The example given by Mr. Davis involves corrections of about $-0''\cdot008$ to x, $-0''\cdot007$ to $d\mu$, and barely $+0''\cdot001$ to π. If this example is really representative we may consider the parallaxes as given sensibly correct; for no one attaches much importance to $0''\cdot001$ or even to $0''\cdot01$. Parallaxes quoted by Mr. Davis with approval in the table from which he excludes Pritchard's measures range from $0''\cdot20$ to $0''\cdot52$.

Description of a Floating Photographic Zenith Telescope and some Preliminary Results obtained with it. By Bryan Cookson, M.A.

The instrument which is described in this paper was constructed with a view to undertaking a determination of the constant of aberration by Küstner's adaptation of the Talcott Method. Observations for this investigation have not yet been begun, but a description of the instrument and of some preliminary results obtained with it may be of sufficient interest to justify its publication.

In the usual form of zenith telescope the level is the essential part; in the present case the level is abolished and the verticality of the axis, about which the instrument is rotated, is assumed by floating the support of the telescope in a bath of mercury.

The correctness of this assumption is shown in the paper. The principle of floatation was employed as long ago as 1825 by Captain Kater in his floating collimators (*Phil. Trans.* 1825 and 1828), but seems to have been forgotten till Dr. Chandler adopted it in 1884 and applied it with great success to an instrument of very novel design which he called the almucantar. It was shown by Dr. Chandler that the floating part of his instrument returned after disturbance to within $\frac{1}{20}$ of a second of arc of the original position; that is, it resumed its original inclination to the horizon with a higher degree of accuracy than the bubble of a sensitive level would do. A zenith telescope, then, which depends on the principle of floatation might reasonably be expected, other things being equal, to give better results than one which depends on a level. In 1891 the Georgetown College Observatory erected a floating zenith telescope (a short description of it will be found on pp. 43 to 56 of the publications of that observatory): the results obtained with it seem to have been satisfactory. This is, so far as I know, the only floating zenith telescope which has hitherto been made. Two large almucantars, however, have been recently constructed, one by Professor Sampson at the Durham Observatory (*Monthly Notices*, vol. lx. p. 572), the other by Professor Howe at the Case Observatory, Cleveland, U.S.A. (*A.J.* vol. xxi. p. 57). Results obtained with these instruments have not as yet been published.

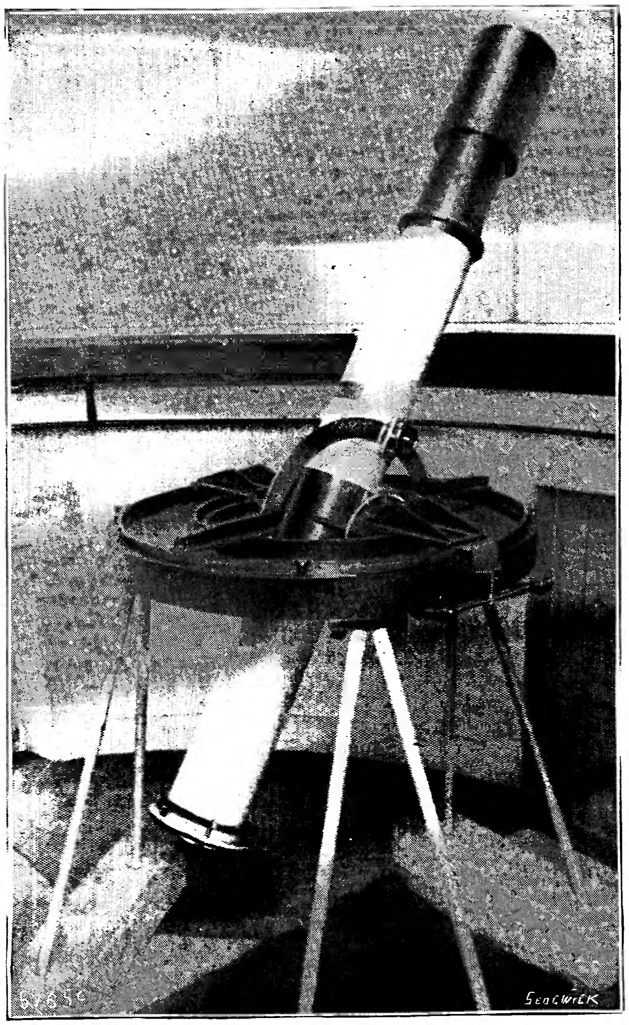
I believe there are also two instruments exactly similar to Dr. Chandler's second and larger almucantar which are in regular use in America. This completes the list of astronomical instruments actually constructed on the floatation principle.

A photographic zenith telescope of the usual form and dimensions was set up in 1895 at the Berlin Observatory, and the latitude determined with it by Dr. Marcuse, who obtained results quite as accurate as those with the visual telescope. In the case of the instrument now to be described the photographic method was adopted on account of the difficulty anticipated in the divining of some form of micrometer for use with a floating telescope, and also because, as the instrument has only to be approached in order to rotate it, there is much less chance of the heat of the observer's body affecting its condition than if he were close up to it, making bisections with the micrometer. There is also the advantage common to all photographic methods of having a permanent record of observation in the photographic plate which can be measured and reduced at the convenience of the observer. The quantity to be measured is the perpendicular distance of the marks or trails which the stars make on the sensitive plate by virtue of their diurnal motion. The results obtained by Marcuse were satisfactory in showing that the accuracy of measurement of star trails was of a high order; indeed it might be expected that a star trail on a photographic plate could be set upon at any rate as accurately as a moving star in a visual telescope, although this can be done by a skilful observer with surprising accuracy.

Description of Instrument.—It will be best first to give a general idea of the form of the instrument. There are three principal parts—the trough, the float, and the telescope. The trough and float are shallow annular basins; the float is concentric with the trough, and fits inside it with half an inch clearance all round. Mercury is poured into the trough, and the float is free to take up its position of equilibrium in the bath of mercury. The telescope passes through the centre of the annulus, and its trunnions rest in V's, which are carried by the float. The trough is fixed, but the float is free, and can be rotated in azimuth.

It was decided to adopt the annular shape for the trough and float for two reasons: first, because the rotation of the telescope about the vertical could be most easily performed by moving the float round inside the trough; and secondly, because the float could be rotated exactly through 180° by always bringing two points on it opposite two fixed points on the trough. It follows from this and the fact that the axis of rotation is vertical that the line of intersection of the plane of the meridian with the plane of the photographic plate is the same line on the plate before and after rotation.

