# GREENWICH
# ASTRONOMICAL OBSERVATIONS,
# 1876.

## INTRODUCTION.

### I. *Personal Establishment and Arrangements.*

During the year 1876 the establishment of Assistants in the Astronomical Department of the Observatory has consisted of the following persons :—

Chief Assistant,—William Henry Mahony Christie, Esq., M.A., Fellow of Trinity College, Cambridge.

Assistants of the First Class,—Edwin Dunkin, Esq., F.R.S.; William Thynne Lynn, Esq., B.A., Univ. London.

Assistants of the Second Class,—George Stickland Criswick, Esq.; Arthur Mathew Weld Downing, Esq., B.A., Trinity College, Dublin; Edward Walter Maunder, Esq.; William Grasett Thackeray, Esq.

The duties of the establishment are distributed in the following manner :—

The Chief Assistant, in the absence of the Astronomer Royal, is empowered to act in all respects as his representative, and to conduct confidential as well as routine business. In the ordinary transactions, the Chief Assistant superintends the calculations generally; and observes, occasionally, with any of the instruments. The observations made by Mr. Christie are distinguished by the signature W.C.

Mr. Thackeray is charged with the observations necessary for the determination of the errors of division, of the form of the pivots, and of the flexure of the telescope, of the Transit-Circle. Mr. Lynn has the superintendence of the Altazimuth, which is specially devoted to extrameridional observations of the Moon. The ordinary observations with both these instruments have been generally made by Mr. Lynn, Mr. Criswick, Mr. Downing, and Mr. Thackeray; occasionally observations have been made by Mr. Maunder. The initials of these observers are L., C., A.D., T., and M. Other persons who have occasionally observed with these instruments are:— Mr. Walter Wickham, Mr. Edward Graham, Mr. William Pritchard Pulley, Mr. Walter David Laird, Mr. Robert Thomas Pett, Mr. Harry Pead, Mr. William Baker, Mr. Benjamin Dennison, Mr. James William Fenner Bromley, and Mr. Frank Disney, who are employed as computers in the Observatory; their signatures are W., E.G., P., W.L., R.P., H.P., B., B.D., J.B., and F.D.

A few observations were also made by Herr Kühnert in connexion with the determination of the longitude of Vienna.

The observations with the South-East, or Great Equatoreal, have been generally made by Mr. Christie and Mr. Maunder. Miscellaneous observations with the other Equatoreals are not distinctly appropriated to any special observers.

The management of the Galvanic Apparatus for Chronographic Registry of Transits, movement of sympathetic clocks, and external distribution of time-signals; the receiving, issuing, and rating of Chronometers; the raising of the Time-Signal-Ball at 1 o'clock; and the computations belonging to the same; are intrusted to Mr. Criswick.

The Photoheliographic and Spectroscopic Observations, and the reductions connected with them, are specially intrusted to Mr. Maunder.

With regard to the Reduction of the Observations.—The Chief Assistant is always charged with the duty of making the examination of observations, as entered in the Books of First Calculations, in order to ascertain that no error has crept into the records of individual wire-transits or individual microscope-readings; and with the adoption of Clock-rates, instrumental zeros and instrumental errors. Mr. Dunkin superintends the reduction of the Transit-Observations, and the Results of the Meridional Observations, and the reading of the proof-sheets of these observations and reductions when printed. Mr. Dunkin is also charged with the general superintendence of the supernumerary computers of the astronomical department; by whom the great mass of calculations and of reading proof-sheets is effected. Mr. Lynn and Mr. Thackeray respectively superintend the reduction of Altazimuth-Observations and Circle-Observations, and the reading of the proof-sheets of these observations and reductions when printed. Mr. Thackeray also translates the chronograph-barrel-readings into figures.

Mr. Criswick arranges the Money Accounts of the Observatory.

Mr. Downing has the general charge of the Observatory Library and Manuscripts.

The whole of these works are under the immediate direction of the Astronomer Royal, who is responsible for every part.

Correspondence relating to the affairs of the Observatory, not transacted by the Astronomer Royal himself, is managed under his general or special instructions.

The course of observations and the succession of observers are arranged every Monday by the Chief Assistant and sanctioned by the Astronomer Royal. In general, the Assistant who makes the observations with the Transit-Circle is charged with all the observations that may occur from $15^h$ mean time (3 o'clock in the morning) to the next $15^h$; although it is sometimes found necessary (especially during the latter part of the Lunation, when the Moon passes the meridian in early morning) to appoint separate observers for the morning and the evening. It is established as a rule, to be adhered to as closely as circumstances permit, that no Assistant be occupied on two successive days with astronomical observations. And it is always arranged, if possible, when the Moon's time of transit passes $15^h$, that the same Assistant should not be required to observe the Moon and accompanying stars late in the night when the Moon passes last before $15^h$, and early in the morning when the Moon passes first after $15^h$.

In October 1863, a convention was made with M. Le Verrier, under which the Observatory of Greenwich is charged with the meridional observations of the Asteroids from new moon to full moon, the Observatory of Paris undertaking their observation from full moon to new moon. Since this arrangement has come into effect, the aid of the additional observer, previously necessary for the evening observations, when the Moon passed the meridian in early morning, has not often been required; it is found at the same time that all requisite observations can be made without greatly increasing the labour of the observer.

For many particulars relating to the internal constitution of the Observatory, reference may be made to the "Regulations of the Royal Observatory," forming the Appendix to the volume for 1873.

## II. *Instruments.*

The principal Instruments used by Halley, Bradley, Bliss, and Maskelyne, are still preserved in the Royal Observatory: namely, Halley's Transit, with pivots unequally distant from the Telescope; Bradley's Transit; Bradley's small Equatoreal; the Zenith Sector of Bradley and Maskelyne; and the two Mural Quadrants, mounted on their pier, the Quadrant on the Western side of the pier being now included in the smaller fire-proof room of the Observatory. The ancient instruments first mentioned, together with the Telescopes for investigating the parallaxes of $\alpha$ Aquilæ and $\alpha$ Cygni, formerly attached respectively to the West side of the pier of Troughton's Mural Circle, and to the Quadrant pier, are now, with proper labels, suspended on brackets on the Western wall of the Transit-Circle Room.

Troughton's Transit Instrument and Mural Circle, used to the end of the year 1850, were dismounted in the year 1851, and are suspended, the one on the West and the other on the East wall of the Transit-Circle Room. The object-glass of the Transit Instrument is now inserted in the Reflex Zenith-Tube.

The 25-foot Zenith-Sector was dismounted, and its tube was divided (at its joints) into several parts, in May 1848; and the separate portions of the instrument are stored away in frames constructed to hold them. The object-glass, as will shortly be mentioned, was removed from the tube in 1850, to be used for the Collimator of the Altazimuth.

Jones's Cape Circle was transferred in November 1851 to the Observatory of Queen's College, Belfast.

The Instruments now in use are the following:—

The Transit-Circle, constructed by Messrs. Ransomes and May, as engineers, and by the late Mr. William Simms, as optician, erected in the year 1850, and brought into use at the beginning of 1851.

The room in which this instrument is mounted occupies the site of the old Circle Room, but is extended to the south, so that its entire length is 36 feet. The ridge of the roof is in the north-and-south direction. The opening in the roof, along the ridge, is 3 feet wide, and is covered by four shutters: the vertical openings, in the north and south walls, are also 3 feet wide, and each is covered by a single shutter. Any one of the shutters can be opened without disturbing the others.

A detailed description of the instrument, illustrated by plates, is given in Appendix I. of the volume for 1852: a reprint of which, with some modifications, is attached to the volume for 1867. The following particulars may be given here. The center of the instrument is about $5\frac{1}{2}$ feet South and 19 feet East of the old transit-instrument. The length of its telescope is nearly 12 feet, and the clear aperture of the object-glass is about 8 inches. The length of the axis between the extremities of the pivots is 6 feet. The axis of the instrument is of cast iron, in two similar pieces: each half includes half the central cube, one cone, and the pivot which terminates it. The mould of the pivot was made of iron, for the purpose of hardening it by the process technically called *chilling;* the moulds for the other parts were sand. The two halves are connected by bolts through flanges at the junction-plane in the middle of the cube. The two portions of the telescope-tube (also of cast iron, with the exception of the object-glass cell and the eyepiece-work) are bolted on the cube. The diameter of each pivot is 6 inches. The bearing of each pivot is upon two portions of a concave cylinder. For examination of the form of the pivots, each is perforated; within the hollow of the eastern pivot there is fixed a plate of metal perforated with a hole about 0·01 inch in diameter, behind which a light can be placed for illumination; at the distance of 6 inches from this hole is a lens of 1 inch focal length, producing an image of the hole about 0·002 inch diameter, which in fact is the real mark for collimation; and in the hollow of the western pivot there is fixed an object-glass at a distance from that image equal to its focal length. This combination forms a reversed telescope revolving with the instrument. It is viewed by a telescope of 7 feet focal length, which, when required, is placed on Y's, one of them planted in the opening of the western pier, and the other in a hole made for that purpose in the western wall of the room.

On 1871, April 15, observations were made for the determination of the relative errors of the form of the pivots of the Transit-Circle. The process employed is fully explained in Appendix I. of the volume of *Greenwich Observations* for 1852.

The following table contains the residual errors, which define the apparent changes of position of a certain imaginary line in the material axis of the instrument.

| N. P. D. Pointer Reading. | Horizontal Error, Micrometer Head to Left. | Vertical Error, Micrometer Head Below. | N. P. D. Pointer Reading. | Horizontal Error, Micrometer Head to Left. | Vertical Error, Micrometer Head Below. | N. P. D. Pointer Reading. | Horizontal Error, Micrometer Head to Left. | Vertical Error, Micrometer Head Below. | N. P. D. Pointer Reading. | Horizontal Error, Micrometer Head to Left. | Vertical Error, Micrometer Head Below. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° ′ | ″ | ″ | ° ′ | ″ | ″ | ° ′ | ″ | ″ | ° ′ | ″ | ″ |
| 2. 30 | +0·46 | +1·20 | 92. 30 | −0·01 | −1·35 | 182. 30 | +0·18 | +1·68 | 272. 30 | −0·05 | −0·87 |
| 7. 30 | +0·38 | −0·57 | 97. 30 | −0·60 | −0·50 | 187. 30 | +0·13 | +0·21 | 277. 30 | −0·49 | −0·15 |
| 12. 30 | +0·74 | −0·35 | 102. 30 | −0·48 | −1·17 | 192. 30 | +0·30 | +0·46 | 282. 30 | −0·48 | +0·41 |
| 17. 30 | +0·39 | +0·37 | 107. 30 | −0·87 | −0·25 | 197. 30 | +0·52 | +0·08 | 287. 30 | +0·41 | +0·29 |
| 22. 30 | +1·56 | −0·64 | 112. 30 | −0·65 | +0·11 | 202. 30 | +1·08 | +0·26 | 292. 30 | −0·41 | +0·17 |
| 27. 30 | +0·89 | −0·51 | 117. 30 | −0·31 | +0·29 | 207. 30 | +1·75 | −0·61 | 297. 30 | −0·18 | +0·26 |
| 32. 30 | +1·08 | +0·33 | 122. 30 | −0·34 | −0·17 | 212. 30 | +1·26 | −0·55 | 302. 30 | −0·95 | +0·28 |
| 37. 30 | +0·98 | +0·83 | 127. 30 | −1·20 | +0·13 | 217. 30 | +1·40 | −0·99 | 307. 30 | −0·96 | +0·31 |
| 42. 30 | +1·07 | −0·05 | 132. 30 | −0·45 | +0·30 | 222. 30 | +0·97 | −0·14 | 312. 30 | −0·21 | −0·39 |
| 47. 30 | +0·02 | +0·28 | 137. 30 | −1·02 | +0·26 | 227. 30 | +0·92 | −0·37 | 317. 30 | +0·66 | −0·08 |
| 52. 30 | +0·06 | +0·48 | 142. 30 | −1·16 | +0·05 | 232. 30 | +0·52 | −0·47 | 322. 30 | +0·10 | −0·01 |
| 57. 30 | −0·93 | +0·99 | 147. 30 | −1·12 | −0·46 | 237. 30 | +0·84 | −1·21 | 327. 30 | −0·44 | −0·19 |
| 62. 30 | −0·55 | +1·38 | 152. 30 | −0·86 | −1·04 | 242. 30 | +0·19 | −1·37 | 332. 30 | −0·37 | +0·82 |
| 67. 30 | −1·16 | −0·21 | 157. 30 | −0·81 | −0·06 | 247. 30 | +0·10 | −0·18 | 337. 30 | −0·08 | +1·21 |
| 72. 30 | −0·24 | +0·37 | 162. 30 | −1·50 | +0·49 | 252. 30 | −0·12 | −1·06 | 342. 30 | +0·27 | +1·49 |
| 77. 30 | −0·78 | +0·52 | 167. 30 | −0·65 | +0·19 | 257. 30 | +0·18 | −0·74 | 347. 30 | +0·56 | +0·83 |
| 82. 30 | −1·03 | −0·30 | 172. 30 | +0·20 | −0·03 | 262. 30 | +0·40 | −0·86 | 352. 30 | +0·57 | +1·24 |
| 87. 30 | −0·29 | −0·54 | 177. 30 | +0·19 | +1·10 | 267. 30 | −0·31 | −0·61 | 357. 30 | +0·59 | +0·32 |

These observations agree with those previously made, in not assigning any appreciable error to the form of the pivots.

