 0,84
	Ditto - - ditto - -	31,6	— 3,2	— 0,96
	Ditto - - ditto - -	37,3	+ 5,7	+ 1,71
	Ditto - - ditto - -	33,1	— 4,2	— 1,26

Experiments to show the effect of turning the box round.

	15th Set.	Divisions of Microm.	Difference.	Error in Sec^s. affecting the Horiz. point.
Dec. 29	Previously to moving - -	33,3		
	Turned round, (much agitation) -	32,5	— 0,8	— 0,24″
	Back again - - -	31,6	— 0,9	— 0,27
	Turned round - - -	31,0	— 0,6	— 0,18
	Back again - - -	31,2	+ 0,2	+ 0,06
	Turned round - - -	30,4	— 0,8	— 0,24

I now laid aside the long float to try the short heavy float.

Short heavy Float.

	16th Set.			
	Out and replaced, S first - -	57,2		
	Ditto - - ditto - -	59,7	+ 2,5	+ 0,75″
	Ditto - - ditto - -	60,6	+ 0,9	+ 0,27
	Ditto - - ditto - -	56,1	— 4,5	— 1,35
	Ditto - - ditto - -	58,0	+ 1,9	+ 0,57
	Ditto - - ditto - -	57,6	— 0,4	— 0,12
	17th Set.			
	Out and agitated the mercury, S first	67,0		
	Ditto - - ditto	65,5	— 1,5	— 0,45″
	Ditto - - ditto	68,1	+ 2,6	+ 0,78
	Ditto - - ditto	64,7	— 3,4	— 1,02
	Ditto - - ditto	60,7	— 4,0	— 1,20
	Ditto - - ditto	66,0	+ 4,7	+ 1,41

The utmost care taken. The mercury carefully strained.

Short heavy Float.

	18th Set.	Divisions of Microm.	Difference	Error in Sec^s. affecting the Horiz. point.
Dec. 30 A. M.	Out and replaced, S first - -	32,1	+ 2,8	+ 0,84″
	Ditto - ditto - -	34,9	— 0,2	— 0,06
	Ditto - ditto - -	34,7	— 1,5	— 0,45
	Ditto - ditto - -	33,2	+ 1,0	+ 0,30
	Ditto - ditto - -	34,2	— 2,4	— 0,72
	Ditto - ditto - -	31,8		

Experiments to show the effect of turning the box round.

	19th Set.			
	Previous to moving - -	31,0	+ 2,2	+ 0,66″
	Turned round - -	33,2	+ 0,7	+ 0,21
	Back again - - -	33,9	— 1,3	— 0,39
	Turned round - - -	32,6	— 1,9	— 0,57
	Back again - - -	30,7	+ 0,6	+ 0,18
	Turned round . - -	31,3		

Mercury carefully strained.

	20th Set.			
	Out and replaced, S first - -	21,1	+ 5,9	+ 1,77″
	Ditto - - ditto - -	27,0	— 4,9	— 1,47
	Ditto - - ditto - -	22,1	+ 3,6	+ 1,08
	Ditto - ditto -	25,7	— 1,3	— 0,39
	Ditto - ditto - -	24,4	— 0,8	— 0,24
	Ditto - ditto -	33,6		

Great care taken that the side of the float should be in contact with the mercury its whole length, previously to putting down the surface.

	21st Set.	Divisions of Microm.	Difference.	Error in Secs. affecting the Horiz. point.
Dec. 30 A. M.	Out and replaced, S first -	25,1		″
	Ditto - ditto - -	24,1	— 1,0	— 0,30
	Ditto - ditto -	24,8	+ 0,7	+ 0,21
	Ditto - ditto - -	20,6	— 4,2	— 1,26
	Ditto - ditto -	23,1	+ 2,5	+ 0,75
	Ditto - ditto - -	21,6	— 1,5	— 0,45
	22d Set.			
Jan. 1	Out and replaced, S first -	25,9		″
	Ditto - ditto - -	19,4	— 5,5	— 1,65
	Ditto - ditto - -	21,9	+ 2,5	+ 0,75
	Ditto - ditto -	21,4	— 0,5	— 0,15
	Ditto - ditto - -	23,5	+ 2,1	+ 0,63
	Ditto - ditto -	21,9	— 1,6	— 0,48

Having caused the long float to be ground smooth, and browned it by rusting it with nitric acid, and rubbing it with oil, the oil was very thoroughly cleaned off, and the following experiments made with the greatest care.