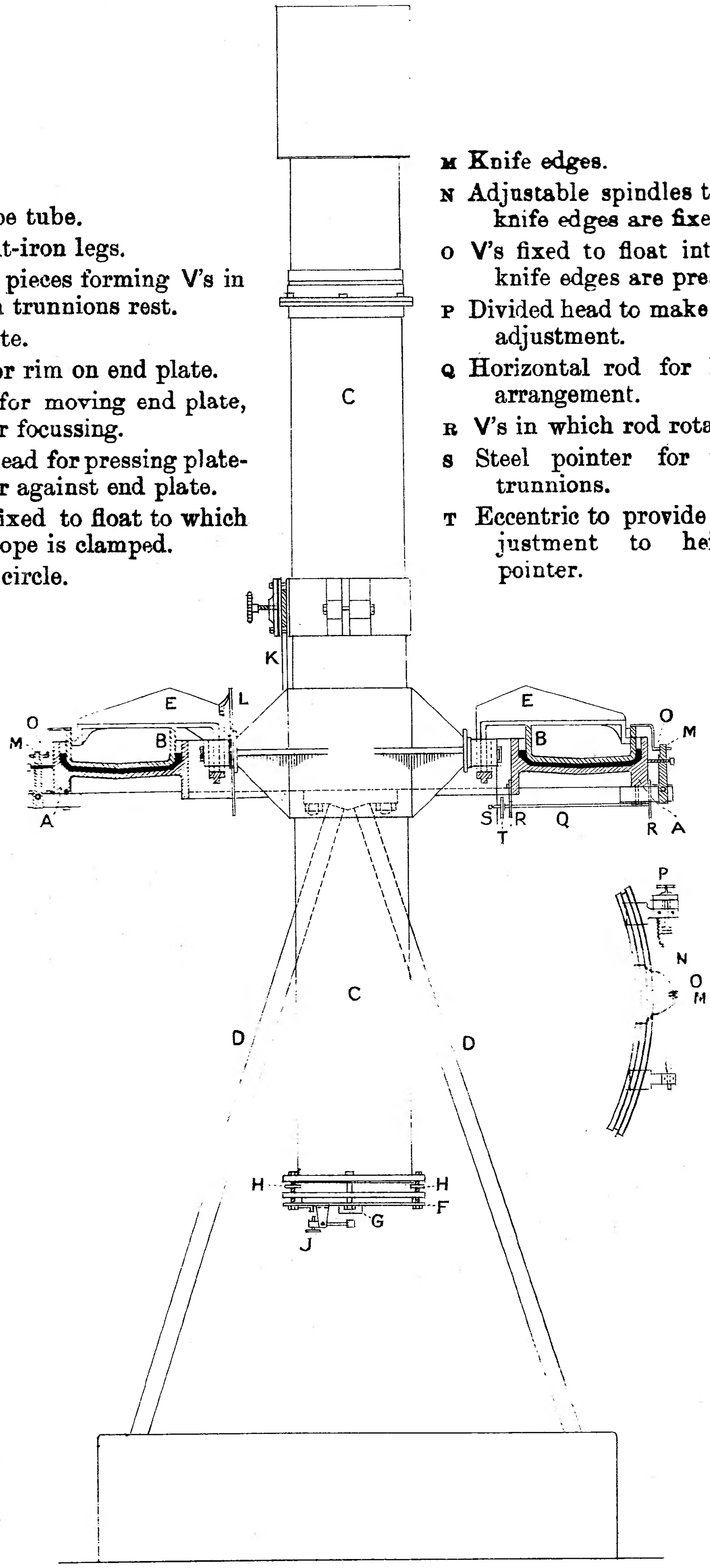
The trough, A, and float, B (Plates 8, 9), are of cast iron, and the whole of the outside of the latter is turned and polished. The out-



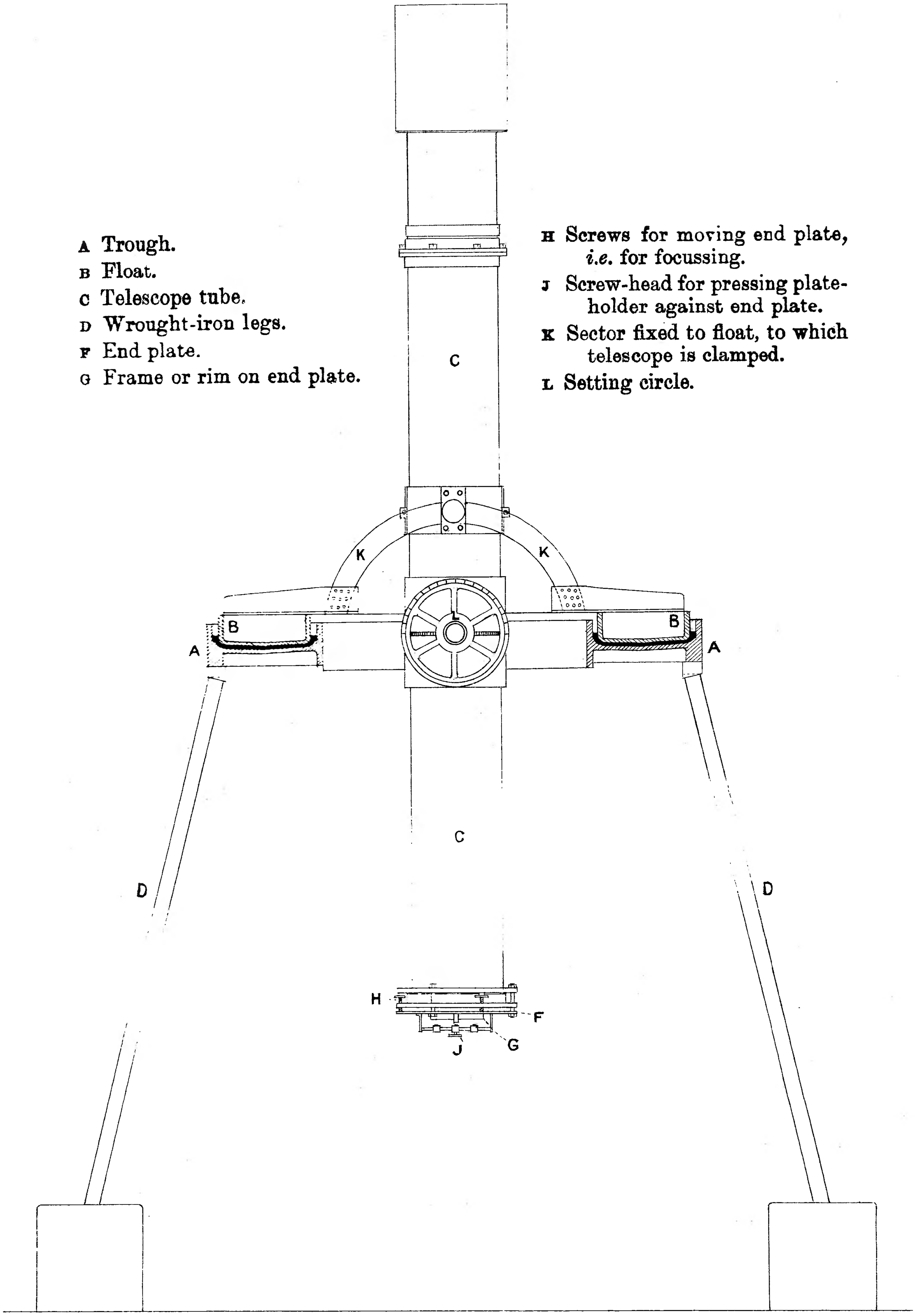
FLOATING PHOTOGRAPHIC ZENITH TELESCOPE.

BRYAN COOKSON.