The wire frame contained originally (besides the horizontal wire, to be noticed shortly) seven vertical wires, adapted to observations of transits by eye-and-ear; to which six were added in the spring of 1854, for more convenient use in the observations of transits by galvanic contact: the whole frame and whole system of vertical wires are moved horizontally by a micrometer-screw, whose graduated head is locked up in a small box attached to the eyepiece, to prevent inadvertent disturbance of the micrometer after it has been set to the reading which is adopted for the line of collimation. The micrometer-head is on the eastern side of the eyepiece, and the readings increase as the wire is moved towards the micrometer-head. The field of view is illuminated by the light from a central gas-lamp (to be mentioned hereafter), which enters the axis and is reflected by an internal annular reflector; by inclining the reflector, the illumination is diminished and finally destroyed; and by inclining it still more, the light is thrown in such a manner as to illuminate the wires, leaving the field dark. The intensity of illumination of the wires was, in the original construction of the apparatus, practically constant: but in 1865, October, an apparatus was introduced by which the intensity of the light is graduated with great delicacy.

For determining the error of collimation, two horizontal telescopes of about 6 feet 10 inches focal length and 7 inches aperture, with their object-glasses turned towards the center of the instrument, are mounted on Y's which are carried by massive brick piers, one on the north and one on the south side of the transit-circle. The height of the axes of these telescopes is as nearly as possible the same as that of the axis of the transit-circle. External reflectors are provided, by which the light of the sky is directed into the eye-ends of these reversed telescopes. Each telescope is furnished with wires in its principal focus, to be used as collimating marks; and each telescope may be used as presenting a distinct mark for the other, or for the transit-circle-telescope. The system of wires is the same in both, consisting of two parallel wires inclined to the vertical at an angle of about $2\frac{3}{4}°$, two other parallel wires at right angles to the former, and therefore inclined to the horizontal line at the same angle (the intersection of this pair with the former producing a square), and a fifth wire parallel to the two last mentioned, and at a distance from the nearest of about ten times the side of the square. The middle of that portion of the nearly horizontal fifth wire which is included by the two nearly vertical wires, is in the same vertical with the middle of one of the nearly vertical sides of the square; and these middle points are the points adopted for observation. Those wires are finer than the others. For adjustment of these North and South Reversed Telescopes accurately on each other, the plates carrying the wires are moveable by micrometer-screws: that of the South Telescope in altitude only, and that of the North Telescope in azimuth only. Each micrometer-head, when not in use, is locked up in a box attached to the eye-piece. In order to view either telescope by the transit-circle-telescope, it is only necessary to direct the transit-circle-telescope towards that telescope; but in order to view one telescope by the other it is necessary to place the transit-telescope vertical, and to uncover the perforations in the opposite sides of its central cube, which permit one Reversed Telescope to view the other through eight holes of sector-form in those perforations. This apparatus was mounted and brought into use on 1866, December 17. To obtain a somewhat more perfect view of one Reversed Telescope by the other, it is necessary to raise the transit-circle so far that there shall be no impediment to a direct view. A mechanical apparatus is provided for the express purpose of sufficiently raising the transit-circle.

The process of adjusting the Reversed Telescopes, and of using them for determining the line of collimation of the Transit-Circle-Telescope, is as follows:—

The transit-telescope being placed in proper position, and illumination being given to the South Telescope, the eye is applied to the eyepiece of the North Telescope, and the systems of wires in both are distinctly seen: the nearly vertical wires of one being inclined about $5\frac{1}{2}°$ to those of the other. By means of the micrometer screw of the North Telescope, the middle of one nearly vertical side (the fine-wire side) of the square of the North Telescope is made to coincide with the image of that of the South Telescope, and the micrometer-reading is taken. This operation is usually repeated six times, and, the mean of all the readings being found, the micrometer is left in the position indicated by that mean. The geometrical line in each telescope, which passes through the focal center of its object-glass and through the adopted point of the delicate wire, being considered as the axis of the telescope, it is plain that, in the positions in which the wires are thus left, the axes of the two telescopes are in the same line, or at least are strictly parallel to each other: and, therefore, when the transit-telescope is employed to view the wires in the two telescopes, the images of the adopted points of their wires in all respects represent two objects at infinite distance and exactly opposed to each other.

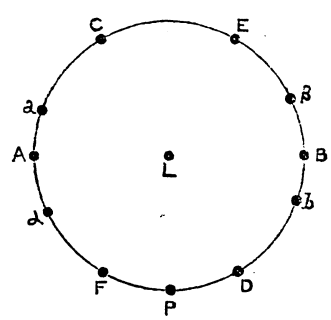
This operation is performed whenever, for the purpose of cleaning the pivots, &c. (which is usually done on every Monday), the instrument is raised; and these opportunities are preferred, as the wires are then seen very sharply defined. On other days, however, upon placing the transit-telescope vertical and uncovering its apertures, the wires are very well seen; and the coincidence of the images of the wires of the two Reversed Telescopes is therefore examined every day.

The daily observation for collimation of the transit-telescope is then made by bringing, by means of its micrometer, the central vertical wire several times in succession upon the proper point of the image of the nearly vertical fine wire of the North Telescope, and several times upon the corresponding point of the South Telescope, and reading the micrometer for each coincidence. The mean of the readings for the North and South Telescopes gives the reading for the position of the line of collimation. The observation admits of extreme accuracy, since the eye can judge with great delicacy of the equality of the two acute-angled triangles formed by the central transit-wire and the collimator-wire in the process of observation.

Tables of the micrometer-readings of the South Telescope-wire for coincidence with North Telescope-wire, and of the daily readings of the Transit-Micrometer for coincidence with the wires of both telescopes, are given at the end of the section of printed Transit Observations.

The instrument is not well adapted to the application of a spirit-level or other contrivance for determining the difference of level of the surfaces of the pivots. The error of level is ascertained by the use of a Bohnenberger's eyepiece, with three lenses, and a transparent glass reflector whose surface makes an angle of 45° with the axis of the eyepiece, and which is placed between the lowest lens and the wires of the telescope. A beam of light being thrown horizontally upon the reflector, and a trough of quicksilver being placed below the object-glass of the telescope, the image of the central wire is seen by reflexion at the same time as the wire itself; by means of the micrometer-screw the images are made to coincide, or to touch alternately on the two sides; the mean of the micrometer-readings is taken; and the difference between the mean reading and the reading corresponding to the line of collimation is the error of level. This process is perhaps in every case preferable to the use of a spirit-level.

The graduated vertical circle for zenith-distance-observations is fixed on the cylindrical basis of the axis-cone on the west side of the central-cube. It is shielded from the Sun's rays by the steps which are used by the observers for ascending to the upper part of the pier. It is of cast iron, 6 feet in diameter, and has two sets of divisions: one set, on its western side, cut upon a band of silver, which is let into the internal surface of a very flat cone, is accurately divided to five-minute spaces, and is read by the microscopes; the other set, on its eastern side, is roughly divided by points to every 5′, and is intended for setting the telescope to any object by means of two pointers reading respectively North Polar Distances and Zenith Distances. The tubes of the reading microscopes are inclined perforations through the western pier (not furnished with any metallic tube), pointing to the graduations on the flat internal conical surface of the graduated circle. Their eye-pieces are all carried by one massive brass plate at the back of the pier, and are arranged in a circle, whose center is 5 feet 2 inches above the floor, and whose diameter is about 21 inches. Their object glasses are separately attached to the inner or eastern side of the pier, and are arranged in a circle of about 5 feet in diameter. Each of the microscope perforations through the pier is accompanied with a perforation for illumination; these illumination-perforations all diverge from one central gas light near the western face of the pier. Each is furnished with a lens, by adjustment of which the light from the lamp, after specular reflexion from the graduated surface, is thrown up through the microscope-perforations to the microscope eye-pieces. A lining of double tin plates, inserted in the central opening of the pier, screens, from the radiation of the gas flame, the stone pier, the brass plate, the micrometers, and the eye-pieces. The number of microscopes is eleven; they are arranged in the following order:—




L is the illuminating lamp. P is a microscope usually furnished with an eye-piece of low power, carrying no micrometer, and intended only for reading of the integral graduations; A, C, E, B, D, F, are the six micrometer-microscopes at intervals of 60°, used in ordinary observations; a and b are supplementary micrometer-microscopes at 20° distance from A and B respectively, and $\alpha$ and $\beta$ similar microscopes at 25° distance from A and B; these supplementary microscopes are used for ascertaining the errors of graduation of the circle.

At the end of 1875 new micrometer screws were applied by Mr. Simms to the six ordinary micrometers A, B, C, D, E, F.

There are two clamps attached to the eastern pier, at the same height as the center of the circle (one on the north side, the other on the south side), which can take hold of the clamping circle of the instrument; but they have no slow motion. The eye-piece of the telescope contains only one horizontal wire, moveable by a micrometer, with which all observations of zenith-distance are made. For reducing every observation, therefore, it is necessary to combine the value of the reading of the telescope-micrometer with that of the mean of readings of the microscope-micrometers. When the telescope points vertically upwards, the head of the telescope-micrometer is on the north side; and the telescope-micrometer-readings increase as the wire is moved towards the head. The reading $20^{rev.}$ corresponds nearly to the center of the field of view.

On 1873, June 20, an apparatus was attached to the telescope-micrometer for mechanical registration of its readings. In this arrangement, punctures corresponding to each bisection of an object, in its passage across the field, are made on a strip of paper, fixed on a light drum immediately above the divided head of the micrometer, and turning with it. To distinguish the several bisections, the pricker is, after each puncture, moved through a definite space in the direction of the axis of the drum, by turning a screw, which carries it, through a quarter turn. After a set of bisections the punctures are successively brought up to a straight edge, $0^{r}\cdot050$ from the pricker, and the micrometer-head is read off; each is then marked with a pencil to distinguish it from any which may be made afterwards. By this arrangement several bisections of an object can be made without the observer having to move his eye from the telescope, and a permanent record is obtained, giving facilities for the correction of mistakes.

The reading (consisting of the combination of telescope-micrometer-reading and mean of microscope-readings), corresponding to the nadir-position of the telescope, is found by the use of the Bohnenberger's eyepiece and the trough of mercury; the direct and reflected images of the horizontal wire being made to coincide or to touch alternately on the two sides, and the mean of the readings of the micrometer being taken.

Other explanations necessary for the understanding of the process of reduction of the observations will be given under the proper heads. In this place it may be useful to explain briefly the methods employed in making the various classes of observations which are required.

For star-observing generally, the telescope is directed approximately towards the object by the indications of the N.P.D. pointer, and, the telescope being moved by hand till the star is brought near the horizontal micrometer-wire at or near the reading of $20^{rev.}$, the clamping circle is fastened. The transit of the star is then observed over the vertical wires in the usual way, either by galvanic touch or by eye and ear;

and, during the transit, by means of the micrometer-screw which acts on the horizontal wire, that wire is made to bisect the star near the passage over one or more of the vertical wires. The telescope-micrometer, and the pointer and the six microscope-micrometers, are afterwards read, and the observation is complete. If the star be too faint to allow of illumination of the field, the wires are illuminated, and the observation is made in a field perfectly dark.

For observations of stars by reflexion, the telescope is placed, some minutes previously to the transit of the star, in the direction which is proper for viewing the reflected image of the star; and the mercury-trough is carefully placed in the requisite position, and the microscope-micrometers are read after the instrument is clamped. The observer then ascends to the eyepiece of the telescope, and, by means of the micrometer-screw which carries the horizontal wire, bisects the reflected image of the star near the passage of the first aud second vertical wires (if the star has large polar-distance), or near the second and third wires (if the star is circumpolar), and reads the revolution-counter of the telescope-micrometer. He then descends rapidly into the pit, unclamps the instrument, turns the telescope to the position proper for direct view of the star, and fastens the clamping circle; bisects the star near its passage over one or more of the vertical wires by means of the micrometer-screw, and completes the direct observation in the usual way, by reading the microscope-micrometers for the second observation, and the punctures on the telescope-micrometer register for both observations.

In observing the Sun, the transits of both limbs are taken for Right Ascension, and observations are made both of the upper and lower limb for North Polar Distance, in the following manner. The observer at the telescope is aided by two assistants (usually two of the supernumerary computers), who are stationed in readiness to read the microscope-micrometers. After the transit of the first limb is completed, the telescope is moved by hand till one of the limbs (upper or lower) is brought near to the horizontal wire, when near the reading $20^{\text{rev.}}$; then the instrument is clamped, and the horizontal wire is moved, by means of the micrometer-screw which carries it, to touch the limb while passing one or more of the vertical wires (the Nos. of which are registered), corresponding punctures being made on the micrometer register. The revolution-counter of the telescope-micrometer is then read by the observer, and the microscope-micrometers by the assistants, who in fact had commenced to read the micrometers as soon as the instrument was clamped. The instrument is then unclamped, the telescope is directed to the other limb (lower or upper), the instrument is clamped, the telescope-micrometer is turned to place its wire upon the limb in its passage across one or more of the vertical wires, and the micrometers are all read again. Finally, the instrument is unclamped, and the transit of the second limb over the vertical wires is taken. The punctures on the micrometer-register are then read off at the observer's leisure. This operation requires readiness and expertness in the observers; but, when the transits are made by galvanic touch, it is found perfectly easy to take those of the first and the second limb over all the nine wires, still leaving time enough for the observations of both limbs in N.P.D.

For the Moon before opposition, (that is, when the transit of the first limb is observed,) after the transit is completed, the telescope is moved till the limb (upper or lower), which is to be observed in Zenith Distance, is brought near to the middle of the field; the instrument is clamped; and the horizontal telescope-micrometer-wire is brought repeatedly upon the limb (upper or lower) at its passage over the seven original vertical wires at wide intervals, the punctures on the micrometer register being read afterwards. The microscope-micrometers are afterwards read, and the observation is complete.