Long float browned.

	23d Set.			
Jan. 2	Out and replaced, S first - -	1,4		″
	Ditto - ditto -	2,7	+ 1,3	+ 0,39
	Ditto - ditto - -	2,1	— 0,6	— 0,18
	Ditto - ditto -	3,4	+ 1,3	+ 0,39
	Ditto - ditto - -	3,3	— 0,1	— 0,03
	Ditto - ditto -	5,7	+ 2,4	+ 0,72

Long float browned.

	24th Set.	Divisions of Microm.	Difference.	Error in Sec^s. affecting the Horiz. point.
Jan. 3	Out and replaced, S first - -	51,1		″
	Ditto - - ditto - -	49,4	— 1,7	— 0,51
	Ditto - - ditto - -	48,7	— 0,7	— 0,21
	Ditto - ditto - -	50,2	+ 1,5	+ 0,45
	25th Set.			
Jan. 3	Out and replaced, S first - -	57,5		″
	Ditto - ditto - -	56,7	— 0,8	— 0,24
	Ditto - ditto - -	60,3	+ 3,6	+ 1,08
	Ditto - ditto - -	57,4	— 2,9	— 0,87
	Ditto - ditto - -	59,0	+ 1,6	+ 0,48
	Ditto - ditto - -	58,1	— 0,9	— 0,27
	26th Set.			
	Out and replaced, S first - -	63,3		″
	Ditto - - ditto - -	63,6	+ 0,3	+ 0,09
	Ditto - - ditto - -	61,1	— 2,5	— 0,75
	Ditto - - ditto - -	59,6	— 1,5	— 0,45
	Ditto - - ditto - -	60,9	+ 1,3	+ 0,39
	Ditto - - ditto - -	61,2	— 0,3	— 0,09

Of the one hundred and fifty one results in the column indicating the errors affecting the determination of the horizontal point, only twenty-eight are found exceeding one second; viz. one of 2″,58, another of 2″,01, ten between two seconds and one second and a half, and sixteen between a second and a half and one second; the remaining one hundred and twenty-three errors being all less than one second.

But as it is not to be supposed that an observer would be satisfied with a single determination, when he has the power in a very few minutes of attaining far greater accuracy, I shall

now show the effect that would result from using the mean of a few of the preceding observations.

	Wooden Float.	Error in Seconds.
1st Set.	Mean of the first four - -	— 0,34″
	Mean of the second four -	— 0,67
2d Set.	Mean of the first five - -	+ 0,36
	Mean of the second five -	— 0,66
	Iron Float.	
3d Set.	Mean of the first five -	— 0,16
	Mean of the second five -	— 0,40
	Mean of the third five - -	— 0,02
	Mean of the last six -	0,00
4th Set.	Mean of five - -	+ 0,02
5th Set.	Mean of five - -	— 0,31
6th Set.	Mean of five - -	— 0,24
7th Set.	Mean of five - -	— 0,09
8th Set.	Mean of four - -	— 0,22
9th Set.	Mean of five - -	— 0,17
10th Set.	Mean of five - -	+ 0,12
11th Set.	Mean of five - - -	— 0,17
	Iron Float browned.	
12th Set.	Mean of five - -	+ 0,02
13th Set.	Mean of five - -	— 0,35
	Long Iron Float.	
14th Set.	Mean of five - -	+ 0,13
15th Set.	Mean of five - - -	— 0,17
	Short heavy Float.	
16th Set.	Mean of five - -	+ 0,02
17th Set.	Mean of five - - -	— 0,10
18th Set.	Mean of five - -	— 0,02
19th Set,	Mean of five - -	— 0,02
20th Set.	Mean of five - -	+ 0,15
21st Set.	Mean of five - - -	— 0,21
22d Set.	Mean of five - -	— 0,18
	Long Float browned.	
23d Set.	Mean of five - -	+ 0,26
24th Set.	Mean of three - -	— 0,09
25th Set.	Mean of five - -	+ 0,04
26th Set.	Mean of five - -	— 0,16

On examining the above table, it appears that by taking the mean of a very few results, the greatest error, if the experiments with the wooden float be rejected, is four-tenths of a second, consequently the place of the horizontal point may be speedily determined by the use of the collimator, to the utmost degree of accuracy which the astronomical circle employed, is capable of attaining.