A Trough.
B Float.
C Telescope tube.
D Wrought-iron legs.
E Bracket pieces forming V's in which trunnions rest.
F End plate.
G Frame or rim on end plate.
H Screws for moving end plate, *i.e.* for focussing.
J Screw-head for pressing plate-holder against end plate.
K Sector fixed to float to which telescope is clamped.
L Setting circle.
M Knife edges.
N Adjustable spindles to which knife edges are fixed.
O V's fixed to float into which knife edges are pressed.
P Divided head to make azimuth adjustment.
Q Horizontal rod for levelling arrangement.
R V's in which rod rotates.
S Steel pointer for touching trunnions.
T Eccentric to provide fine adjustment to height of pointer.



A Trough.
B Float.
C Telescope tube.
D Wrought-iron legs.
F End plate.
G Frame or rim on end plate.
H Screws for moving end plate, *i.e.* for focussing.
J Screw-head for pressing plate-holder against end plate.
K Sector fixed to float, to which telescope is clamped.
L Setting circle.



side diameter of the float is 39 inches, the inside 24 inches, and there is $\frac{1}{4}$ inch of mercury between the trough and float, except at the free surface where there is $\frac{1}{2}$ inch. The float is $\frac{3}{8}$ inch thick, weighs very nearly 150 lb., and its cross-section is slightly V-shaped at the bottom to assist small bubbles of air in the mercury to escape from under it. About 142 lb. of mercury are in use, and the whole of the floating parts weighs 350 lb. To prevent the float from knocking against the trough whilst being rotated, a circumscribing polygon of wire is attached to the trough and stretched round the float, so as just to clear it when it is in position. This wire acts as a spring, so that the float suffers no jarring knocks against the sides of the trough.

The trough is supported by three pairs of wrought-iron rods, D, $1\frac{1}{4}$ inch in diameter, each pair forming an inverted V. The plane of these V's slopes outwards from the trough to give clearance room for the telescope when it is being rotated at considerable zenith distances, and also to increase the stability of the support. The height of the bottom of the trough above the floor is 4 feet 6 inches, and the maximum zenith distance at which the telescope can be rotated is 45°.

The telescope is carried in the centre of the annular float by means of two overhanging cast-iron bracket pieces, E E, forming the V's in which the telescope trunnions rest. The tube C is brass, $\frac{1}{8}$ inch thick and $7\frac{1}{4}$ inches internal diameter. The upper end carries the object glass attached to a flange, and at the lower end there is a circular end plate, F, perforated by a rectangular aperture which is slightly smaller than the sensitive plate, and which admits the light from the object glass to it. This aperture is surrounded by a raised rim or frame, G, $\frac{1}{2}$ inch deep, against which the plate is pressed during exposure. The focussing is effected by means of three screws, H, which move the end plate relatively to the telescope tube: their pitch is 1 mm., and they have divided loads so that the focus can be set to 0·01 mm. These screws also regulate the tilt of the photographic plate to the optic axis of the lens; and once the focus found and this adjustment made, they are clamped.

The instrument is used for photographing the trails of stars across the meridian; the point on the trail corresponding to the moment of meridian passage is marked by a gap or break in the trails. This gap is the shadow cast by a thin copper wire, about 0·1 mm. in diameter, which is attached to the above-mentioned frame so as to lie just level with the top of it. Means are provided for making the necessary adjustment to bring this wire into the meridian. There are also two similar parallel side wires, each distant 9 mm., or 75 equatorial seconds from the central wire.

There are six plate holders made of brass, and they fit like a lid on to the frame of the plate aperture. They are held in this position by a simple arrangement, and after the dark slide is drawn are pressed home by simply turning a screw head, J, so that the sensitive plate rests against the frame, G, on the end plate; the frame then lifts the plate off the ledge in the holder, and springs at the back of it press the plate at three points against three small steel points let into the frame on the end plate. In this way every plate is exposed at exactly the same distance from the object glass. The marks on the gelatine made by the steel points are useful in showing the position in which the plate was exposed.

A great deal of trouble has been found in devising an efficient clamp to hold the telescope relatively to the float, and a new one has recently been added. The original clamp, with a slow-motion screw, acted on one of the trunnions, and its arm was held by one of the bracket pieces which carry the telescope. The origin of the trouble was eventually proved to be in the bracket piece itself: it was not sufficiently rigid, acting through the short arm of the clamp, to make the telescope exactly respond to the rapid changes of direction of motion which the float undergoes when executing its metacentric oscillations, and this of course entirely vitiated all results for the latitude. In the new clamp the telescope tube itself is clamped to a circular sector, K, which is firmly fixed to the float: this arrangement has been found to perform most satisfactorily. The old clamp with its slow-motion screw can be used for setting to the required zenith distance.

The brass finding circle, L, 9 inches in diameter, is a very simple and inexpensive one: it is divided to half a degree and the setting is made to $0^\circ{\cdot}1$ simply by a pointing index, which is quite sufficient for all practical purposes. The divisions are cut on a strip of celluloid let into the brass circle.

A few words must be said concerning the object glass. A good deal of time and trouble was taken over the choice of a lens, and it was eventually decided, after making some experiments, that a Cooke lens, Series I. c (Taylor's patent), of $6\frac{1}{2}$ inches clear aperture and 65·4 inches focal length, would be most suitable. This lens has a flat field of 14° diameter, but owing to the distance between the first and third component lenses not more than half its field is illuminated with full aperture, though for its present purpose this is no disadvantage, as the maximum angular distance that is covered by the plates is $3^\circ{\cdot}2$. The performance of this lens is satisfactory in the highest degree: the star trails are wonderfully sharp and distinct. Though the curvature of the middle lens—a negative flint—is considerable, the change of focal length with temperature is small, because the part due to altered refractive index is compensated by that caused by change in the separation of the component lenses. I have calculated the change due to a rise of temperature, and find that the sensitive plate, which is connected to the lens by means of a brass telescope tube, will be removed just over 0·01 inch from the focus for a rise of 10° C. Observations made to determine the focus are in complete accordance with Lord Rayleigh's formula,* and show that this is just the limiting displacement possible without impairing definition.

The three instrumental adjustments are: 1. Azimuth. 2. Level. 3. Collimation.

1. When the instrument is being used for observations the float must be held in azimuth, so that the axis of the telescope shall be in the meridian, but in such a way that there shall be no force to restrain its free oscillatory motion in the plane of the meridian. Two points therefore at the ends of an east and west diameter are held in the following manner: Knife edges, MM, are fitted to horizontal spindles, N, which are held by the trough, and are pressed by weak springs into two V's, OO, fixed to the float. The knife edges can be pulled back out of the V's, and their positions are adjustable by means of screws with divided heads, P, so as to bring them into the correct azimuth. In this way the only line in the float which is held is the line joining these V's, and it is so arranged that this line lies in the surface of the mercury. There can thus be no force to restrain motion of the telescope in the meridian, and the frictional force of the knife edges in the V's is too small to affect the inclination of the horizontal axis of the telescope appreciably. To change the azimuth by $0^s.5$, each adjusting screw must be turned through one division of its divided head.