After the opposition in Right Ascension, the setting for the full limb (upper or lower) is accurately computed beforehand; the instrument is set with care, and is clamped; and the microscope-micrometers are read previously to the passage. The telescope-micrometer is then brought on the limb at the passage of each of the vertical wires, as explained above; then the clamp is relaxed, and the telescope is turned by hand to a position proper for observing the transits of the second limb in Right Ascension, and the transits over the vertical wires are taken. The punctures on the micrometer-register are then read off, and the observation is complete.

When both the upper and the lower limbs are so nearly full as to admit of observation, as also when the first and second limbs are very nearly full at the opposition of the Moon, another person is employed to read the microscope-micrometers as in the case of the Sun; and the mode of observation will be readily understood from the preceding explanations, applying to the observation of the Sun. In this case, however, the aid of one person is sufficient.

The Chronograph.—In the year 1854 an apparatus was connected with the Transit-Circle for the purpose of registering transits according to the Chronographic method, by means of a galvanic circuit. A detailed account of this apparatus, illustrated by engravings, is given in the Appendix to the Volume for 1856:—in this place it may be desirable to give such a description of the chief parts of it as is necessary for explanation of the observations and of the notes appended to them.

In the ground-floor room of the North Dome, there is mounted a clock of peculiar construction, whose motion is governed by the conical rotation of a sidereal seconds' pendulum. (In the original construction of this instrument, the limitation of the radius of the conical arc depended only on the resistance of the air, or on contact with a light spring: in 1860 an apparatus was introduced which, as the radius of the arc increases, dips a revolving plate deeper into an annular trough of glycerine, and thus supplies the required resistance, without affecting the centripetal force upon the pendulum.) One spindle of the clock gives motion to a revolving brass barrel, about 20 inches long and 12 inches in diameter; and, as the clock with conical pendulum moves without jerks, the brass barrel revolves without jerks, and with a motion sensibly uniform. The barrel revolves in two minutes of sidereal time; its cylindrical surface, therefore, moves through 0·3 inch nearly in one second of time. The barrel is covered with woollen cloth, and upon this a sheet of paper is folded; the ends of the sheet are cemented together; when the sheet is filled by the register about to be described, the cement is softened, the paper is removed, and another sheet of paper is put in its place.

Another spindle of the clock turns two long screws, both parallel to the axis of the barrel, which cause a travelling-frame to traverse the whole length of the barrel. In one revolution of the barrel, the frame moves through 0·1 inch. This travelling frame carries two levers, and each lever is armed at one end with a pricking point; the mounting of each lever being such that, when the opposite end of the lever is pulled away from the barrel, the pricking end is impressed upon the barrel, and makes a permanent puncture on the paper. The prickers are mounted in such a way that, when their points have entered the paper, they yield laterally to the motion of the revolving barrel, and do not scratch the paper. Two galvanic magnets are fixed on the travelling frame, so as to attract the lever-ends opposite to the pricking points. All that is required, therefore, to cause these points to make punctures upon the paper, is, to send galvanic currents through the galvanic magnets.

One of the prickers is devoted to the register of seconds of the Sidereal Standard Clock. For this purpose, the wires of its galvanic magnet (after passing through a galvanic battery) are led to the Sidereal Standard Relay, which completes the circuit at every second, excepting $1^s$ of each minute (see detailed description of Sidereal Standard at page xxviii). The omission of the corresponding puncture on the revolving barrel marks with certainty the commencement of each minute. Proper means are provided for breaking the circuit at pleasure, and at the same time stopping the movement of the travelling-frame, so as to avoid unnecessary consumption of paper on the barrel.

The other or "observations" pricker is used for the register of the times of observations. The wires of its galvanic magnet, after passing through a battery, are led to the Transit-Circle pier, and terminate in two large springs, which touch two large insulated brass rings upon the conical axis of the Transit-Circle. From these brass rings, wires are led within the Transit-Circle-Telescope, to a contact piece near the eye-end, where the observer, by a touch of the finger, can complete circuit, and thus make a puncture on the revolving barrel.

Branches of the same wires are led to the Altazimuth, to the Great Equatoreal, and to the Sheepshanks Equatoreal; on each of which there is a nearly similar apparatus for completing circuit.

On the introduction of the Sidereal Standard clock, a commutator was provided for throwing the contact springs of the clock Hardy (which continues to occupy its former position in the Transit-Circle-Room, and is still employed for the observation of stars near the pole by eye-and-ear) occasionally into circuit with the "observations" pricker-magnet of the chronograph, so as to obtain, at any arbitrary time, from the chronograph-register, the difference between the indications of the two clocks.

The Altazimuth, constructed by Messrs. Ransomes and May (as engineers), and by the late Mr. William Simms (as instrument-maker and optician), and erected in 1847.

This instrument is mounted in a tower (now called the South Dome), which is built on the walls of what was formerly called the Advanced Building (the same in which Flamsteed's Mural Arc and Equatoreal Sector were mounted), and is raised to such a height that the instrument commands the horizon in all directions above the buildings of the Observatory, except the East Dome, the new South-East Dome, and the Octagon Room. Its center is about 28 feet West and $34\frac{1}{2}$ feet South of the old Transit-Instrument, and about 47 feet West and 29 feet South of the new Transit-Circle. Within the Tower is built a three-rayed pier; the rays being carried up nearly to the floor of the Dome, and a central cylindrical mass, 3 feet in diameter, being carried through the floor. Upon this cylindrical mass is planted the Azimuthal Circle, on which the lower pivot for azimuthal rotation rests. For the support of the upper pivot, a horizontal iron triangle is carried by the three-rayed pier; on each side of this there is mounted a vertical iron triangle; and the three vertices of these are connected by an upper horizontal iron triangle: three radial iron bars, supported on its angles, carry, at their point of union, the Y in which the upper pivot of the vertical axis turns. The frame revolving in azimuth consists of a top, and a bottom, connected by two vertical cheeks, all of cast iron: the microscopes for viewing the divisions of the horizontal circle are cast in the same flow of metal with the bottom piece, and those for viewing the divisions of the vertical circle are cast in the same flow with one of the vertical cheeks. The vertical circle and telescope are of gun-metal; the side of the circle which carries the graduated limb, the ends of the telescope, and one of the pivots, being cast in one flow; and the other side of the circle with its pivot being cast in another flow.

The diameter of each of the two circles (horizontal and vertical) is 3 feet; the length of the telescope is 5 feet; the aperture of its object-glass $3\frac{3}{4}$ inches. The top carries two spirit-levels and the bottom carries two spirit-levels, parallel to the axis of the vertical circle: the vertical cheek which carries the microscopes carries also two spirit-levels parallel to the plane of the vertical circle. No important parts are connected by small screws; and no part whatever admits of adjustment; except that the coarse screws on the ends of the upper radial bars are sometimes touched, to bring the vertical axis to a position conveniently near to exact verticality.

The instrument can be firmly clamped in azimuth; and the vertical circle can be firmly clamped; each clamp was furnished with a slow motion at the beginning of 1876. For each movement there is also a moderately-slow motion, by rack and pinion.

For a detailed account of this instrument, illustrated by engravings, and for a description of the processes gone through in its adjustment, I refer to the volume of Astronomical Observations for 1847. The description, with some modifications, is reprinted, and attached to the volume for 1867.

As a fixed mark of reference, and as an object for facilitating the determination of the zenith-point of the vertical circle and the collimation-error for horizontal transits, a reversed-telescope or collimator is used. The object-glass of the telescope is the object-glass of 5 inches aperture and 24 feet 6 inches focal length, which was formerly used for the 25-foot Zenith Sector. It is planted in the north wall of the tower of the South Dome; a brass tube about 1 foot long is fixed by Roman cement in the wall, and the object-glass-cell is screwed to a flat bearing upon a ring within the tube; a small penthouse on the outside of the wall protects it from rain. The mark is the image of a small circular hole, as formed by a lens of short focus. The hole is a perforation $\frac{1}{50}$ inch in diameter, in a small circular piece of metal fixed in a larger circular piece of ivory which is attached to an opaque plate. At the distance of about 7 inches from this perforation is a lens of one inch focal length: and the image of the perforation therefore has a diameter of about $\frac{1}{300}$ inch; this image is in the focus of the $24\frac{1}{2}$-foot object-glass, and is in fact the mark viewed with the telescope of the Altazimuth. The perforated plate and the lens are carried by a very strong brass tube about an inch in diameter (a piece cut from the tubular standard of the Royal Astronomical Society), and this is fixed by strong iron thumb-screws into an iron frame which is strongly bolted to the west side of the west wall of the Upper Computing-Room, below the ridge of the roof of the Passage-Room (part of the ancient Quadrant-Room). The mounting of the mark is thus entirely protected from the Sun and from the weather: and although the separation of the mark and the collimator-object-glass on two unconnected buildings is not unobjectionable, yet the other circumstances of mounting are here as favourable as it is possible to find. The perforation is illuminated by a small gas-light: and its image as viewed through the telescope of the Altazimuth then appears as a very well-defined round point, admitting of most accurate bisection by a wire either in the horizontal or in the vertical direction, surrounded at a little distance by a fainter ring of light. For viewing this mark, the telescope of the Altazimuth is pointed downwards at an inclination of 12°. 18′ below the horizon.

On, 1875, May 20, an alteration was made in the position of the collimator mark, which from that date has been fixed to the chimney of the Upper Computing Room, so as to form a horizontal collimator. The mark is viewed through an opening in the curtain of the dome, which has been raised three inches for this purpose. An apparatus consisting of a galvanic battery and small induction coil has been provided to light the gas-light, which is somewhat difficult of access.

By means of the branches of the galvanic wires leading from the galvanic magnet of the "observations" pricker of the Chronographic Barrel to contact-pieces upon the Altazimuth, the observations of transits are registered on the same sheet of paper as those made with the Transit-Circle, in transit-clock-time; and thus all comparisons of clock become unnecessary, and all errors arising from the transmission of time are avoided.

The wire-plate originally carried six horizontal and six vertical wires, at intervals adapted to eye-and-ear observation of transits; but in the spring of 1854, for more convenient use in the observations by galvanic contact, four additional horizontal wires were inserted at equal intervals between the two central horizontal wires, and four additional vertical wires at equal intervals between the two central vertical wires. On 1861, February 7, a new system of six horizontal wires for observation by galvanic contact was inserted, the middle interval of wires being much larger than either of the other four intervals. On 1864, August 5, another system was inserted by Mr. James Simms, and the intervals were inadvertently made equal. On 1871, January 20, a new system was inserted, having the middle intervals of both the horizontal and vertical sets larger than the others.

For observing an azimuth, the instrument is clamped in azimuth; and when the object enters the field of view with an oblique course, the moderately-slow motion of the vertical circle is used to make the course of the object apparently horizontal through the middle of the vertical wires; the times of transit over the wires are observed, and the azimuth-circle and the levels parallel to the horizontal axis are read. For observing a zenith-distance, the process is similar, *mutatis mutandis.* The two observations can never be made at the same time.

The Altazimuth was dismounted in the autumn of 1872, in order that the bearings of the horizontal pivots in their Y's might be altered, and the pivots themselves re-turned. Each pivot now rests (in the same manner as those of the Transit-Circle) on two concave bearings, portions of cylinders. The instrument was erected again at the beginning of 1873, since which time it has been regularly raised out of its Y's by a lifting apparatus specially provided, and the horizontal pivots cleaned and oiled, once in every lunation, near the time of new moon.

In 1873, May, the pivots of the axis of the Vertical Circle of the Altazimuth were examined. The method employed is the same as that explained in detail in the Introduction to the *Greenwich Observations* for 1847, and in the Description of the Altazimuth attached to the volume for 1867, page 14. The residual errors, showing the movements of certain imaginary points on the ends of the two pivots, are given in the following tables:

Pivot on the side opposite to the Graduated Face.

| Pointer Reading. | Horizontal Error, Micrometer Head to Right. | Vertical Error, Micrometer Head Below. | Pointer Reading. | Horizontal Error, Micrometer Head to Right. | Vertical Error, Micrometer Head Below. | Pointer Reading. | Horizontal Error, Micrometer Head to Right. | Vertical Error, Micrometer Head Below. | Pointer Reading. | Horizontal Error, Micrometer Head to Right. | Vertical Error, Micrometer Head Below. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° | r | r | ° | r | r | ° | r | r | ° | r | r |
| 5 | − 0·002 | − 0·020 | 95 | + 0·026 | − 0·007 | 185 | − 0·045 | + 0·020 | 275 | + 0·029 | + 0·020 |
| 15 | − 0·007 | + 0·006 | 105 | + 0·008 | − 0·012 | 195 | − 0·026 | + 0·012 | 285 | + 0·021 | − 0·019 |
| 25 | + 0·004 | + 0·017 | 115 | + 0·001 | + 0·005 | 205 | − 0·014 | − 0·002 | 295 | + 0·022 | − 0·015 |
| 35 | + 0·006 | + 0·008 | 125 | 0·000 | + 0·012 | 215 | − 0·044 | + 0·004 | 305 | + 0·010 | − 0·014 |
| 45 | + 0·008 | + 0·012 | 135 | + 0·004 | − 0·007 | 225 | − 0·015 | + 0·021 | 315 | − 0·006 | − 0·020 |
| 55 | + 0·032 | + 0·017 | 145 | − 0·014 | + 0·012 | 235 | + 0·010 | − 0·001 | 325 | − 0·022 | − 0·022 |
| 65 | + 0·018 | + 0·014 | 155 | − 0·001 | + 0·010 | 245 | + 0·019 | + 0·028 | 335 | − 0·034 | − 0·025 |
| 75 | + 0·048 | − 0·003 | 165 | − 0·027 | + 0·003 | 255 | + 0·033 | + 0·002 | 345 | − 0·032 | − 0·033 |
| 85 | + 0·030 | + 0·003 | 175 | − 0·024 | + 0·010 | 265 | + 0·025 | − 0·013 | 355 | − 0·040 | − 0·033 |