The results obtained by turning the collimator round without removing the float from the mercury, might have been expected to have been very nearly, if not wholly free from error; but as this does not appear to be the fact, and as the errors are all in defect, they seem to have been influenced by some constant cause, which, as before remarked, I believe to have been expansion of the stand of the micrometer in consequence of increased temperature.

When the float is removed in order to transport the box containing the mercury to the opposite side of the observatory, the manner of replacing it, so as to occasion the least error, seems to be that of bringing the edge of the side of the float first in contact with the mercury, and then gradually lowering it. This mode of removal can be necessary only when the collimator is used with a portable circle; but in a fixed observatory a plank should be laid, or a sort of railway contrived from one support to the other, on which the collimator should be either slid or passed along on rollers without removing the float from the mercury; by this arrangement the greatest, and perhaps the only source of error would be avoided.*

* It may perhaps be found preferable to have two boxes with mercury, and to carry the float from one to the other.

There appears to have been some advantage gained by using a longer float, and it certainly was improved by being browned, as previously to that operation, small particles of mercury were observed, occasionally to attach themselves to the float, which was not the case afterwards.

It may not perhaps be considered altogether superfluous to give in a few words the manner of using the collimator.

The instrument being placed on the north or south side of the observatory with its telescope pointed to the centre of the circle and nearly in its plane, it is to be directed, so that the wires of the telescope of the circle may be seen through it, when reciprocally the cross wires of the collimator will be visible through the telescope of the circle, and the collimator is to be so placed, that the cross wires may appear in the centre of the field of view. The place of the box should then be carefully marked, to ensure its being at once restored as nearly as possible to the same situation.

The collimator is then to be removed to the opposite side of the observatory, and the same process repeated, the situation of the box being here also carefully marked.

In observing, the star having been taken and the readings of the microscopes registered, the telescope is to be depressed to the collimator, and the angle formed by the cross wires carefully bisected. The collimator is then to be taken to the opposite side of the observatory, and the cross wires again bisected; the mean of the readings at the bisections will give the inclination of the collimator to the horizon, and the difference between this and the apparent inclination at either position of the collimator will be the correction to be applied to the mean of the readings registered at the bisection of the star.

For example, let the mean of the readings of the bisection of the cross wires when the collimator is to the south of the instrument be 7′.30″ of altitude, and when it is to the north 8′.40″. The mean of these readings 8′.5″, is the true inclination of the collimator to the horizon, and the difference between this and 7′.30″ (0′.35″) must be added to all altitudes taken to the south, or subtracted from those to the north of the zenith.

The instrument I have described may be called *the horizontal collimator*, but another and in most respects a preferable arrangement may be employed, similar to that suggested by Professor BESSEL. The telescope may be firmly fixed in a position perpendicular to the float, and I should then name it *the vertical collimator.** This must be placed directly under the telescope of the circle; and though not in a convenient position for observing, it yet possesses the very great advantage of obviating the necessity for carrying the collimator from one side of the observatory to the other, nothing more being requisite than to turn the float half round in azimuth, and to take the readings of the microscopes when the angle formed by the cross wires is bisected in each position of the collimator, the mean of which will be the place of the zenith point.

This is the construction which appears best calculated for a public observatory; but in addition, it would perhaps be adviseable that it should be furnished with a horizontal collimator, having a float of increased length. It is intended that

* The float of the *vertical collimator* should be circular, and an opening be made in the bottom of the tube of its telescope to throw light on its cross wires by means of an inclined plane mirror.

the horizontal collimator should remain stationary, and that the usual course of observations should be referred to it, its inclination to the horizon having been previously determined, and its permanency, when thought requisite, being examined by means of the vertical collimator.