2. It did not seem advisable to employ the usual striding level to test the inclination of the horizontal axis, because the application of it would change the inclination of the floating instrument. The limit assigned to the level error is $\pm 1^s$, which corresponds to 0·03 mm. at an arm equal to the distance between the trunnions, viz. 20 inches, and no very elaborate arrangement is therefore required. The method adopted is to bring first one and then the other trunnion over a fixed arrangement for touching them, and thereby finding when they are at the same height over it. It consists simply of a horizontal rod, Q. which turns in V's, RR, fixed to the trough. Through the end of the rod, and perpendicular to its length, runs a stiff steel wire, S, and by rotating the rod with the fingers it can be felt with great nicety when the point of the wire just touches the trunnion. By mounting the rod eccentrically in a pulley-wheel which turns in the V, and moving the rod in this eccentric, the necessary fine adjustment is provided. The diameters of the trunnions do not differ by 0·01 mm.; and as the fingers can feel a difference of 0·01 mm. in the height of the trunnion over the touching point, it is clear that this arrangement enables the adjustment to be made with the necessary accuracy. A sliding weight is attached to one of the bracket pieces on the float, and is moved till the pointer passes both trunnions with the same ease.

3. To correct for collimation error, the frame carrying the three transit wires can be moved by loosening the screws which attach it to the frame on the end plate.

* *Phil. Mag.* Series V, vol. xx. p. 355.

With the exception of the object glass and the trough and float, the instrument was made by the Cambridge Scientific Instrument Company, and I wish to express my deep sense of gratitude to Mr. Horace Darwin for all the care he has devoted to its construction, and for the many ingenious devices which have so largely contributed to the success of the instrument.

My thanks are due to Messrs. Cooke and Sons for much valuable information, and for the loan of a lens with which to make experiments; also to Mr. Norman Cookson and the Hon. C. A. Parsons for the casting and turning of the trough and float.

The instrument is mounted in a dome at the top of the main building of the Cambridge University Observatory. This dome, and the instrument it contained, had long been out of use. Sir Robert Ball had the old telescope removed and the dome put into thorough working order, and offered me the use of it. I wish to express my best thanks to him for this and for many other kindnesses.

The diameter of the dome is 15 feet, and it can be easily pushed round by hand. The aperture of the dome is opened by three independent shutters which are pulled aside by cords, and the exposures on the stars are made by opening the appropriate shutter at the proper moment. Windows are provided for efficient ventilation of the dome. The mean difference between the temperature of the outside and of the inside air is found to be $1^\circ{\cdot}5$ C.

The Measuring Micrometer.—To determine the linear distance between the trails on the plate, one of Zeiss's Standard "Comparators" is used: with this instrument distances up to 100 mm. can be measured. A division on its micrometer head represents 0·001 mm., which corresponds to $0''{\cdot}12$ on the photographic plate; consequently the last or estimated figure in a reading is the equivalent of $0''{\cdot}01$. In the microscope for viewing the trails there are four horizontal and two close vertical wires, and the plate is moved by a slow-motion screw till the trail bisects the space between the vertical wires. This is done at eight different points on the trail, four on each side of the meridian break at equal distances from it. The horizontal wires, corresponding to the vertical wires in a visual telescope, are used to indicate these points. With the magnifying power which is always used, viz. 24, the distances of the eight points from the meridian break are $\pm 1^s{\cdot}4$, $\pm 2^s{\cdot}7$, $\pm 4^s{\cdot}1$, $\pm 5^s{\cdot}5$.

This instrument belongs to Mr. Newall, who very kindly allowed me to use it, and to have the system of wires described above put into the eyepiece. I wish to sincerely thank him for this, and also for the encouragement and advice he has always been ready to give.

In measuring, the eight settings on a trail are all made before moving to the next star. Each point is set upon twice, though lately through pressure of time the bisection has been made only once. Preliminary experiments show that there is no systematic error depending on the direction in which the trail is brought between the vertical wires, or depending on the direction in which the plate is measured.

The division errors of the silver scale have been fully investigated by Mr. Newall, who has determined the error of every division and constructed a table of them. The error of run was found to be negligible, and the errors both periodic and progressive of the micrometer screw over the part of it in use only amount to one or two estimated places on the screw head. The only correction that is applied to the micrometer readings is therefore that for error of division. The correction for temperature, arising from the difference of expansion of the glass plate and the scale, amounts to one part in 100,000 per degree centigrade, which corresponds to $0''\cdot01$ in an arc of $21'$. Excepting in the most careful measurements, no account is taken of this.

Plates and Development.—The plates in use are Ilford Empress and Ilford Special Rapid, and all those intended for measurement are on patent plate glass. The developer has always been Metol. The Special Rapid plates are twice as fast as the Empress, and from exposures on the *Pleiades* made within a few minutes of one another, it was found that measurable trails were obtained of stars of magnitude 7·4 on Pickering's scale with the faster plate, as compared with those of magnitude 6·9 with the slower. Trails of zenith stars of magnitude 7·8 are quite easily measured on the Special Rapid plates; the grain of these plates has caused no inconvenience in the measurement.

The size of the plates is 5×2 inches.

Adjustments.—The errors of collimation and azimuth can be determined either visually or photographically, after the axis of the trunnions has been levelled in the way described above. For visual observations a negative eyepiece is fitted to the frame, G, on the end plate, and transits of suitable stars over the central wire are observed. The collimation error is found from the times of transit of two stars, culminating within a degree of the zenith, one star having been observed with the circle west, the other circle east. With the collimation error thus determined the azimuth error may be found by observing the transit of a polar star. The photographic method is, however, the easier of the two, and gives much better results. The instrument in this case is practically used as a photographic transit circle. The procedure is very similar, excepting that the collimation error of one of the side wires is determined from one star independently of the star's right ascension, the clock error and the azimuth error. Breaks in the trails are made at noted times by putting a cap before the object glass, and the distances of these breaks from any of the three wires are measured at the micrometer.

As it is important to know the limits within which the errors must be kept, in order that their effect on the latitude deduced from a Talcott pair of stars may not amount to $0''\cdot01$, the following expression for the correction due to errors a, b, c of azimuth, level, and collimation respectively was found:—

$$\delta\phi = D\,(a^2\cos^2\phi + b^2\sin^2\phi + c^2) + Abc + Bca + Cab + \frac{\sin 2\phi}{2}(b^2 - a^2)$$

where

$$D = \tfrac{1}{2}\,\frac{\sin 2\phi}{\cos\delta_s\cos\delta_n} \qquad B = \sin 2\phi\,\frac{\sin z}{\cos\delta_s\cos\delta_n}$$

$$A = \sin 2\phi\,\frac{\cos z}{\cos\delta_s\cos\delta_n} \qquad C = \sin 2\phi\,\frac{\sin z\cos z}{\cos\delta_s\cos\delta_n}$$

and δ_s δ_n denote the declinations of the south and north stars respectively, and z is their mean zenith distance. It will be found from this formula that $\delta\phi$ will not amount to $0''\cdot01$ if a, b, c are kept within the limits $\pm 1^s$. These limits are smaller than those usually assigned, but the reason of this is that the part of $\delta\phi$ depending on the products of the errors is generally neglected.

An attempt was made to find the level error by observations of stars at zenith distances, varying from 36° N. to 52° S.; the error of the chronometer was otherwise known. The resulting error was $-0^s\cdot5$, circle west: this shows that the method adopted for levelling the axis of the trunnions performs satisfactorily.