Pivot on the same side as the Graduated Face.

| Pointer Reading. | Horizontal Error, Micrometer Head to Right. | Vertical Error, Micrometer Head Above. | Pointer Reading. | Horizontal Error, Micrometer Head to Right. | Vertical Error, Micrometer Head Above. | Pointer Reading. | Horizontal Error, Micrometer Head to Right. | Vertical Error, Micrometer Head Above. | Pointer Reading. | Horizontal Error, Micrometer Head to Right. | Vertical Error, Micrometer Head Above. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° | r | r | ° | r | r | ° | r | r | ° | r | r |
| 5 | + 0·061 | + 0·038 | 95 | + 0·002 | − 0·042 | 185 | + 0·029 | + 0·016 | 275 | − 0·041 | − 0·009 |
| 15 | + 0·031 | − 0·003 | 105 | − 0·005 | − 0·021 | 195 | + 0·032 | + 0·024 | 285 | − 0·043 | − 0·022 |
| 25 | + 0·051 | − 0·017 | 115 | − 0·012 | − 0·001 | 205 | + 0·032 | + 0·043 | 295 | − 0·044 | − 0·020 |
| 35 | + 0·045 | − 0·015 | 125 | + 0·013 | + 0·020 | 215 | + 0·032 | + 0·043 | 305 | − 0·019 | − 0·043 |
| 45 | + 0·045 | − 0·042 | 135 | + 0·026 | + 0·026 | 225 | + 0·003 | + 0·037 | 315 | − 0·017 | − 0·016 |
| 55 | + 0·018 | − 0·040 | 145 | + 0·011 | + 0·044 | 235 | − 0·034 | + 0·010 | 325 | − 0·023 | − 0·011 |
| 65 | + 0·023 | − 0·060 | 155 | + 0·021 | + 0·061 | 245 | − 0·056 | − 0·004 | 335 | − 0·024 | + 0·002 |
| 75 | − 0·019 | − 0·025 | 165 | + 0·020 | + 0·047 | 255 | − 0·073 | − 0·010 | 345 | − 0·015 | − 0·014 |
| 85 | − 0·005 | − 0·023 | 175 | + 0·023 | + 0·053 | 265 | − 0·059 | − 0·006 | 355 | − 0·032 | − 0·022 |

Value of one revolution of the Micrometer = 22″·45.

The zero in azimuth of this instrument has sometimes undergone sudden changes, from some cause not yet ascertained. It appeared to me not improbable that the radii of the horizontal circle, which rest in three iron forks fixed on the top of the cylindrical pier, might be so strongly held by friction (being pressed down by the weight, not only of the horizontal circle but also of the whole rotating apparatus and its counterpoise, which were carried by the horizontal circle) that they could not obey the laws of thermal expansion, until the strain became so great that they jumped into a new position. In order to obviate this, Mr. James Simms, in May 1865, under my instruction, placed the support of the counterpoise apparatus on the pier (leaving no pressure upon the horizontal circle except the unrelieved portion of the weight of the rotating instrument) and polished the rubbing surfaces of the three bearing radii and the forks in which they rest. It does not appear, however, that the steadiness of the circle has been materially improved.

At the end of May, 1876, a new and more powerful lever-counterpoise was applied by Mr. Simms to the vertical axis, as it had been found that the original counterpoise did not allow the lower pivot to descend low enough into its conical bearing, the bearing parts having worn considerably in process of time.

The 5-foot Equatoreal in the North Dome, constructed by Ramsden.

This instrument was the property of Sir George Shuckburgh, and is fully described by him in the Philosophical Transactions for 1793. It was presented to the Observatory in the year 1811. It was intended to be mounted in what is now called the East Dome, as an Altitude and Azimuth Instrument; but the fixed supporting columns (similar to those of the Palermo Circle) were found so unsteady that it was never once used; and it was then mounted as an Equatoreal in the North Dome (formerly called the North-Eastern Dome), where it has since remained. The situation of this dome is most unfavourable, as the South-Western sky in every part to the altitude of 35°, and through a considerable horizontal extent to the altitude of 53°, is concealed by the Octagon Room. The position of the instrument is about 52 feet West and 90 feet North of the old Transit-Instrument, or 71 feet West and $97\frac{1}{2}$ feet North of the new Transit-Circle. This Equatoreal is one of that class, usually called the "English Equatoreal," in which the two pivots of the polar-axis are at the two extremities of the polar-axis, and the two pivots of the declination-axis are at the two extremities of the declination-axis: the telescope and declination-circle being between the pivots of the declination-axis, and the declination-axis being within the frame of the polar-axis, and the complete polar axis and hour-circle being between the polar supports. The whole length of the polar-axis, between the extremities of the pivots, is about 9 feet. These pivots turn in Y's (having proper adjustments), which are carried by two piers within the Dome, one being a lofty pier on the North side, the other a pier of small elevation on the South side. The North pivot is at the center of a circular frame; the South pivot is at the apex of a cone; and the polar frame consists of six pillars, connecting the base of this cone with the circular frame. Three pillars are united by intervening bars to form the Eastern side of the polar frame, and three to form the Western side: they carry the Y's for the declination-axis and the microscopes for reading the declination-circle. The length of the declination-axis between the extremities of its pivots is about 2 feet 2 inches; the diameter of the declination-circle is 4 feet, and the circle is divided to 5′ of arc. The telescope is 5 feet 4 inches in length, and has an object-glass of 4·1 inches aperture. The hour-circle is connected with the cone; its diameter is 4 feet, and it is divided to 10′ of arc: these divisions are read by fixed micrometer-microscopes. The graduations of the hour-circle had become very indistinct, and the circle was therefore redivided by Mr. James Simms in the month of November 1860.

The Equatoreal in the Eastern Dome (formerly called the South or South-Eastern Dome).

This instrument was erected in the year 1838. The aperture of the object-glass is about 6·7 inches, and its focal length about 8 feet 2 inches. The object-glass was made by M. Cauchoix, of Paris, and was presented to the Observatory by the late Rev. R. Sheepshanks. Its definition is good: a small quantity of colour from the secondary spectrum, and a diffusion of light from brilliant objects, being the principal defects. It is mounted in the Eastern Dome, 38 feet East and 6 feet South of the old Transit-Instrument, or 19 feet East and $1\frac{1}{2}$ feet North of the Transit-Circle; with a mounting similar in general form to that known as the "German Equatoreal." A stone pier is erected, whose extreme breadth from East to West is 1 foot 4 inches, and from North to South 5 feet 4 inches: the southern or principal portion of the upper surface of this pier is sloped so that its plane produced passes through the celestial-pole: upon the surface is fixed a cradle of cast iron, having the lower bearing of the polar-axis in a projection from its lower end, and the upper bearing at its upper end: the distance between the two bearings is 3 feet 7 inches. The axis is of cast iron; its form is nearly conical: the end which rests in the lower bearing is a more obtuse cone. The diameter of the axis, where it turns in the upper bearing, is 6 inches: it rests here in a Y upon two plates of gun-metal. At a small distance below the upper bearing, a strong circular plate parallel to the equator, 14 inches in diameter, is fixed to the axis: and close above it, another plate of the same size is mounted, parallel to the former, turning freely round the axis; in that surface of each of these two plates which is nearest to the other plate, a dove-tailed groove is turned, and a moveable clamping-piece has one clamp in the groove of one plate, and the other clamp in the groove of the other plate. By means of this clamping-piece, the two circular plates can be fixed together at pleasure, in any relative position. The moveable circular plate is inseparably connected with a long flat arm, or sector, of 24 inches in length (measured from the circumference of the plate) in the plane of the equator: the edge of this sector is cut into teeth, in which works the endless screw carried by the clock, which is fixed to the North side of the pier. Therefore, if the clamping-piece above-mentioned is not fixed to either plate, or is fixed to only one, the action of the clock-work upon the sector, though it turns the moveable circular plate, does not turn the fixed circular plate; but if the clamping-piece is fixed to both plates, the action of the clock-work on the sector carries the moveable plate and the fixed plate (now connected with it), and therefore turns the polar axis, and the telescope, &c., which is supported by the polar axis. Between that part of the clamping-piece which is connected with the fixed plate, and that part which is connected with the moveable plate, there is a slow-motion screw, turned by means of a Hook's joint and a long handle. Immediately above the upper bearing, the polar axis carries the hour-circle, 12 inches in diameter; it is divided on its edge to $1^m$ of time, and is read off to $2^s$ by two verniers. Above this, a square box is firmly fixed to the axis; perforated in a direction parallel to the equator for the insertion of the declination-axis. The diameter of the declination-axis at each of its two bearings is about 4 inches; it is supported at each by a Y. To one end of the declination-axis is fixed the cradle, carrying the telescope; to the other is fixed the declination-circle, and the counterpoise. The diameter of the declination-circle is 11 inches; it is divided on its edge to 15′ of arc, and is read off to 30″ by two verniers attached to the square box. The telescope-tube is of wood; its form is square in the middle, chamfered off towards the ends so as to become octagonal: several stops, or transversal plates with holes of the proper magnitude, are fixed in it; it is very firm, and free from tremors. Upon a large ring which is fixed to the square box there turns with stiff friction another ring, carrying two sector-arms, graduated at their extremities; these graduations are read by micrometer-microscopes, carried, one by the eye-end of the telescope-tube and one by the object-end; the use of this graduated double sector is, to measure small differences of declination (not exceeding 10°) with great accuracy; as, being brought by the hand under the telescope, it is then retained in its position by friction, and is not affected by the motion of the telescope. Upon another ring, which is fixed to the square box, there turns a ring-clamp, or brake, that admits of being fastened to it in any position; with this ring-clamp the telescope-cradle is connected by means of a slow-motion screw, which fixes the telescope in declination, or gives the means of imparting to it a slow motion in declination. The speed of the clock is regulated by two balls, suspended to the ends of a horizontal arm of $4\frac{3}{4}$ inches in length, which is carried by a vertical spindle; when the velocity is so great as to cause the suspending-rods to make a certain angle with the vertical, small projections, carried by the balls, are thereby made to rub against the lower surface of a fixed horizontal ring, and the friction thus caused prevents the weight which urges the clock from greatly increasing the velocity. This mounting was constructed by Mr. T. Grubb, of Dublin. Besides several negative eyepieces unfurnished with wires, this telescope has a wire-micrometer, a comet-eyepiece with thick wires, and a double-image micrometer constructed on the principles explained in the *Memoirs of the Royal Astronomical Society*, vol. xv, page 199, and *Monthly Notices*, vol. x, page 160; (and described in page xxiv, below).

The Great Equatoreal, constructed by Messrs. Ransomes and Sims as Engineers, and the late Mr. William Simms as Instrument Maker and Optician.—A complete description of this instrument, with engravings, is attached as Appendix to the volume for 1868. The following account will give information on its principal peculiarities. It is to be premised that the form of the instrument is the "English Equatoreal;" the polar-axis turning on pivots at its extreme ends, and including between its two sides the telescope and declination-circle attached to it; the frame which carries the telescope and declination-circle having its pivots at opposite extremities of the declination-axis.

The "South-East Dome," which contains this instrument, is in close proximity to the south-east corner of the Record Room, and occupies part of the isthmus which connects the Observatory Hill with the upper part of Greenwich Park. It is in form an octagon, with an attached projection on the north side, containing the staircase. The length of the line drawn perpendicularly through opposite sides of the octagon is 31 ft. 4 in.; or, within the room, 28 ft. 8 in. The building consists of three stories; that of the ground floor contains the Water-Clock-Movement (to be mentioned below), and is used for other purposes unconnected with the Equatoreal; the middle story has been used, since 1868, as a room for chronometers; the upper story is properly the Equatoreal Room. To the top of the walls of that room, the building is fire-proof.

The walls are built to the height of 9 ft. 5 in. above the floor of the Equatoreal Room. Arches are turned across the angles of the octagon, so as to make the upper surface of the walls a polygon of sixteen sides. Upon this surface is planted a circular wooden ring or curb, upon which is fixed an iron curb, containing a channel in which cannon balls run, and containing also a circular rack or toothed wheel (its teeth pointing upwards), which surrounds the room. Upon the balls runs another curb with inverted iron channel, which curb is the foundation of the revolving dome. The dome is drum-shaped; its clear inner height above the floor being 25 ft. 8 in. It carries a toothed wheel which works in the fixed rack just mentioned, so that a rotation of the wheel causes the dome to revolve. This rotation is effected by winch-work, which is carried by an iron frame that is attached to the interior of the dome, and projects downwards to a convenient level. The person who turns the winch must follow the movement of the dome; his place is always opposite to the shutter opening. The opening for observation is 3 feet wide; it extends, without interruption, from the curb of the dome to the top of the dome-wall, and along its nearly flat top about 2 feet beyond its center. One nearly horizontal shutter covers the whole opening in the flat top, and one vertical shutter covers the whole opening in the dome-wall; each of these parts can be opened independently of the other. An iron frame attached to the interior of the dome projects downwards to a convenient position, and carries the winch-machinery by which the shutters are opened and closed.

The South Pier, which supports the lower extremity of the polar-axis, is built from the ground through the lower and middle stories, nearly to the floor of the Equatoreal Room, where the iron foundation-frame is planted which carries the bearing-piece for the lower pivot and its antifriction wheels, the attachment for the slow-motion screw, and the fixed time-microscope. The North Pier is built to the same height in two massive trapezoidal pillars (upon one foundation), united by strong stones at each of the floors; the entrances of the lower and middle rooms pass between these pillars. Upon the upper surface of the pier is planted a lofty iron frame (cast in one piece by Messrs. Ransomes and Sims), the top of which carries the bearing piece for the upper pivot, the antifriction wheels, and the apparatus subservient to the transmission of gas and to galvanic communications. The entrance to the Equatoreal Room passes between the upright parts of this iron frame; they are, however, sufficiently distant from the wall to permit the passage of the irons, projecting downwards from the dome, which carry the winch-apparatus for moving the dome and that for opening its shutters.