As it is not necessary for the telescope of the collimator to have a tube, the object glass and the cross wires in the horizontal construction may be fixed in two uprights cast in one piece with the float. The distance of the object glass from the cross wires must be capable of the nicest adjustment. This may be effected by a screw cut on the outside of the tube in which the object glass is set, and a collar, by means of which after it is adjusted, it may be firmly secured in its proper place. There should be short pieces of tube screwed on each side of the upright, to protect the cross wires from injury, and also to contain the eye glass, which is convenient, as well for illuminating the wires, as for placing the collimator in the proper direction. This construction appears to promise the most perfect invariability of relative position between the line of collimation and the float. The box should be sufficiently deep to include the whole instrument, and should have apertures made in the ends, opposite to the object glass and to the cross wires. It is scarcely necessary to add, that it should also have a cover to exclude dust from the mercury, and a piece of ground glass or oiled paper should be placed between the cross wires and the lamp by which they are illuminated.

The accurate adjustment of the cross wires is a point of extreme importance. Upon whatever portion of an object glass parallel rays fall, they are converged precisely to the

same point in its focus, and consequently, whether the collimator be placed above or below the axis of the telescope of the circle, so long as the cross wires continue visible, the image will suffer no change of position. This affords an excellent method of discovering any want of parallelism in the rays; for if on placing the collimator as much above the axis of the telescope as possible, without losing sight of the cross wires, the image appears elevated above the horizontal wire, or if on placing it below the axis, the image appears to have descended, it is a proof that the rays falling upon the object glass of the circle are not parallel, but that they converge, and consequently that the cross wires of the collimator are too far from its object glass, and *vice versa.* It is necessary that this adjustment should be made with the utmost care.

It might possibly be supposed that the accuracy of the collimator would be augmented by increasing the length of its telescope, but this is not the case. It is the *direction* of a ray passing through the cross wires, and the centre of the object glass of the collimator, which is the subject of observation; and the direction of this ray is as definite in a telescope of an inch in length, as in one of ten feet focus. The degree of precision with which any variation in the horizontal inclination of this ray can be estimated, depends upon the length and power of the telescope employed to view the cross wires, and not upon the length of that of the collimator. There is an inconvenience however in using a telescope of too short a focus, as the cross wires are very much magnified, and consequently appear not so well defined; in addition to which, if a permanent point of reference be required, there might be some fear that the relative positions of the

float and telescope might suffer derangement, and the direction of the ray be consequently changed.

I may here point out an advantage, and not the least valuable, which this instrument presents, that of enabling the observer, by varying the inclination of the float, to bring a different part of the arc into use, and thus to check erroneous division of the circle: this may readily be done by securely fixing weights to either end of the float.*

I shall now proceed to give a description of the manner in which the floating collimator may be applied to the zenith tube.

The first zenith tube was I believe constructed for Dr. TIARKS. It was a telescope hanging in Y s upon pivots projecting from each side of the tube near the object end, and furnished with a wire micrometer: to this telescope a plumb line was attached.

When the star was upon the meridian, and of course sufficiently near the zenith to be seen in the telescope; it was bisected by the micrometer wire, and the divisions registered. The telescope was then inverted in the Y s, re-adjusted by means of the plumb line, and the following evening the star again taken, when the mean of the readings of the micrometer gave its zenith distance.

In the construction of the superb zenith tube 25 feet long, now making by Mr. TROUGHTON for the Royal Observatory at Greenwich, I understand it is intended that the axis of the tube shall be the centre of motion, and the plumb line be

* The above advantage may be considerably extended by the collimator being so constructed as to allow the inclination of the telescope to the float to be varied at pleasure.

suspended at the side. When the observations have been made a sufficient number of times with the plumb line on one side, the tube will be turned half round, and the observations repeated with the plumb line on the other side. The mean of both giving the zenith distance as before.

In this construction the zenith distance cannot be obtained in one evening; for were the telescope to be turned half round after the first observation, so much motion would be communicated to the plumb line, that there would not probably be time to re-adjust the instrument before the star would have passed out of the field of view.

As it is highly desirable that the completion of the observation should not be postponed, I endeavoured to effect this in a very fine zenith tube, which was constructed under my directions by Mr. Dollond for Colonel Lambton, and in another for Sir Thomas Brisbane, by placing the plumb line in the centre of motion; but these various forms are still subject to one or other of the inconveniences which have been detailed in the preceeding parts of this paper, and which it is the object of the floating collimator to remove.

The accuracy of the instrument I am about to describe, will depend upon the goodness of the telescope and of the wire micrometer employed. Exclusively of these it is within the reach of every observer, as the whole arrangement may be completed without difficulty and at a very trifling cost. Expence may contribute something in point of convenience, but can add nothing to its efficiency.