No appreciable difference can be found between the azimuth error for circle west and that for circle east. At present it amounts to $+0^s\cdot45$.

The errors of collimation at the ends of the central wire are $-0^s\cdot46$ and $-0^s\cdot05$ circle west. The wire is therefore inclined at an angle of $0^\circ\cdot03$ to the meridian, the effect of which is quite inappreciable. The side wires are distant 75·0 equatorial seconds from the middle wire, and they do not deviate by more than $0^s\cdot05$ from parallelism to it. No correction has therefore to be applied for collimation error of any of the three wires.

Scale Value.—Though the accurate and definitive scale value is not required in the present paper, yet it may be worth while to present the result of measurements to give an idea of the degree of accuracy attained in the measurement of trails, and to show that the optical distortion of the lens is at any rate small up to the $1\frac{1}{2}^\circ$ from the centre of the field. This is a point, however, which requires further careful investigation. The scale values derived from seven pairs of stars in the *Pleiades* are given in full in the table below. The positions of the stars were taken from Elkin's Memoir, *Yale Observations*, vol. i. Part I. p. 87, and ten measurements have been made from the star h and not η (*Alcyone*), as is usually done, because it was anticipated that the closeness of the trails of η and b (*Electra*) would interfere with measurements of η. The focussing screws have not been touched or the telescope interfered with in any way during the interval in which these photographs have been taken. The values deduced from them are therefore comparable *inter se.*

Date.	h−28. mm. 20·7.	h−34. mm. 12·2.	h−d. mm. 5·6.	c−h. mm. 6·5.	e−h. mm. 9·3.	k−h. mm. 11·9.	m−h. mm. 20·1.	Daily Mean.	Temp. Telescope Tube. C.	Position of Circle.
Nov. 27	124″·627	″·599	″·531	″·725	″·614	″·636	″·606	″·620	+6·7	E.
Dec. 7	·571	·632	·588	·643	·628	·647	·638	·621	6·4	W.
13	·594	·605	·606	·586	·598	·622	·633	·606	7·2	W.
14	·633	·629	·689	·477	·576	·582	·605	·599	9·2	W.
16	·638	·624	·642	·579	·628	·580	·582	·610	6·1	E.
Jan. 14	·589	...	·589	·585	·646	·648	·617	·612	3·3	E.
18	·619	...	·622	·618	·623	...	...	·621	5·0	W.
Mean	124″·610	·618	·610	·602	·616	·619	·614	124″·612		
Jan. 29	·581	·614	·687	·655	·641	·662	·631	·639	3·8	W.
31	·619	...	·650	·579	·544	·583	·573	·591	3·6	W.
Feb. 1	·621	·646	·601	·464	·560	·542	·569	·572	4·0	E.
Mean	124″·607	·630	·646	·566	·582	·596	·591	124″·601		

Under the names of the stars the approximate distance in millimetres is given; the angular distances in minutes of arc may be roughly found by multiplying by 2. These values have been corrected for geometrical distortion, due to the fact that the photograph is a plane projection of the celestial sphere; and to see if there was any marked optical distortion, the last three plates were exposed with their centres 1° from the star h. From the first seven plates the probable error of a single determination comes out as $\pm 0''\cdot0256$; that of the mean of seven is therefore $\pm 0''\cdot0096$, and of three $\pm 0''\cdot0148$, so that the two means for each pair agree within the limits of their probable errors. An attempt was also made to find the distortion by measurements of some other stars whose positions were well known. Their declinations were taken from Newcomb's *Catalogue of Fundamental Stars*, and the following scale values were derived:—

Stars in Taurus. Z.D. 36°·2 S.				Stars in Perseus. Z.D. 3°·5 S.				Stars in Auriga.			
α−80	25·7	124″·576	4	λ−μ	55·6	124″·633	4	ε−η	74·4	124″·613	4
δ−α	28·9	·637	4	λ−c	76·1	·629	4	ε−ζ	79·3	·612	3
68−α	40·2	·620	4	c−μ	20·5	·610	4	ζ−η	4·9	·420	3
α−ρ	48·4	·602	4								

After the names of the stars the approximate distance between the trails is given in millimetres, and after the scale value the

A A

number of plates taken. It will be seen that very considerable arcs have been measured—the largest is 2° 45′—and if there were any distortion its effect would be greatest on these large distances. I tried to deduce from all these results by least squares an expression of the form bs^2+cs^3 to represent the distortion, but the coefficients b and c came out smaller than their probable errors. No explanation has at present suggested itself for the abnormally small value 124″·420 derived from the standard stars ξ and η *Aurigæ*. It may, however, be safely concluded that the optical distortion of the lens over the field at present in use is very small, and a considerable series of very careful measurements would be required to show it.

For the present it will be sufficient to take as the scale value that derived from the *Pleiades* stars, namely 124″·610 ±0″·0034.

Accuracy of Measurement.—The probable error of a single bisection of a star trail has been determined for three separate cases :

1. Star on meridian, float fixed so as to prevent oscillations.
2. Star on meridian, but float not fixed.
3. Star on one of the side wires and float not fixed.

In the first two cases the trail is practically parallel to the vertical wires in the microscope, but in the last the curvature of the star's path is very marked, and it was thought that this might interfere with accurate setting. Corrections having been applied for curvature of path, the probable errors of a single bisection are as follows :—

	Probable Error.	Number of Trails.	Zenith Distance.
1. Star on meridian, float fixed	″ ±0·17	34	° 28·5
2. Star on meridian, float not fixed	±0·17	37	28·5
3. Star on wire 75ˢ from meridian, float not fixed	±0·14	22	0·5

The small difference between these probable errors may be referred to the greater refraction irregularities that naturally occur in the trails of stars of greater zenith distance, and the accuracy of setting may be taken as equal in all three cases.

Now it often happens that there are perceptible traces of oscillatory motion of the float to be seen in the trail when viewed with the measuring microscope, and though a wind screen has been erected round the instrument, it seems almost impossible to entirely prevent minute oscillations from arising. The existence of undulations with an amplitude of about 0″·25 on the plate makes the trail apparently easier to set upon, but it was feared that the result might not be reliable. The equality of the probable errors in the three cases above proves, however, that neither the existence of minute undulations of the trail, nor the curvature of the star's path, nor both combined have any deteriorating effect on the accuracy of setting on a star trail.

But the accuracy of setting is far from being a true indication of the accuracy to be expected in making measurements of the same distance at different times. The probable errors, therefore, of the distances measured for scale value have been determined; for this purpose the distances have been divided into three groups, and the error found for each. The sum $[vv]$ is formed for each distance, and the probable error for the group found by the usual formula

$$p.e. = 0{\cdot}67\sqrt{\frac{\Sigma[vv]}{m-n}}$$

m being the total number of measures, n the number of separate means. The probable errors thus derived from all the stars observed for scale value are :—

Distance. mm.	Distance. arc.	Probable Error of One measured distance.
0–15	0′–31′	±0″·218
15–30	31′–62′	±0·358
30–80	62′–166′	±0·503

These results are deduced from plates exposed when the float was fixed, and are therefore independent of the fact that the instrument is floating; it might, however, be imagined that if the float were free the inclination of the telescope to the horizon would be changed between the transits of the stars by a disturbance of the instrument caused by the wind. The corresponding probable errors for the case of the free float have therefore been determined in the same way.