The polar-axis consists of two braced skeleton-prisms, each about 22 feet long, 2 feet apart, united at the bottom and at the top by ovals about 8 feet long (in the direction parallel to the declination-axis), and 5 feet broad (in the transverse direction). The pivot of the lower oval, projecting downwards, is long enough to carry the Hour-Circle, which is a cast-iron circle 6 feet in diameter, revolving freely on the long pivot, but admitting of being connected with the lower oval by clamp and slow-motion-screw. The circumference of this circle is racked, and the worm or endless screw, to which motion is given by the clock-movement, acts in it. The circle bears two graduations; one which is viewed by a fixed microscope (attached to the iron foundation-frame), whose reading, when the circle has been properly placed and the clock-movement is properly adjusted, always gives True Sidereal Time; another, which is viewed by two microscopes carried by the lower oval, and whose reading (when the clock-movement, &c., are adjusted) always gives the Right Ascension of the object under view. There are also independent means of fixing the lower oval, when the use of the clock-movement is not desired. The upper oval is cut through on one side as far as its pivot, to allow the telescope to view the pole. Its pivot is perforated to allow the passage of a gas pipe, by which lights on various parts of the instrument are supplied; and it carries four insulated galvanic rings (connected, as will presently be mentioned, with four wires that lead to springs which touch rings upon the declination-axis), touched by four springs which are attached to the lofty iron frame, and to which are attached four wires; one pair of these wires communicates with the galvanic magnet of the "observations" pricker upon the chronographic barrel, and the other pair with one of the sets of springs of the Sidereal Standard Clock Relay.

Other galvanic wires, for spectroscopic purposes, are carried from the north support to the eye-end of the telescope, but they are not connected with the polar axis.

The declination-axis is supported on brackets, which are carried nearly at the middle of the prisms' length, in such a position that the telescope, when parallel to the earth's axis, is so far removed from the imaginary axis joining the two pivots of the polar axis, that it can view the pole through the cutting of the upper oval already mentioned.

The telescope in its declination-axis nearly represents a transit-instrument. It carries on one side a graduated circle 5 feet in diameter, which is viewed by two microscopes attached to one of the prisms of the polar-axis. On the same side is also a graduated sector-arm, which can be fixed in any convenient position by means of a bridle rod, and read off by a vernier at the eye end of the telescope. On the other side it carries a clamp and slow-motion screw, which connects it with a circle affixed to the other prism. One pivot is perforated for a gas pipe: it also carries four rings which are touched by four springs that are connected by wires with the rings on the polar-axis, two wires are led from these rings through the telescope-tube to a touching-piece at the eye-end, and a contact made there produces a puncture upon the chronographic-barrel; and the other two wires are led to a galvanic chronometer on the eye-end of the telescope, which is thus regulated to synchronism with the transit-clock. The telescope tube is of mahogany; it is square in the middle of its length, and octagonal at the ends. The focal length of the object-glass, made by Messrs. Merz and Son, of Munich, is about 17 ft. 10 in. Messrs. Merz originally contemplated the supply of an object-glass of greater focal length, in consequence of which the whole frame of the instrument is made in larger dimensions than are necessary for the object-glass actually supplied. The clear aperture of the object-glass is about 12·8 inches. Its definition, as shown by examination of close double stars, is very fine; the components of the small star of $\gamma$ Andromedæ being widely separated; and there is very little stray colour.

The clock-movement is fixed in the ground-floor story, upon a frame which is attached to the South Pier. The power is given by the flow of water, acting through a reaction-machine. The water was in the first instance received directly from the water pipes which supply the Observatory, under a pressure of 100 feet. But it was found that the irregularities of pressure on the reaction-machine, produced by opening and closing taps, even on very distant connexions with the same pipes, were so violent as greatly to disturb the motion of the instrument. To remedy this, a cistern was fixed in the Ball Turret, at a height of about 50 feet above the reaction-machine, and fed from the water pipes with the usual ball service, and from that cistern a pipe is led to the reaction-machine, having no other connexion or discharge-tap. This apparatus was first brought into action on 1874, November 28.

The reaction-machine is made to revolve four times in one second of mean solar time, or one second of sidereal time, according to the adjustment of a supplementary weight on the rod of the conical pendulum (to be shortly mentioned). Its spindle rises through the lower and middle rooms, and acts by an endless screw in a wheel of 480 teeth, which revolves in two minutes and whose axis carries an endless screw which acts in the rack of the hour-circle. Very great care was taken in the preparation and examination of this large endless screw. The supply of water to the reaction-machine is determined by the construction called "Siemens' Chronometric

Governor," in which the first of three wheels of a train is connected with the machine, the third maintains the motion of a conical pendulum (so arranged by water-resistance that its arc is sensibly invariable), and the axis-frame of the second or intermediate wheel is moveable, and is connected with the throttle-valve of the water-supply. If the supply accelerates the machine too much, its excess of motion is immediately impressed on the frame of the second wheel, and the supply of water is diminished.

The Spectroscope, carried by the South-east Equatoreal.—The form of this spectroscope (made by Browning) has been arranged so as to give great facility for varying the dispersive power, and its attachment to the Great Equatoreal has been planned with special reference to the examination of the prominences round the Sun's limb by an excentric rotation of the spectroscope. The light of the object viewed passes through a narrow slit at the focus of a collimator; and, after divergence upon the collimator object-glass and refraction by it, falls as a parallel-pencil upon the first prism. The full train of prisms consists of one "half-prism," four whole prisms, and another "half-prism" silvered on the back. The prisms are compound, being each composed of a prism of flint with an angle of about 94°, and two thin prisms of crown cemented to the flint. The "half-prisms" are virtually formed by cutting a whole compound prism in halves by a plane perpendicular to the base. The "half-prism" silvered on the back or perpendicular face can be inserted in any part of the train, so as to give a dispersive power of two, four, six, eight, or ten prisms, the rays being reflected directly back at the same level, and passing twice through the train and collimator. A spectrum is thus formed in the plane of the slit, and is viewed by means of a diagonal prism with eye-piece within the collimator-tube, which is placed just clear of the course of the cone of incident rays, and intercepts the rays for one-half of the field on their return after passing twice through the train of prisms, the collimator itself being thus used as viewing telescope.

A lower dispersive power is given by inserting a plane reflector immediately behind the first half-prism; the rays thus pass twice through this half-prism, and a dispersive power of one prism is obtained. In another form of the instrument, a viewing telescope can be inserted in any part of the train, receiving the rays after they have passed once through one half-prism, or one half-prism and one, two, or three whole prisms.

The prisms are each 2 inches high and 1·6 inches broad in cross-section, the thickness being 3·4 inches at the base and 2·1 inches at the refracting edge. The collimator has an aperture of 1·6 inches and a focal length of 7 inches, but this is virtually increased to 24 inches by a concave lens within the principal focus of the object-glass. From the circumstance that the rays are reflected directly back to form the spectrum, some trouble was occasioned by false light reflected from the surfaces of the lenses in the collimator, the spectrum with the full power of ten prisms being greatly enfeebled by absorption in passing through nearly three feet of glass. To obviate this inconvenience two concave lenses, placed side by side, with an intervening diaphragm, were substituted on 1874, August 24, for the single concave lens in the collimator-telescope, so that the rays which returned through the collimator to the eye passed through a different concave lens from that on which the incident pencil fell. As the results for displacement of lines in stellar spectra appeared to be affected by this arrangement, it was abandoned and the original plan reverted to on 1875, March 4. For comparison with the spectrum of hydrogen or other chemical element, a vacuum tube was, in the earlier observations, placed centrally within the tube of the Equatoreal, at a distance of either two or four feet from the slit, but as systematic errors appeared to be introduced by the different conditions of the pencils from the star and from the vacuum tube, another method has been used from 1875, May 31, in which an image of the vacuum tube (or electrodes) is formed on the slit immediately above and below that of the star, by means of two comparison prisms in connexion with a collimating lens, so that the cone of rays from the comparison-light, as well as that from the star, fills the whole of the object-glass of the collimator. Both the collimator-telescope and the viewing telescope are provided with micrometers; larger differences of wave-length are inferred from the readings of a scale and tangent-screw which show the space through which the train of prisms has been moved.

The spectroscope is carried by two rods, which are fixed to two collar-bearings on the eye-end of the telescope, giving the means of rotation round the axis, and carrying a position-circle. The spectroscope-plate is held by clamping nuts on three strong elevator-screws fixed to the two rods and passing through slots in the plate; and an excentricity, either radial or tangential, can be given by altering the height of the nuts or by displacing the spectroscope laterally. The slit can thus be carried round the Sun's limb radially or tangentially, as may be desired.

Ample provision is made of the necessary auxiliary apparatus; namely, a Sprengel air-pump, with Crookes' improvements, made by Hicks; an induction-coil, by Browning; and a battery, by Ladd. At the head of the stairs to the Equatoreal room, a water-sink is fitted up, and a glass-blower's bench is mounted.

The Double-Image Micrometer.—The general form of the double-image eyepiece, together with the mode of use, and the advantages and disadvantages attending the use of it, are described fully in the preceding volumes, for 1840 and for 1843 to 1849. It is a four-glass erecting eyepiece, in which the lenses are so arranged that the axis of the pencil of rays from each point of an observed object passes through the center of the second lens (as measured from the object-glass), so that in fact an image of the object-glass is formed on this lens, which is divided by a plane passing through the axis of the telescope. The two halves of this lens are moved by a micrometer-screw in opposite directions, and the whole eye-piece is made to revolve round the axis of the telescope by a toothed-wheel and pinion movement.

The arrangement of this double-image eyepiece is described in vol. xv. of the *Memoirs of the Royal Astronomical Society.* The characteristic of this construction is, that the colour produced by the prismatic dispersion, which is occasioned by the passage of the rays through each half of the divided lens where the images are separated, is corrected by a new arrangement of the lenses. In this construction the focal length of the first lens, or that nearest to the object-glass, is arbitrary; so that the power is changed by change of this first lens instead of the fourth, as in the original construction. The eyepiece now used is the same as that which was first used in 1851, and was made on the principles above explained, adopting, among the various admissible relations of the focal lengths and intervals of lenses, one which was suggested by Mr. B. Valz, of Marseilles, and which is described in the *Monthly Notices of the Royal Astronomical Society*, 1850, June 14. The principal difference between this eyepiece and that used in 1850 consists in the circumstance that the divided lens is concave, instead of being convex, as in the former case. By this means much less light is lost from the central portions of the pencil in its passage past the divided surfaces of the lenses, and the construction is undoubtedly preferable to that used before.

The numbers defining the construction of this eye-piece are as follows:—

Focal length of 1st lens, or that nearest the object-glass, arbitrary, or *a*;
Distance from 1st lens to 2nd lens, the same as focal length of 1st lens, or - - - - - - - - - *a*;
Focal length of 2nd or divided lens, which is concave - - 1;
Distance from 2nd lens to 3rd - - - - - 1;
Focal length of 3rd or field-glass - - - - - 1;
Distance from 3rd to 4th - - - - - - 3;
Focal length of 4th or eye-glass - - - - - 1;

where the numbers 1 and 3 may be applied to any scale of linear measure.

And the forms of the lenses should be the following:—

1st lens - - equi-convex.
2nd or divided lens - equi-concave.
3rd or field-glass - plano-convex, with its plane side next the divided lens.
4th or eye-glass - equi-convex.

The same double-image micrometer which in preceding years was used with the Sheepshanks Equatoreal in the Eastern Dome was in the year 1861 mounted (by use of an adapting-tube) on the South-East Equatoreal; the value of its micrometer is thereby necessarily altered.

The Reflex Zenith-Tube, constructed under my direction by the late Mr. William Simms.—A detailed account of this instrument is given in Appendix I. to the volume for 1854; in this place the following account will suffice: The object-glass (formerly the object-glass of Troughton's Transit-Instrument) is mounted upon a fixed tube, which is in a vertical position; upon this tube it can be turned in azimuth. To the cell of the object-glass is firmly fixed the micrometer-frame (with its plane horizontal), revolving with the object-glass when the object-glass is turned. The bearing of the screw of the micrometer A is on the fixed micrometer-frame. The moving frame of the micrometer A carries the bearing of the micrometer-screw of the micrometer B. The micrometer B carries the wires by which the star's image is bisected. The eyepiece is a 4-glass diagonal eyepiece bent at right angles between its third lens and its fourth lens (counting from the eye), and having a diagonal-prism-reflector at the place where it is bent; and so placed that the fourth lens can receive rays of light from the direction of the nadir, and can, by means of the diagonal prism, transmit them horizontally to the eye. The fourth lens (which looks vertically downwards), and the diagonal prism, are placed nearly over the center of the object-glass, being carried by arms which are fixed to the large tube; the small horizontal tube which carries the remaining lenses of the eye-piece is supported by the large tube of the telescope, and does not project over any part of the object-glass. Below the object-glass, at a distance nearly equal to half its focal length, is a trough of quicksilver. The image of the star, as it passes near to the zenith, is formed in the plane of the micrometer wires. These particulars will probably suffice for enabling the reader to understand the reductions. It will easily be seen that, to ensure accuracy of result, no firmness of construction is requisite in this instrument, except in the connection between the micrometer and the object-glass. The instrument is mounted in a new building erected for it in the Middle Garden, in the angle between the passage behind the Astronomer Royal's Official Room and the south projection of the Transit-Circle-Room.