To a firm wall, at a sufficient height, let a shelf be fixed and supported by a bracket at each end. In the middle of this shelf let a circular aperture be made, rather larger than the object glass of the telescope. Precisely beneath, and at a

little distance from this aperture, the telescope is to be securely fastened to the wall in the direction of the zenith. This may perhaps be conveniently done by two irons driven into the wall, terminating in rings, into which the telescope may be passed and clamped. A box of sufficient size to contain the floating collimator being prepared with a circular aperture in the bottom of it, a very little less than that in the shelf, a piece of tube made of sheet iron, varnished brass, or even tinned plate, well painted or varnished, of a size to fit very tightly into the aperture of the box, must be passed into it and secured so as to project above the bottom on the inside an inch or two, and on the outside two or three inches more than the thickness of the shelf. The part of the tube outside the box must be passed through the hole in the shelf, and the box may then be readily turned about the axis of the tube as a centre. The side of the box being placed nearly in the direction of the meridian, its position must be determined by a pin driven perpendicularly into the shelf, so as to come in contact with a pin projecting from one corner of the box near the bottom, and in the direction of one of its sides. The box is then to be turned half round in azimuth, and a pin is to be fixed in the opposite end of the box in con-contact with that in the shelf. By this contrivance, the box may be turned at pleasure half round the azimuth.

The float should be of cast iron, with a hole in the middle an inch larger in diameter than the tube. It is to be furnished with pins, and the box with corresponding grooves to steady it, as before described. An arm of plate iron is to be fixed to the float, its edge being at right angles to the surface. This arm is to project over the aperture, and to terminate in a small tube at the centre, to receive a telescope not

larger than that of a sextant furnished with crossed wires,* and having its object glass next that of the zenith tube.

To any convenient part, either of the shelf or of the wall, a support must be fixed, to which a circular screen of blackened tin may be attached by a joint, so as to be elevated to the vertical or lowered to the horizontal position at pleasure. In the centre of this screen a hole is to be made rather smaller than the telescope of the collimator. The screen is intended when in use to occupy a horizontal position, just above the crossed wires of the collimator, and to exclude false light from the object glass of the zenith tube. In order to illuminate the wires of the collimator, a small plane reflector, which may be of planished tin, is to be attached at a convenient angle to the upper side of the screen over its aperture. This may be made to turn stiffly upon a hinge to vary its inclination.

Having put a sufficient quantity of mercury into the box to enable the float to act freely, the screen must be turned up and the micrometer adjusted, so that a star may pass along its moveable wire. The screen being then restored to its horizontal position, the crossed wires of the collimator will be distinctly seen when the arm carrying its telescope must be bent till they appear in the centre of the field of view, and the telescope of the collimator must be turned in its tube till the opposite angles of the crossed wires are bisected by the micrometer wire. These adjustments may be considered as permanent.

To determine the zenith distance of a star, it must be

* A small black dot upon mother-of-pearl forms a very neat object instead of the crossed wires, but from some trials, I fear it cannot be made sufficiently small.