Distance. mm.	Probable Error.
0–15	±0″·206
30–65	±0·486

There are not sufficient measurements to give a reliable error for the distances 15–30 mm. The agreement of the values for the two cases of a fixed and a free float shows that the fact that the instrument is floating does not interfere with the accuracy of measurement. This is a satisfactory indication of the remarkable stability of floatation of the instrument.

Distortion of Film.—In connection with the accuracy of measurement some experiments were made to see if any appreciable part of the errors of measurement were likely to arise from this source. Six contact photographs of a glass scale were taken, and after having been treated in various ways were measured together with the scale and compared with it. The plates were developed in Metol for periods varying from two to eleven minutes, and after having been fixed were washed in running water. The total length of the scale was 100 mm., and the

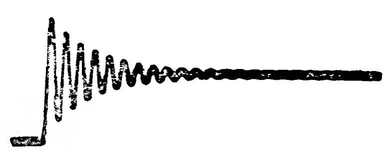
A A 2

maximum difference in the length of the photograph and of the scale amounted to 0·0071 mm.; a difference in a length of 5 mm. amounting to 0·0029 mm. was found in one instance. The mean differences for lengths of 5 and 15 mm. for the six plates measured are given, together with details of treatment of plates.

Plate.	Mean Diff. expressed in 5 mm.	Photograph and Scale, 0·0001 mm. 15 mm.	Developed.	Washed.	Dried.
			m	h	
D. 3.	9·3	17·2	3	6	slowly
D. 6.	6·5	7·5	2	13	very quickly (2^h)
D. 7.	6·6	10·4	2	13	6 hours
D. 8.	9·1	20·7	2	5	slowly
D. 9.	7·8	11·7	4	2	slowly
D. 10.	8·2	9·9	11	2	slowly
Mean	7·9	12·9			

The distortion of the gelatine film does not appear from these measurements to depend on the treatment of the plate within the range of treatment here considered, and is more likely to depend on the evenness and regularity with which the emulsion is applied to the plate.

Oscillations and Stability of the Float.—The oscillations of the float are of two kinds: one is connected with the wave motion of the mercury in the trough, and the other is simply the metacentric oscillations of a floating body. It is from these last that a measure of the stability of the float can be derived, but in the practical working of the instrument they are of no importance compared with the first. Both kinds can be very conveniently studied photographically.



The photograph which is here reproduced was obtained by suspending a weight from the float and suddenly lifting it. The effect of this is to set up the wave motion in the mercury which the figure shows. Measurement of this and other negatives, showing oscillatory motion, has proved that the period—viz. $9^s{\cdot}40$—is constant for all amplitudes. It is of some interest to compare this period with that for the free-wave motion in an annular trough of the same dimensions as the present one. In a paper to be published elsewhere I have done this, and proved that the longest period is $1^s{\cdot}6$ when there is one nodal diameter. The ratio of two successive amplitudes on the same side of the position of equilibrium is constant, and equal to 0·76, and it was found that no trace of any disturbance producing an initial amplitude of 3·5 mm. could be seen after 206 seconds. Representing, then, the motion by the usual equation for damped oscillations, namely,

$$\frac{d^2x}{dt^2}+2a\frac{dx}{dt}+bx=c$$

these data are sufficient to show that an initial disturbance of amplitude x mm. on the photographic plate will have no appreciable effect on the trail after τ seconds, where

$$\tau=169+30\log_e x.$$

The rotation of the instrument between the two stars of a Talcott latitude pair sets up oscillations with an amplitude of about 0·25 mm., and takes 20^s to perform. In this case τ is therefore 127 seconds, and hence the right ascensions of the two stars must differ by two and a half minutes if the trails are to show no undulations. But as the rate at which the oscillations are damped is known, there seems to be no reason why undulatory trails should not be used for even the most careful measurements, for it is quite as easy to set on the crests and hollows of the waves of such a trail as on a perfectly steady one. This, however, has only been done in a few cases, and no definite conclusion can yet be stated.

To find the period of the other kind of oscillations—viz. the metacentric—it is only necessary to know the metacentric height, MG, and the radius of gyration, K, of the floating part of the instrument. In the present case MG is 10·9 feet, and K 1·8 foot. The formula

$$\tau=2\pi K\sqrt{\frac{1}{g\,.\,MG}}$$

therefore gives $0^s\!\cdot\!6$ for the period of the metacentric oscillations. In the figure above these oscillations show themselves in the small dots which can be seen in the first upward stroke; and, by counting them, it is found that their period is $0^s\!\cdot\!6$, showing satisfactory agreement with theory. Direct visual observations give the same result.

The moment required to produce a tilt θ of the float is $g\rho Ak^2\theta$, where ρ is the density of the fluid, A the area of the plane of floatation, and k its radius of gyration. (The distance between the centres of gravity of the floating body and of the displaced fluid is neglected.) It follows that a moment of a pound-foot will produce a tilt of 52″, which corresponds to a movement of the outside of the float through 0·005 inch; in other units a tilt of 1″ is produced by a moment of 260,700 centimetre degrees. Now the forces which prevent the float from returning to exactly its old position after disturbance most probably arise from differences in the surface tension of the mercury before and after disturbance. The tension of the surface of pure mercury and air is

500 degrees per linear centimetre, and it seems hardly likely that the tension of more than 10 centimetres of mercury in contact with the float could be changed by the disturbance, or even by rotation to the extent of 100 degrees per centimetre. It follows from this that the float may be expected to return to within $0''\cdot10$ of its old position; if merely shaken, to within a few hundredths of a second; and observation proves that this is really the case.

It was for directly investigating this point that three transit wires were mounted instead of only one. Their distances are such that a star in the zenith takes just four minutes to cross all three; and one method of observing is to allow two stars, which differ in right ascension by from four to eight minutes, and in declination by a few minutes of arc, to register their trails over both the side wires. The instrument is not touched during the transit of the first star, but is shaken or rotated through 360° between the transits of the second star over the two side wires. The trail of the first star serves as a reference line from which to measure the distance of the second trail at the points where it crosses the wires. We can thus directly discover whether any change of inclination of the telescope has been caused by the disturbance. This has been done with the following results.

Three plates were exposed, on which appeared the trails of six stars, whose declinations were all within 30′ of one another. Between the transits of three of them over the side wires the float or telescope was pushed by hand, but for the other three the instrument was not touched. The only reduction of the measurements that is necessary is to apply to both undisturbed and disturbed trails the mean difference between the readings at the two wires for the undisturbed trails in order to correct for the shift of the plate relatively to the scale of the micrometer in moving from one wire to the other. If there were no errors of measurement the shift of the plate, as shown by the three undisturbed trails, should be the same. The actual figures are as follows:—

	Undisturbed.		Disturbed.	
	$0^{mm}\cdot0001$	Arc.	$0^{mm}\cdot0001$	Arc.
Jan. 29	+ 3	+0″·04	−19	−0″·24
	−24	−0·30	+22	+0·27
	+22	+0·27	− 4	−0·05
Jan. 31	+ 8	+0·10	−16	−0·20
	+ 8	+0·10	+ 6	+0·07
	−17	−0·21	0	0·00
Feb. 1	+21	+0·26	+12	+0·15
	− 4	−0·05	+ 5	+0·06
	−16	−0·20	−29	−0·36

The sums of the squares of these residuals are almost identical, and this shows that the accuracy of floatation is, at any rate, as great as that of the measurement of the trails.