For the support of the quicksilver, the following method has, after several trials, been adopted:—A well was dug to the depth of ten feet below the surface, or seven feet below the deepest foundation of the walls of the Observatory, and was filled with incoherent rubbish. When a stage was placed upon it, the tremor (which had been intolerable while the quicksilver-trough rested on the solid ground) was sensibly diminished. Afterwards from this stage, No. 1, there was suspended by straps of vulcanized caoutchouc, a stage, No. 2, and from this, in like manner, a stage, No. 3, on which the quicksilver was placed. The habitual tremor was now destroyed, but the image slowly floated or oscillated. Finally, this last defect was corrected by connecting the trough horizontally in two directions by shreds of vulcanized caoutchouc with stage No. 1, and by this means the floating was nearly destroyed, leaving the image practically almost perfect. The experiments were concluded in May 1856, and from that time the use of the instrument has been continuous, and no difficulty has been experienced in making observations of $\gamma$ Draconis at its meridian transit, at any hour of the day or night.

The theory of the caoutchouc-suspension may be thus stated:—If the length of a pendulum is such that it will naturally vibrate in a long time; and if a rapid vibration, or a vibration of short period, be given by some external force to the point of suspension; then the disturbance of the pendulum consequent on that movement of the point of suspension will be very much less than that movement itself. Thus, if $y$ be the horizontal abscissa of the point of suspension, $x$ that of the bob, the equation to the pendulum's motion is $\frac{d^2 x}{d t^2} = m^2 (y - x)$, where $m$ is small, the motion of the bob being slow; and if $y = a \,.\, \text{cosine}\; n\, t$, where the motion of suspension is rapid and $n$ is large; the corresponding term in $x$ will be $\frac{-m^2}{n^2 - m^2} \times a \,.\, \text{cosine}\; n\, t$, which is much smaller than that in $y$. Now, the caoutchouc-suspension permits a horizontal oscillation, which is naturally one of long period; and the elasticity of extension of the caoutchouc permits a vertical oscillation, which is also naturally one of long period; but the disturbing tremor of the earth is one of exceedingly short period; and therefore the disturbances, horizontal and vertical, given to the suspended stages are exceedingly small. The duplication of the apparatus again diminishes the disturbance the second time in nearly the same proportion as at the first time.

Two detached telescopes, one of which is 46 inches in focal length, and the other 30 inches; the former is usually kept in the Octagon Room, and the other in the Magnetic Observatory. The diameters of the object-glasses of these telescopes are 3·6 inches and 2·7 inches respectively. The telescope formerly belonging to the Western Equatoreal has also been mounted for use as a detached telescope; its focal length is 36 inches, and the aperture of its object-glass 3·6 inches. The 62-inch telescope mentioned in former years, and that of the transit-instrument formerly used as a collimator to Troughton's transit, are now mounted on tripod stands, for general use. The other achromatic telescope, mentioned in former years, has been given to the Quebec Observatory.

Two Newtonian reflecting telescopes, the largest being one of 10 feet, by Sir W. Herschel.

The following instruments, used in the Transit of Venus Expedition 1874, are now transferred to the Observatory:—

Six 6-inch Equatoreals complete, viz.: the "Lee," "Naylor," "Hodgson," "Corbett," and "Simms No. 1" and "No. 2;" two 4-inch portable telescopes by Simms; five 3-inch portable transit instruments by Simms; a 14-inch Altazimuth and three 14-inch Vertical Circles or Altitude Instruments also by Simms; and five Photoheliographs by Dallmeyer.

The Sidereal Standard clock, constructed by Messrs. E. Dent and Co., is fixed to the north wall of the Magnetic Basement, as in this apartment the temperature is nearly uniform. The escapement will be found described in Vol. III. of the *Transactions of the Cambridge Philosophical Society:* it is a detached escapement, very closely analogous to the ordinary chronometer-escapement, the pendulum receiving impulse only at each alternate vibration; consequently, the escape wheel and seconds hand move only at alternate seconds (the even seconds). The pendulum is compensated in the following way. A central steel rod is encircled by a zinc tube, which rests on the rating nut on the steel rod; the zinc tube is in its turn encircled by another steel tube, which rests at its upper end on the zinc tube, and carries at its lower end the cylindrical leaden pendulum bob attached at its center. Slots are cut in the outer steel tube, and holes made in the intermediate zinc tube, with the object of exposing equally all parts of the compound pendulum rod to the action of temperature. For the final correction for temperature, two straight brass and steel bars, united as in the circumference of a compensation-balance, are carried by a collar holding by friction on the crutch axis. The bars stand precisely opposite each other, and carry weights at their outer extremity. They were placed at first in the upright (neutral) position, and no occasion for testing the efficiency of the arrangement has yet arisen. It is, however, anticipated that, by turning the bars into an inclined position as respects the pendulum rod, the tendency of the weights to move upwards or downwards with increase of heat, according as the steel lamina or the brass lamina is uppermost, will give power to correct, within certain limits, any defect in the primary compensation. For final adjustment of the rate there is placed on the crutch rod a sliding weight, which can be raised or lowered by a nut at the level of the crutch-axis without disturbing the pendulum. The rate of the clock is so steady that, when first mounted, the barometric inequality was indicated with the greatest regularity, the daily losing rate of the clock being increased by $0^{s}\cdot3$ for an increase of 1 inch of barometer reading.

In the autumn of 1873 an apparatus for correction of this inequality was applied to the clock by Messrs. E. Dent & Co., and has been in action regularly since that time. This new compensating apparatus of the Sidereal Standard is founded on the magnetic principle, long previously in use for daily adjustment of the Mean Solar Standard clock (see page xxxi). Two bar magnets, each about six inches long, are fixed vertically to the bob of the clock pendulum, one in front, the other at the back, their lower ends being nearly level with the bottom of the pendulum bob.

The lower pole of the front magnet is a north pole; the lower pole of the back magnet is a south pole. Below these a horseshoe magnet, having its poles precisely under those of the pendulum magnets, is carried transversely at the end of a lever, the opposite arm of which is attached by a connecting rod to a float in the lower leg of a syphon barometer, placed in one corner of the clock case. The lever turns on knife edges. The arèa of the cistern in which the float rests is four times as great as that of the upper tube. For change of one inch of barometer reading the horseshoe magnet is thus shifted two-tenths of an inch; and as the average distance between its poles and those of the pendulum-magnets is about $3\frac{3}{4}$ inches, the change of rate produced by increase or decrease of the magnetic action is sensibly uniform. As the clock gained with low barometer reading, it was necessary to place the horseshoe magnet so that there should be attraction between its poles and the adjacent poles of the pendulum-magnets. The action of this apparatus is found to be quite successful.

The driving weight of the clock is placed in a chamber separate from that of the pendulum, and bears slightly against the side of the chamber, for prevention of sympathetic vibration.

For obtaining galvanic contact, a pin on the upper part of the pendulum rod presses together two light springs at the middle of each vibration, closing thus a circuit at each second of clock time; with interruption, however, at the $1^s$ in each minute; a pin fixed to the 60-seconds-wheel pushing aside a light spring, and breaking the circuit at each revolution. The seconds-currents thus obtained (59 in each minute) are used to drive a relay, from which three independent circuits are derived. One of these is appropriated to the seconds-magnet of the chronograph; in another the current regulates a half-seconds-chronometer fixed to the eye-end of the telescope of the Great Equatoreal; that of the remaining circuit regulates the pendulum of a half-seconds-clock placed on the foundation frame upon the south pier of the Great Equatoreal, drives a tapper in the Great Equatoreal room for making audible the seconds of the clock, and drives also a galvanic chronometer placed, in the Computing Room, on the desk of the Superintendent of the Time Department. The half-seconds-clock is regulated in the manner introduced by Mr. R. L. Jones, excepting that the galvanic coil is fixed to the clock-case, and the bar-magnet is attached to the pendulum. A similar principle is used for regulation of the chronometer on the eye-end of the Great Equatoreal: upon the axis of its balance a small magnet is fixed (its center being pierced by the balance-staff); a fixed coil embraces the magnet as in the ordinary galvanometer, and through this coil pass the currents received from the sidereal standard clock. The omission of one current in each minute is unimportant as concerns the regulated clock and chronometer, but not so as regards the chronometer which is driven by the current. For this chronometer, therefore, the seconds wheel is cut with 59 teeth only, and the seconds-circle on its dial-plate is correspondingly divided into 59 equal parts (instead of 60), so that one particular division corresponds to two consecutive seconds, and at this division the seconds hand of the chronometer remains during one second (that corresponding to $1^s$ of Sidereal Standard clock time) at rest.

The clock Hardy, in the Transit-Circle-Room, was originally furnished with Hardy's escapement, for which a dead-beat escapement was substituted by Dent in the year 1829. The jewelled holes were removed by Dent in 1836, and the pivots now turn in brass holes. The clock is provided with contact-springs for the purpose of occasional registration of its seconds on the chronograph (as mentioned on page xii). Upon the escape-wheel-arbor a wheel having 59 teeth is mounted (that is, 60 teeth with one cut away), and at each second the start of a tooth of this wheel presses together two springs during a very small portion of a second. The omitted tooth in the wheel corresponds to the $1^s$ of each minute.

A clock in the East Dome, marked "Arnold 1," having contact apparatus similar to that in the clock Hardy, in order that the clock may, if required, be temporarily used either in place of Hardy or of the Sidereal Standard clock; one in the South Dome (the place of the Altazimuth), marked "Graham 1;" one in the Reflex-Zenith-Tube-Apartment, marked "Mudge and Dutton," which was presented in the year 1846 to the Observatory by the Rev. Charles Turnor; one marked "Arnold 2," one marked "Graham 2," and one marked "Earnshaw," used for occasional purposes, which have been supplied with new zinc and steel pendulums (similar to that of the Sidereal Standard), and have been used in the expeditions for observing the Transit of Venus in 1874; and one marked "Graham 3," formerly used for the daily dropping of the Time-Signal-Ball at $1^h$, but now occasionally employed for facilitating the regulation of the galvanic motor-clock. There is a clock marked "Dent" placed in the Chronometer-Room, and used occasionally for comparisons of chronometers in case of accidental failure of the galvanic clock placed there; also a chronometer "Brockbanks," generally kept in the Computing-Room, but occasionally used for extra-meridional observations. Besides these, there are some journeyman or assistant clocks, two of which, occasionally used in longitude operations, are fitted with contact springs, for the purpose of giving galvanic signals; and a watchman's clock.

There are also two sidereal clocks with zinc and steel compensation pendulums, and nine sidereal clocks with wooden pendulum rods, all made by Messrs. E. Dent and Co., and used in the Transit of Venus Expedition 1874.

The clock Hardy is wound up every Monday and Thursday, and the other ordinary clocks in daily use, every Monday.

The Mean Solar Standard or "motor" clock is placed in the lobby at the foot of the Octagon-Room staircase, near to the trigger of the ball-apparatus. It is a clock of Shepherd's construction, in which the swing of the pendulum completes three galvanic circuits: by one of these the movement of the pendulum is maintained, independently of any train of wheels; by the other two a frame of magnets is made to oscillate, and thus to give motion to the seconds-wheel, and, through it, to the other wheels. The wire which carries the current that produces that oscillation is led through corresponding parts of six similar clocks, and the current, by relay action, drives a seventh clock, and regulates another. The movements of the whole of these clocks are therefore necessarily synchronous with those of the motor-clock. One of the clocks has a large dial exposed to public view on the east boundary wall of the Observatory; three are in the Chronometer-Room, and are used in the daily comparisons of chronometers; one is in the Computing-Room; one (of the dimensions of a chronometer) is upon the desk of the Superintendent of the Time Department; one is in the hall of the Astronomer Royal's dwelling house; and one (the regulated clock) is at the London Bridge Station of the South-Eastern Railway. The regulation of the last-mentioned clock is effected by the method (slightly modified) of Mr. R. L. Jones, and the clock is used for automatic alteration of galvanic contacts which determine the direction of hourly galvanic signal-currents sent from the Royal Observatory. A comparison of the Mean Time chronometer, with the chronometer on the same desk synchronous with the Sidereal Standard clock (as mentioned in a preceding paragraph), is, in fact, a comparison of the Mean Solar Standard with the Sidereal Standard. The time shewn by the Sidereal Standard at comparison being corrected for its error (as ascertained from star-transits), the true sidereal time at the comparison is found; and this is converted, by calculation, into true mean solar time at the comparison. The difference between this and the Mean Solar Standard time is the error of the Mean Solar Standard. Then, by means of a turn-plate on the same desk, the superintendent of clocks completes the circuit of a galvanic current, which, passing through a galvanic coil (with no iron core) in the clock case, can be made either to attract or to repel a magnet attached to the pendulum, and thus to accelerate or retard the Mean Solar Standard as long as may be necessary for its correction. The clocks connected with the Mean Solar Standard necessarily receive the same correction. The arrangement for giving hourly signals is as follows. The Mean Solar Standard closes a circuit precisely at each hour: that at $1^h$, by the intervention of electro-magnets, pulls automically the ball-trigger and drops the Signal-Ball at Greenwich. At every hour also the primary clock current by relay-action causes galvanic currents to pass, on one line of wire to the central station of the Post Office Telegraphs, St. Martin's-le-Grand, London, and on another line to the London Bridge Station of the South Eastern Railway. The currents received in St. Martin's-le-Grand are distributed daily, by automatic action of the "Chronopher," on some of the principal lines of railway and to important provincial towns. The current at $1^h$ is used to fire signal guns at Newcastle and North Shields. The hourly currents pass also to the clock tower of the Westminster Palace for the guidance of the superintendent of the clock, which is not regulated or corrected by any direct galvanic action. And return-currents are received at definite times from the Westminster clock and from a clock in the Post Office, which show daily at Greenwich the deviations of the clocks from true time. The hourly currents which pass from Greenwich on the wire to London Bridge are there distributed at different hours in different directions, by the regulated clock before spoken of, principally to places on the South-Eastern lines of railway. At $1^h$ the current drops a Signal Ball at Deal, the property of the Admiralty; and from this ball a return galvanic current is automatically communicated to Greenwich at the instant that the ball has completed its descent.