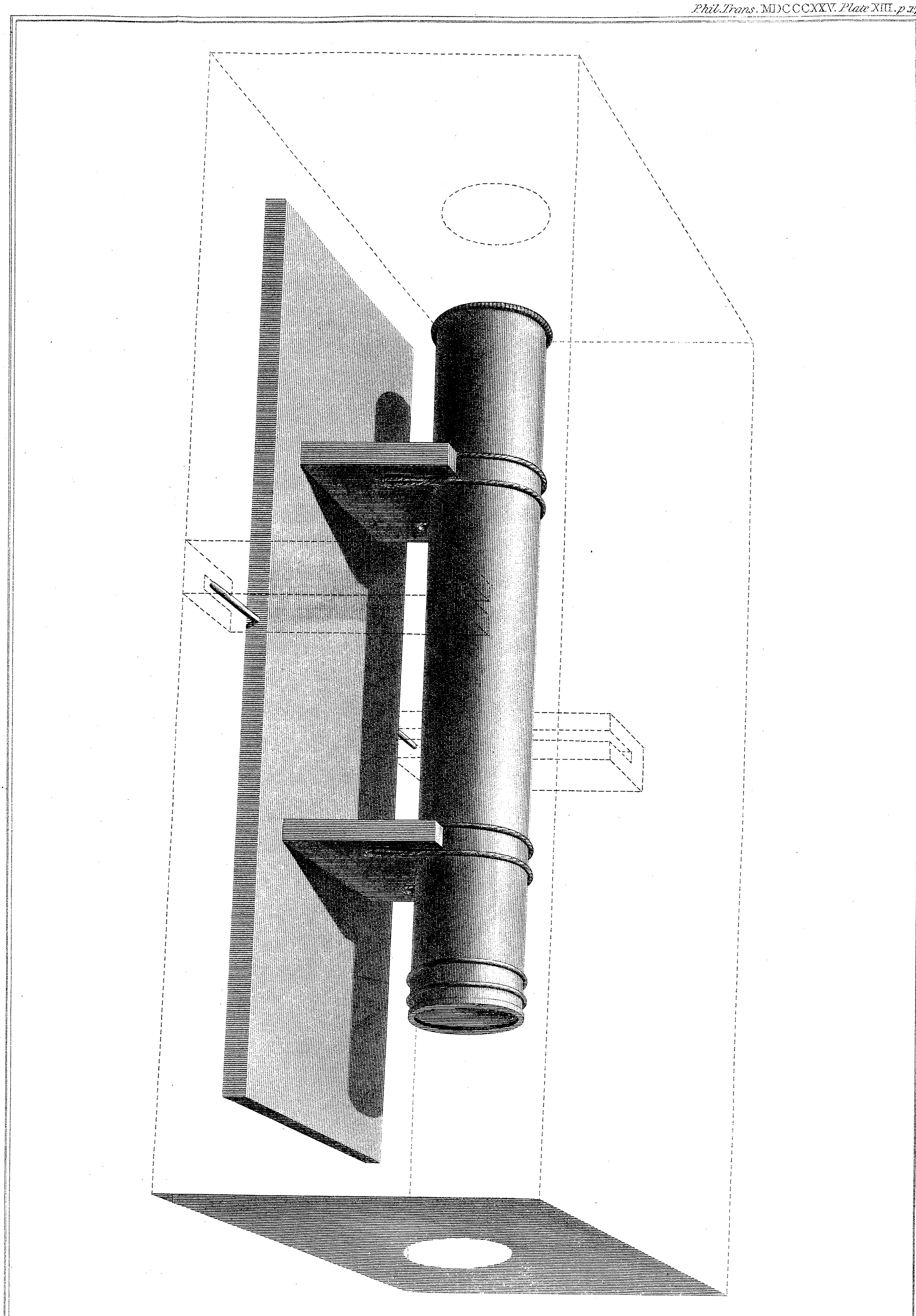
bisected by the micrometer wire at the time of its passing the meridian, and the division of the micrometer head read off and registered. The screen being then turned down, the angle formed by the crossed wires of the collimator is to be bisected, and the reading of the micrometer registered. The collimator is then to be turned half round, the angle again bisected by the micrometer wire, and the reading noted. The mean of these bisections is the place of the zenith, and the difference between this and the reading when the star was bisected, is the star's zenith distance.

It is evident that the operation for finding the place of the zenith may be repeated at pleasure, and consequently that the error, if any, in the zenith distance, may be ultimately referred to inaccurate bisection of the star, or imperfection of the screw of the micrometer.

I may remark, before I conclude, that a telescope,* similar to that I have used in the horizontal collimator, may be employed as a meridian mark for a transit instrument when a distant one cannot be obtained, and that the crossed wires afford an excellent object for the adjustment of the line of collimation. For this purpose, the telescope must be firmly fixed in the proper position. I attempted some years since to effect this by means of a convex lens, having cross wires in its focus, but as it did not occur to me to use an eye-glass, I was unable to place it in the proper direction, and after many unsuccessful trials I laid it aside.†

* The length of the telescope is here important to accuracy.

† Since this Paper was written, I have discovered that in the year 1785, such a meridian mark was actually used by Mr. RITTENHOUSE, who employed for the purpose the object glass of a telescope thirty-six feet long, in the focus of which was placed a metal plate, having several concentric circles drawn upon it. See Transactions of the American Philosophical Society, vol. ii.



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