To test the effect of not merely shaking the float but of rotating it through 360°, four other pairs of stars in about declination +58° were chosen and observed in the same way, but for the addition of the complete rotation. The figures given below are the excess of the distance between the trails before rotation over that after rotation; the approximate distance is also added.

	I.	II.	III.	IV.
	20′·1	9′·4	27′·9	7′·6
Jan. 29	−0″·21			
31	−0″·51			
Feb. 2		+0″·20	+0″·80	−0″·76
3		−0″·15	−0″·35	+0″·19

The rotation of the float and telescope was purposely not made with any particular care, so that the performance of the instrument is very severely tested. Now the mean of these eight differences, regardless of sign, is 0″·40, and the mean formed in exactly the same way for the three undisturbed trails above is 0″·30, the total distance for these last being only one-seventh of the total distance of the trails in the present four pairs of stars. This leads to the satisfactory conclusion that even a complete revolution of float and telescope does not appreciably disturb the inclination of the telescope to the vertical. With regard to the accuracy of measurement here indicated, it is interesting to note that the probable errors found for a single bisection of a trail or of a measured distance compare very favourably with those found by other observers with different but comparable instrumental means.

To test the stability of floatation yet further a method has been devised to investigate the effect of a half revolution of the float—a rotation through 180°; and this case is really of the most interest because it is that which actually occurs in observations of the latitude. The method is as follows: A star culminating within 1° 20′ of the zenith is allowed to register its trail over the first side wire, the telescope being clamped and pointed exactly to the zenith; the float and telescope are then rotated through 180°, so that the wire which was first before rotation is now the last. The time required for a zenith star to cross the wires being four minutes, there is plenty of time to effect the rotation and for the telescope to come to rest before the star again crosses the wire. This it does, but of course in the opposite direction and on the opposite side of the zenith on the plate. The zenith then is the point midway between the two trails made by the star; and if several stars are allowed to register their trails the zenith points derived from them should agree within the limits of errors of measurement. At the same time if the declination of the star is known, half the distance between the trails of the star added to or subtracted from, as the case may be, the apparent declination will give the latitude. The discussion of this is reserved for another section.

The following is an example, chosen at hazard, of the method employed :—

	Star.	Corrected Reading. mm.	Zenith Point.
L. 7, Feb. 11	2*a*	60·6393	41·8202
	b	23·0010	
	3*a*	26·3290	41·8237
	b	57·3184	
	5*a*	49·7550	41·8194
	b	33·8837	
	1*a*	33·4036	39·5275
	b	45·6513	
	4*a*	33·2343	39·5305
	b	45·8267	

No corrections are necessary except those for errors of the micrometer. The first three stars registered their trails over the wire called III, the last two over wire I ; and the maximum difference in right ascension of the stars on the same wire is 16·2 minutes. The thermometers both inside and outside the dome and on the instrument showed, as is usual, no change of temperature during this interval. The two stars 2 and 3, having very nearly the same right ascension, form a pair, and the zenith points deduced from them would be the same were there no errors of measurement. Twenty-four determinations of the zenith point from two or more stars, similar to the two examples given here, have been made ; but the differences of the zenith points determined by the two stars of the pair 2 and 3 above and another such pair, the probable error of the determination of a zenith point arising from error of measurement alone, is found to be $\pm 0''\cdot 223$; and from the stars not forming pairs, such as 1 and 4 above, the probable error due to error of material is not sufficient to make it possible to deduce the probable errors of the determination of the zenith point arising from accidental errors of measurement and from the error of floatation. All that can be stated at present is that the mean difference in the reading for the zenith point is $0''\cdot 30$ for a pair of stars, and $0''\cdot 37$ for stars not forming pairs : the former figure rests on ten determinations, and arises from error of measurement alone ; the latter is the mean of twenty, and is due to the errors of measurement and of floatation combined.

Latitude.—Owing to continued bad weather it has not been possible to secure a series of observations of Talcott stars, but the measurements of trails of zenith stars taken to test the stability of the float have been reduced and the latitude derived from them. This method of finding the latitude consists simply in the observation of the zenith distance of single stars. A star registers its trail across a wire two minutes before its meridian passage: the float and telescope which is pointed to the zenith are then rotated through 180° in azimuth, and the star crosses the same wire as before two minutes after meridian passage; but the two trails made by the star are on opposite sides of and at equal distances from the projection of the zenith on the plate. From half the measured distance between the trails the meridional zenith distance of the star is found by applying the following corrections:—

1. Correction for curvature of star's path or reduction of the meridian given by the formula

$$c=\frac{15^2}{2}\sin 1'' \tan\delta\, C^2$$

where C is the collimation constant expressed in equatorial seconds. This correction is a constant for each star, and is always to be added to the declination.

2. Correction for projection of the celestial sphere on to the photographic plate. The sign of this correction is the same as that of the star's zenith distance, and its magnitude is found from the expression

$$1''\cdot 52\, x^3\, 10^{-5}$$

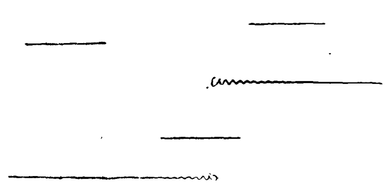
where x is the distance in millimetres from the centre of the plate. When the distance x' is not measured along a line passing through the centre of the plate, but along a line distant y millimetres from the centre, the correction is

$$\delta x' = 1''\cdot 52\, x'(x'^2+y^2)10^{-5}$$

This correction is most easily applied by reading off its value from a large scale chart showing the values of $\delta x'$ for a given value of x', y being an instrumental constant.

3. The last correction is that for refraction. This is small, as only stars culminating within $1\frac{1}{2}°$ of the zenith can be used; but it undergoes small variations with the meteorological conditions unless the zenith distance does not exceed 20′.

Of these three corrections the first two are constants for a given star, and are to be applied once and for all to its mean declination. The only day corrections are the refraction and the reduction to date. The latter has been carried out by means of Finlay's Star Tables.



The appearance of a latitude plate is shown above; the oscillations are caused by the rotation of the float and telescope.

Twenty-six stars were chosen, so that the sums of the north and of the south zenith distances were very nearly equal. The mean latitude from all the stars would in this way be made very nearly independent of the scale value, but cloudy weather unfortunately prevented these observations from being completely carried out on even one night. The following results, however, are given in order to show what may be expected from this method of observing with the instrument.

In the following table the declinations are given of those stars of which observations have been secured. In the second column N. denotes Newcomb's *Catalogue of Fundamental Stars*, 1900; P. the Poulkova Catalogue of 1855, published in vol. viii. of the *Poulkova Observations*; and A.G.C. the Harvard Zones of the *Astronomische Gesellschaft* Catalog. The declinations of the Poulkova Catalogue have been reduced to Newcomb's system by applying the corrections given in his Catalogue, p. 234, and the Harvard declinations by means of those given in the introduction of the Catalogue of that observatory.