In 1873, February, the Kew Photoheliograph was erected, with the consent of the Royal Society and of the Kew Committee, in a new dome connected with the magnetic offices in the south ground, and photographs of the Sun were taken regularly with that instrument. One of the Dallmeyer photoheliographs for the Transit of Venus Expedition, of which there are five, was erected in place of the Kew Photoheliograph in 1875, September, and from that time has been used exclusively for solar photographs.

The Dallmeyer Photoheliographs have each an object-glass of 4 inches aperture and 5 feet focal length, forming an image of the Sun half an inch in diameter; this image is enlarged by a secondary magnifier to 4 inches on the camera screen, where the sensitive plate is inserted, the whole length of instrument being about 8 feet. The exposure is given by a shutter, having a slit of adjustible width, which is carried by a spring across the primary image. At the principal focus cross-wires are placed, which give facilities for determining the position-angles of spots on the photographs. The instrument is equatoreally mounted, though this is not absolutely necessary to its efficient action, as the exposure is practically instantaneous, amounting only to a few thousandths of a second in ordinary cases.

## III. *Subjects of Observation in the Year* 1876.

The Sun has been observed on the meridian at every practicable opportunity, except on Sundays: the Moon and Moon-culminating stars have been observed at every opportunity without exception.

With regard to the Planets, the following rules have been observed: The inferior Planets, Mercury and Venus, have been observed on the meridian at every practicable opportunity, excepting Sundays. The superior large Planets, Mars, Jupiter, Saturn, Uranus, and Neptune, have not generally been observed when their solar time of meridian passage is greater than $15^h$, excepting at times when the Moon passes the meridian later than $15^h$. The small Planets have been observed only when the time of meridian passage is earlier than $13^h$, and only in the first part of each Lunation from New Moon to Full Moon (the observations from Full Moon to New Moon being undertaken by M. Le Verrier, as is mentioned above, page iii). The observations of all Planets are intermitted on Sundays.

In the meridional observations of the stars, it has been considered as the first object to establish with indisputable accuracy the places of those included in the Nautical Almanac list (as far as they are visible in this latitude), together with 103 other stars which are used in connection with the Nautical Almanac Stars, for determining clock-error. For this purpose the number of observations of each star, made since the preparation of the last Seven-year Catalogue, was ascertained, and the additional number required to make this up to 15 in R.A. and 10 in N.P.D. was considered to be the number due for that star.

The other stars observed are principally: Circumpolar Stars with polar distance up to 40°, both above and below the pole; about 850 Stars used for determination of Zenith-points; Moon-culminating Stars to the end of the list in the Nautical Almanac, 1876; Stars whose occultations by the Moon have been observed at Greenwich; Variable Stars; Stars which pass near the North or South horizon; Stars suspected or known to have large Proper Motions; Stars of which observations have been requested by Astronomers for special purposes.

The Altazimuth has been used for observations of the Moon on every day when she could be seen, without exception; and for the observations of Stars necessary for instrumental adjustments, and of the collimator for the same purpose. Its telescope has also been occasionally used for observing Occultations of Stars by the Moon, and for the phenomena of Jupiter's Satellites.

The Reflex-Zenith-Tube has been used throughout the year 1876 for observations of $\gamma$ Draconis. The observations are made at every opportunity (Sundays excepted), unless when $\gamma$ Draconis passes the meridian very early in the morning. In these cases the observation is only made when the Moon also passes in the early morning.

The North Equatoreal, the East Equatoreal, and the South-East or Great Equatoreal, have been used for observing Occultations of Stars by the Moon, and for the phenomena of Jupiter's Satellites.

## IV. *Explanation of the Printed Observations.*

§ 1. *Transits observed with the Transit-Circle, and Computations of Apparent Right Ascension*, page [1] to [89].

The *first* column on each page contains the day, which is always supposed to commence with the transit of the Sun.

The *second* column contains the numbers for convenience of reference.

The *third* column contains the name of the object observed. With respect to the Sun, Moon, and Planets, the limb whose transit is observed is always mentioned. If no limb is mentioned it is to be understood that the estimated center was observed. The center is observed only when the planet's disc is so small and so round as to make it easier to estimate the center than to determine with accuracy the place of the limb. With regard to the stars, the proper names which have commonly been used in the Greenwich Observations and the Nautical Almanac are adopted in preference to other names. For other stars, the names have been taken in the following order of preference:—

1. Flamsteed's constellation-N° and constellation, with Bayer's letter; taken from Baily's edition of Flamsteed. When the description thus found differs from that in the British Association Catalogue, the difference is mentioned in the notes.
2. The N° in Bessel's Fundamenta, &c., deduced from Bradley's Observations, referred to as "Bradley."
3. The hour and N° in Piazzi's Catalogue, edition 1814.
4. The N° in Groombridge's Catalogue.
5. The N° in Baily's edition of Flamsteed's Catalogue, referred to as "B.F."
6. The hour and N° in Weisse's two Catalogues of the Stars in Bessel's Zones, referred to as "W.B." and "W.B. (2)" respectively.
7. The N° in Lalande's Catalogue, published by the British Association, or in that edited by Fedorenko.
8. The N° in Lacaille's Catalogue of Southern Stars, published by the British Association.
9. The N° in Oeltzen's two Catalogues of Argelander's Zone Observations, referred to as "Oeltz. Arg. (N)" or "S" respectively.
10. The N° in the First Radcliffe Catalogue.
11. The N° in Carrington's Red Hill Catalogue.
12. The Zone and No. in Argelander's Zone Observations of 110,984 Stars (Bonn Observations, 1859), referred to as "Arg. Zone."
13. The N° in the Greenwich Catalogues; or in the British Association Catalogue, referred to as B. A. C.

In observing a double star, the brighter star (if it is not otherwise expressed) is always observed.

When no mark is attached to the name of the object observed, it is to be understood that the observations were made by the galvanic or chronographic method, which was generally in use throughout the year. In any exceptional case where the eye-and-ear method is employed, the observation is distinguished by having the initials (E & E) affixed to it.

The *fourth* column contains the initials of the observer's name.

The next *nine* columns contain the clock-times (seconds and decimals of a second only) at which the object was observed to pass each of the wires. For eye-and-ear transits, the wires used are those which were in use before the commencement of the galvanic observations, and they are denoted by the letters N, O, P, T, X, Y, Z. Polaris and other stars very near the pole, are, however, observed by eye-and-ear over the wires intended for the galvanic transits. The wires used for galvanic transits are denoted by the letters P, Q, R, S, T, U, V, W, X; P, T, and X, being wires of the original system, and Q, R, S, U, V, W, being new wires inserted between P, T, and X. The intervals P–Q, Q–R, R–S, U–V, V–W, W–X, are nearly equal; the intervals, S–T, T–U, are nearly double of the former, for convenience of easily distinguishing the central wire.

In observing by galvanic contact, the observer merely makes contact of the galvanic spring at the instant of the object passing the wire. Occasionally, when no object is under observation, he makes contacts in any arbitrary manner (usually by the commutator, in the way described on page xii), recording in his book the time by the clock Hardy; and thus the numeration of hours and minutes on the punctured sheets (referred to the Sidereal Standard clock) is easily established. The punctured sheets are examined the next day, the numeration of minutes and seconds is written upon them, and the transits are read into the transit-book.

In observing by eye-and-ear, it is the practice to take a second from the clock-face before the transit over the first wire, and to preserve the counting by listening to the beats of the clock, and not to look again at the clock-face till the transit is completed. The fraction of the second is estimated by remarking the place at which the object is seen at the successive beats of the clock. Errors in the hours and minutes are seldom alluded to in the notes of the printed observations; but every alteration of the seconds is carefully recorded.

All transits of stars observed by galvanic contact are referred to the Sidereal Standard clock; but for stars very near the pole observed by eye-and-ear, the clock Hardy is necessarily still used. The times printed in the columns "Seconds of Transit over the Wires" are those of the observations as made, the letters (E & E) in the third column indicating when the clock Hardy was used. The difference between the indications of the two clocks is given in the notes.

The *fourteenth* column contains the Concluded Transits, giving the hour and minute of the time of meridian passage (which have not been given in the preceding columns), as well as the mean of seconds.

For stars observed by eye-and-ear by the clock Hardy, the *Concluded Transits* includes the correction (obtained from the chronographic register as mentioned on page xii) for reduction of the transit as observed by Hardy to such as would have been observed by use of the Sidereal Standard. The correction in each instance applied is given in the foot notes.

When transits have not been observed over all the wires, a correction is applied to the mean of those actually observed, in order to give the mean of the transits as it would have resulted if each had been reduced separately to the center wire. When transits have been observed over all the wires, the same process of correction is used, but the amount of correction for the mean is very small.

The equatoreal intervals of the wires were determined by observations of stars. From the nature of the process, these intervals are necessarily corrected for the mean effects of refraction. The following are the intervals, determined from 200 transits, which were in use from 1876, January 1 to March 22, and which are the same as those used throughout the two preceding years:—

| | | | |
|---|---|---|---|
| | | | s |
| Wire N | = | + | 41·547 |
| O | = | + | 27·723 |
| P | = | + | 13·834 |
| Q | = | + | 10·973 |
| R | = | + | 8·279 |
| S | = | + | 5·523 |
| T | = | | 0·000 |
| U | = | − | 5·556 |
| V | = | − | 8·333 |
| W | = | − | 11·066 |
| X | = | − | 13·864 |
| Y | = | − | 27·668 |
| Z | = | − | 41·464 |

For λ Ursæ Minoris, assuming its declination = 88°. 55′ + $n''$:

| | | | | |
|---|---|---|---|---|
| | | | m s | |
| Wire P | = | + | 12. 12·05 | + $n$ × 0·191 |
| Q | = | + | 9. 40·57 | + $n$ × 0·152 |
| R | = | + | 7. 17·96 | + $n$ × 0·115 |
| S | = | + | 4. 52·16 | + $n$ × 0·076 |
| T | = | | 0·00 | |
| U | = | − | 4. 53·92 | − $n$ × 0·706 |
| V | = | − | 7. 20·84 | − $n$ × 0·115 |
| W | = | − | 9. 45·47 | − $n$ × 0·152 |
| X | = | − | 12. 13·65 | − $n$ × 0·191 |

For Polaris, assuming its declination = 88°. 38′ + $n''$:

| | | | m s | | s |
|---|---|---|---|---|---|
| Wire P | = | + | 9. 40·20 | + $n$ × | 0·120 |
| Q | = | + | 7. 40·18 | + $n$ × | 0·095 |
| R | = | + | 5. 47·16 | + $n$ × | 0·072 |
| S | = | + | 3. 51·58 | + $n$ × | 0·048 |
| T | = | | 0·00 | | |
| U | = | − | 3. 52·98 | − $n$ × | 0·048 |
| V | = | − | 5. 49·44 | − $n$ × | 0·072 |
| W | = | − | 7. 44·05 | − $n$ × | 0·095 |
| X | = | − | 9. 41·47 | − $n$ × | 0·120 |

For Cephei 51, assuming its declination = 87°. 14′ + $n''$:

| | | | m s | | s |
|---|---|---|---|---|---|
| Wire P | = | + | 4. 46·62 | + $n$ × | 0·029 |
| Q | = | + | 3. 47·35 | + $n$ × | 0·023 |
| R | = | + | 2. 51·52 | + $n$ × | 0·017 |
| S | = | + | 1. 54·42 | + $n$ × | 0·011 |
| T | = | | 0·00 | | |
| U | = | − | 1. 55·12 | − $n$ × | 0·011 |
| V | = | − | 2. 52·65 | − $n$ × | 0·017 |
| W | = | − | 3. 49·27 | − $n$ × | 0·023 |
| X | = | − | 4. 47·25 | − $n$ × | 0·029 |

For δ Ursæ Minoris, assuming its declination = 86°. 36′ + $n''$:

| | | | m s | | s |
|---|---|---|---|---|---|
| Wire P | = | + | 3. 53·27 | + $n$ × | 0·019 |
| Q | = | + | 3. 5·04 | + $n$ × | 0·015 |
| R | = | + | 2. 19·60 | + $n$ × | 0·011 |
| S | = | + | 1. 33·13 | + $n$ × | 0·008 |
| T | = | | 0·00 | | |
| U | = | − | 1. 33·69 | − $n$ × | 0·008 |
| V | = | − | 2. 20·52 | − $n$ × | 0·011 |
| W | = | − | 3. 6·59 | − $n$ × | 0·015 |
| X | = | − | 3. 53·78 | − $n$ × | 0·019 |

On 1876, March 22, the wires S, T, and U were found broken. They were replaced on March 23. Provisional equatoreal intervals, determined from 20 transits of ordinary stars and three transits of polar stars, were used from March 23 to April 30.

| | | | s |
|---|---|---|---|
| For wire P | = | + | 13·912 |
| Q | = | + | 11·082 |
| R | = | + | 8·364 |
| S | = | + | 5·552 |
| T | = | | 0·000 |
| U | = | − | 5·551 |
| V | = | − | 8·237 |
| W | = | − | 10·953 |
| X | = | − | 13.763 |