Group and Number.	Catalogue.	Approx. R.A. 1901. h m	Declination 1901. ° ′ ″	Proper Motion 0″·001.	Approx. z. d.
L. 1. 1	N. 182	2 47·2	52 21 26·95	− 3	− 8·9
2	A.G.C. 1353	53·7	51 57 30·83		+15·0
3	N. 190	57·6	53 7 8·24	− 4	−54·6
4	A.G.C. 1388	3 0·9	51 49 56·74		+22·6
5	A.G.C. 1405	4·5	51 47 20·28		+25·2
L. 2. 1	P. 694	4 32·0 }	52 52 55·96	− 19	−40·3
2	P. 693	32·0 }	53 16 41·48	− 91	−64·1
3	A.G.C. 1932	37·1	52 9 12·56		+ 3·4
4	A.G.C. 1996	45·2	52 40 27·41		−27·9
5	P. 770	58·8	51 27 59·86	−166	+44·7
6	A.G.C. 2116	5 6·7	53 5 47·12		−53·1
x	P. 739	4 49·3	53 35 38·05	+ 12	−83·0
L. 5	N. 520	8 1·0	51 47 32·17	− 3	+25·4
L. 6	N. 546	8 32·0	53 3 31·78	− 22	−50·6
L. 7. 1	P. 1448	9 1·9	52 0 16·56	− 35	+12·7
2	A.G.C. 3354	13·5 }	52 52 5·58		−39·1
3	P. 1476	13·8 }	51 40 48·22	+137	+32·2
4	A.G.C. 3380	18·1	51 59 55·34		+13·1
5	P. 1509	28·0	52 29 30·71	− 37	−16·5

From observations of these stars seventy-one determinations of the latitude have been derived. All the stars in each of the groups L. 1, L. 2, and L. 7 were taken on one plate. Since the exposures are made for one minute, while a star is crossing a wire, the total exposure of a plate to the sky is about 10 minutes.

When the Moon is nearly full and very bright this causes a slight fogging of the plate, but not sufficient to seriously impair the definition of the faintest stars used; that is, of magnitude 6·6 on the scale of the Draper Catalogue. The sums of the zenith distances in the groups L. 1 and L. 7 are —0′·7 and +2′·4 respectively, and the mean latitudes derived from them are therefore nearly independent of scale value. The latitude given by the star L. 2 *x* has been found by measuring the distance of its trail from the zenith point given by the trails of the stars 3 and 5. The agreement of the values thus found shows that this procedure is capable of giving accurate results. In the next table the seconds of the latitude are given under the number of the star, together with the approximate zenith distance.

TABLE I.

L. 2.	1 −40″·3.	2 −64″·1.	3 +3″·4.	4 −29″·9.	5 +44″·7.	6 −53″·1.	*x* −83″·0.	L. 5. +25″·4.	L. 6. −50″·6.
	″	″	″	″	″	″	″	″	″
Feb. 3	...	...	...	...	...	...	...	51·05W.	
6	50·40W.	51·40W.	...	...	52·14 E.	...	52·57 E.	...	...
10	50·42 E.	50·93 E.	51·04W.	52·15 E.	...	...	...	...	...
11	50·69W.	51·72W.	50·60 E.	51·89W.	52·51 E.	...	52·16 E.	51·33 E.	51·88 E.
12	49·84 E.	50·89 E.	50·90W.	52·62 E.	51·97W.	50·83E.	52·34W.	...	...
13	50·48W.	51·50W.	50·77 E.	52·11W.	52·90 E.	51·21W.	52·91 E.	51·56W.	51·98W.
Mean	50·37	51·29	50·83	52·19	52·38	51·02	52·50	51·31	51·93

TABLE II.

L. 1.	1 −8″·9.	2 +15″·0.	3 −54″·6.	4 +22″·6.	5 +25″·2.	Mean
	″	″	″	″	″	″
Jan. 22	51·52W.	52·04 E.	51·25W.	51·93 E.	...	51·90
31	51·03 E.	52·35W.	51·49 E.	51·64W.	52·78 E.	51·88
Feb. 1	...	51·80 E.	51·51W.	51·74 E.	52·39W.	51·75
Mean	51·28	52·06	51·42	51·77	52·59	51·85

L. 7.	1 +12″·7.	2 −39″·1.	3 +32″·2.	4 +13″·1.	5 −16″·5.	Mean.
	″	″	″	″	″	″
Feb. 2	51·75W.	50·71 E.	50·52 E.	50·49W.	50·64 E.	50·82
3	52·06 E.	51·22W.	51·38W.	51·05 E.	51·36W.	51·41
5	51·52W.	50·92 E.	50·97 E.	50·80W.	50·75 E.	50·99
11	51·56W.	50·90 E.	50·42 E.	50·58W.	51·37 E.	50·97
13	51·95 E.	51·13W.	50·84W.	50·97 E.	51·48W.	51·27
Mean	51·77	50·98	50·83	50·78	51·12	51·09

It will be seen from this table that in no case do the values of the latitude determined from the same star differ by as much as 1″·0, even for such considerable zenith distances as 1 degree.

The probable error of one determination from all the values above is ±0″·200, but it will be noticed that there is a large systematic difference between the values found for circle east and circle west, which considerably increases the probable error. Thus the differences for the five stars in L. 7 in the sense E.—W. are

1	+0″·40	4	+0″·45
2	−0·34	5	−0·50
3	−0·47		

If a correction of ±0″·20 is applied to the values of the latitude in this group according as the circle is west or east, the probable error of a single determination is reduced to ±0″·115, which is smaller than the value found by a skilful observer with a visual telescope, viz. ±0″·125. If, now, the differences from the daily mean are found for each of the five stars, and the mean difference for each star is applied as a correction to every determination of the latitude by that star, the following values are found :—

L. 7.	1	2	3	4	5	Mean.
	″	″	″	″	″	″
Feb. 2	51·27	51·02	50·98	51·00	50·81	51·02
3	51·18	51·13	51·44	51·16	51·13	51·21
5	51·04	51·23	51·43	51·31	50·92	51·19
11	51·08	51·21	50·88	51·09	51·14	51·17
13	51·07	51·04	50·90	51·08	51·25	51·07

An explanation of the difference E.—W. has yet to be found; but its existence seems to be so conclusively shown that the above may be taken as an example of the result to be expected from the instrument.

Note accompanying Photographs of the Spectrum of Nova Persei. By Frank McClean, LL.D., F.R.S.

The observations made by me of the spectrum of *Nova Persei* at present extend from February 25 to March 6. On the 23rd and 24th the star was not visible. On the 25th some glimpses of the spectrum were obtained through passing gaps in the clouds. The star was then considerably brighter than *α Persei.* The general character of its spectrum did not subsequently change, although apparently the red hydrogen line became brighter.

From February 27 till March 3 photographs of the spectrum were obtained by me on each night with the 12-inch object glass prism, and again on March 5 and 6.