From May 1 a new set of intervals of the nine wires usually employed in chronographic transits was used. The intervals were determined from 200 transits of ordinary stars and 11 transits of polar stars. The following are the adopted values of the intervals of all the wires used to the end of the year:—

| | | | s |
|---|---|---|---|
| For wire N | = | + | 41·612 |
| O | = | + | 27·788 |
| P | = | + | 13·899 |
| Q | = | + | 11·052 |
| R | = | + | 8·353 |
| S | = | + | 5·537 |
| T | = | | 0·000 |
| U | = | − | 5·551 |
| V | = | − | 8·258 |
| W | = | − | 10·971 |
| X | = | − | 13·775 |
| Y | = | − | 27·579 |
| Z | = | − | 41·375 |

For λ Ursæ Minoris, assuming its declination = 88°. 56′ + $n''$:

| | | | m s | | | | s |
|---|---|---|---|---|---|---|---|
| Wire P | = | + | 12. 26·99 | + | $n$ | × | 0·197 |
| Q | = | + | 9. 53·88 | + | $n$ | × | 0·157 |
| R | = | + | 7. 28·79 | + | $n$ | × | 0·118 |
| S | = | + | 4. 57·46 | + | $n$ | × | 0·079 |
| T | = | | 0·00 | | | | |
| U | = | − | 4. 58·21 | − | $n$ | × | 0·079 |
| V | = | − | 7. 23·68 | − | $n$ | × | 0·118 |
| W | = | − | 9. 49·52 | − | $n$ | × | 0·157 |
| X | = | − | 12. 20·32 | − | $n$ | × | 0·197 |

For Polaris, assuming its declination = 88°. 38′ + $n''$:

| | | | m s | | | | s |
|---|---|---|---|---|---|---|---|
| Wire P | = | + | 9. 42·93 | + | $n$ | × | 0·120 |
| Q | = | + | 7. 43·47 | + | $n$ | × | 0·095 |
| R | = | + | 5. 50·26 | + | $n$ | × | 0·072 |
| S | = | + | 3. 52·16 | + | $n$ | × | 0·048 |
| T | = | | 0·00 | | | | |
| U | = | − | 3. 52·75 | − | $n$ | × | 0·048 |
| V | = | − | 5. 46·28 | − | $n$ | × | 0·072 |
| W | = | − | 7. 40·07 | − | $n$ | × | 0·095 |
| X | = | − | 9. 37·72 | − | $n$ | × | 0·120 |

For Cephei 51, assuming its declination = 87°. 13′ + $n''$:

| | | | m s | | | | s |
|---|---|---|---|---|---|---|---|
| Wire P | = | + | 4. 46·25 | + | $n$ | × | 0·029 |
| Q | = | + | 3. 47·61 | + | $n$ | × | 0·023 |
| R | = | + | 2. 52·02 | + | $n$ | × | 0·017 |
| S | = | + | 1. 54·03 | + | $n$ | × | 0·011 |
| T | = | | 0·00 | | | | |
| U | = | − | 1. 54·32 | − | $n$ | × | 0·011 |
| V | = | − | 2. 50·06 | − | $n$ | × | 0·017 |
| W | = | − | 3. 45·94 | − | $n$ | × | 0·023 |
| X | = | − | 4. 43·69 | − | $n$ | × | 0·029 |

For δ Ursæ Minoris, assuming its declination = 88°. 36′ + $n''$:

| | | | m s | | s |
|---|---|---|---|---|---|
| Wire P | = | + | 3. 54·37 | + $n$ × | 0·019 |
| Q | = | + | 3. 6·36 | + $n$ × | 0·015 |
| R | = | + | 2. 20·85 | + $n$ × | 0·011 |
| S | = | + | 1. 33·36 | + $n$ × | 0·008 |
| T | = | | 0·00 | | |
| U | = | − | 1. 33·60 | − $n$ × | 0·008 |
| V | = | − | 2. 19·25 | − $n$ × | 0·011 |
| W | = | − | 3. 4·99 | − $n$ × | 0·015 |
| X | = | − | 3. 52.28 | − $n$ × | 0·019 |

For stars above the pole, the designations of Wires I., II., III., &c., at the heads of the columns of printed transits, correspond to P, Q, R, &c., (or to N, O, P, &c., when the object is observed by eye and ear (E & E), in all cases excepting Polaris, &c.) For stars below the pole, the designations I., II., III., &c., correspond to X, W, V, &c., or to Z, Y, X, &c.

The signs of the numbers must be changed when the star is below the pole.

The correction to the imperfect transit of a star can be found by adding together the equatoreal numbers from one of the tables given above for the wires observed, then dividing by the number of wires, and multiplying by the secant of the star's declination.

For a planet, the correction, computed as for a star, is to be multiplied by

$$1 + \frac{\text{daily increase of R.A. in seconds of time}}{24 \times 60 \times 60};$$

$$\text{or by } 1 + \frac{\text{hourly increase of R.A. in seconds of time}}{60 \times 60}:$$

but it has generally been found easier to add, to the computed interval between the mean of wires and the center wire, the amount of the planet's increase of Right Ascension for that interval, which is very readily determined from the numbers given in the Nautical Almanac.

For the Moon, the equatoreal numbers for the wires observed are added together; and the sum is divided by the number of wires; this quotient is then multiplied by,

$$\frac{3600 + \text{I}}{3600} \times \frac{\text{sin Moon's geocentric } Z.D.}{\text{sin Moon's apparent } Z.D.} \times \text{secant of Moon's geocentric declination,}$$

where I is the increase (in seconds of time) of the Moon's R.A., for the transit over a meridian upon the Earth distant by $1^{h}$ of terrestrial longitude, as given in the section *Moon-culminating Stars* in the Nautical Almanac.

For the easy computation of this formula, the following small Table (including the limits of the values of I) of the natural numbers and logarithms of $\frac{3600 + \text{I}}{3600}$, is used:—

| I = Var. in R. A. for $1^h$ of Longitude. | $\frac{3600 + I}{3600}$ Nat. Number. | Log. | I = Var. in R. A. for $1^h$ of Longitude. | $\frac{3600 + I}{3600}$ Nat. Number. | Log. |
|---|---|---|---|---|---|
| s | | | s | | |
| 100 | 1·02778 | 0·01190 | 145 | 1·04028 | 0·01715 |
| 101 | ·02806 | ·01202 | 146 | ·04056 | ·c1727 |
| 102 | ·02834 | ·01213 | 147 | ·04083 | ·01738 |
| 103 | ·02861 | ·01225 | 148 | ·04111 | ·01750 |
| 104 | ·02889 | ·01237 | 149 | ·04139 | ·01761 |
| 105 | ·02917 | ·01249 | 150 | ·04166 | ·01773 |
| 106 | ·02945 | ·01260 | 151 | ·04195 | ·01784 |
| 107 | ·02972 | ·01272 | 152 | ·04222 | ·01796 |
| 108 | ·03000 | ·01284 | 153 | ·04250 | ·01808 |
| 109 | ·03028 | ·01296 | 154 | ·04278 | ·01819 |
| 110 | ·03055 | ·01307 | 155 | ·04306 | ·01831 |
| 111 | ·03084 | ·01319 | 156 | ·04333 | ·01842 |
| 112 | ·03111 | ·01330 | 157 | ·04361 | ·01854 |
| 113 | ·03139 | ·01342 | 158 | ·04389 | ·01866 |
| 114 | ·03167 | ·01354 | 159 | ·04417 | ·01877 |
| 115 | ·03195 | ·01366 | 160 | ·04444 | ·01888 |
| 116 | ·03222 | ·01377 | 161 | ·04472 | ·01900 |
| 117 | ·03250 | ·01389 | 162 | ·04500 | ·01912 |
| 118 | ·03278 | ·01401 | 163 | ·04528 | ·01923 |
| 119 | ·03306 | ·01413 | 164 | ·04556 | ·01935 |
| 120 | ·03333 | ·01424 | 165 | ·04583 | ·01946 |
| 121 | ·03361 | ·01436 | 166 | ·04611 | ·01958 |
| 122 | ·03389 | ·01447 | 167 | ·04639 | ·01969 |
| 123 | ·03417 | ·01459 | 168 | ·04667 | ·01981 |
| 124 | ·03444 | ·01471 | 169 | ·04694 | ·01992 |
| 125 | ·03472 | ·01482 | 170 | ·04722 | ·02004 |
| 126 | ·03500 | ·01494 | 171 | ·04750 | ·02015 |
| 127 | ·03528 | ·01506 | 172 | ·04778 | ·02027 |
| 128 | ·03556 | ·01518 | 173 | ·04806 | ·02039 |
| 129 | ·03583 | ·01529 | 174 | ·04833 | ·02050 |
| 130 | ·03611 | ·01541 | 175 | ·04861 | ·02061 |
| 131 | ·03639 | ·01552 | 176 | ·04889 | ·02073 |
| 132 | ·03667 | ·01564 | 177 | ·04916 | ·02084 |
| 133 | ·03694 | ·01575 | 178 | ·04944 | ·02096 |
| 134 | ·03722 | ·01587 | 179 | ·04972 | ·02107 |
| 135 | ·03750 | ·01599 | 180 | ·05000 | ·02119 |
| 136 | ·03778 | ·01611 | 181 | ·05028 | ·02130 |
| 137 | ·03806 | ·01622 | 182 | ·05056 | ·02142 |
| 138 | ·03833 | ·01634 | 183 | ·05083 | ·02153 |
| 139 | ·03861 | ·01645 | 184 | ·05111 | ·02165 |
| 140 | ·03889 | ·01657 | 185 | ·05139 | ·02176 |
| 141 | ·03917 | ·01669 | 186 | ·05167 | ·02188 |
| 142 | ·03945 | ·01680 | 187 | ·05194 | ·02199 |
| 143 | ·03972 | ·01692 | 188 | ·05222 | ·02211 |
| 144 | ·04000 | ·01703 | 189 | ·05250 | ·02222 |
| 145 | ·04028 | ·01715 | 190 | ·05278 | ·02234 |

The *fifteenth* column contains the numerical values, in seconds of arc, of the errors of collimation, level, and azimuth; the two last being distinguished from the first by a round and a square bracket respectively. These errors will be treated separately, as follows:—

*Error of Collimation.*

The value of this error is given in seconds of arc. The sign of the error is considered positive when it implies an additive correction to the time of observed transits of stars above the pole.

The method of determining the position of the line of collimation by means of the north and south reversed telescopes has been so fully explained above in the description of the instrument, that it is unnecessary to repeat the explanation here. It is only necessary to state that every day the reading of the micrometer of the north telescope, for coincidence of its nearly vertical wire with the image of that of the south telescope, is ascertained (the results of which will be found on pages [92] to [96], and that the micrometer-wire of the north telescope is then left in the position so ascertained. And that the reading of the transit-telescope-micrometer, for coincidence with the image of the wire of each reversed telescope, is then found (the results of which are given in pages [97] to [99]); that the mean of these gives the reading for the line of collimation for the day; and that the mean of these determinations, usually for a week, is adopted as the reading for the geometrical line of collimation of the transit-telescope. From 1874, January 1, a correction of $+0^{r}\cdot019$ has been applied to the "Adopted Mean of Group," to reduce the Collimation-readings resulting from the observations of the Collimator made through the central cube of the Transit-circle to those resulting from observations made when the instrument is raised, this being the discordance found from a comparison of the two methods of observation.

During the year 1851 the observations of the reversed telescopes with the transit-telescope were usually made twice in every day. Upon examination of the results it did not appear that there was any discoverable difference at different hours of the day, and therefore generally, since that time, the observations have been made only once in every day.

The micrometer of the transit-telescope is left at some convenient reading, near to that of the geometrical collimation, but not necessarily coinciding with it. This reading is given at the foot of every page of transits. The algebraical excess of the reading for geometrical collimation above this is the geometrical error of collimation, with the sign as explained above. This excess is converted into arc at the rate of $14''\cdot78$ for one revolution of the micrometer. (This determination of the value of a revolution was made at the end of the year 1850, as is explained in the description of the Transit Circle, page {22}, Appendix I., of the Volume for 1852, or in the reprint attached to the volume for 1867, page 25: a new investigation for verification of the value was made on 1854, June 27, the resulting value of a revolution being $14''\cdot76$, which is essentially identical with the preceding.) To the excess thus converted into arc is then applied $-0''\cdot19$ for diurnal aberration; and the result is the quantity which is given in the fifteenth column of the *Transits* as the Error of Collimation, and which is adopted for correction of the observed transits.

The numerical correction to the time of observed transit, in seconds of time, is,

$$\text{Error of Collimation} \times \frac{1}{15 \sin \text{N.P.D.}}.$$

*Error of Level.*

The error of level of the axis of revolution is considered positive when the western end of the axis is too high.

The process of determining the error of level consists in taking the reading of the transit-telescope-micrometer which makes the image of the wire as seen by reflexion from the surface of quicksilver to coincide with the wire as seen directly, as is explained in the description of the instrument above, and comparing this reading with the reading for the geometrical line of collimation. The excess of the reading for the line of collimation, above the reading for coincidence of direct and reflected images, gives the error of level, with the sign mentioned above. It is converted into arc at the rate of 14″·78 for one revolution of the micrometer. The mean of the results is adopted sometimes for a week, sometimes for a shorter time, as the instrument appears to have been more or less steady in level.

The details of these operations are given in pages [100] to [103].

The result adopted for the error of level is given in the fifteenth column of the *Transits*.

The numerical correction to the time of observed transit, in seconds of time, is,

$$\text{Error of level} \times \frac{\text{cosine zenith distance}}{15 \sin \text{N.P.D.}}.$$

During the year 1851 observations for the error of level were usually made twice every day; but on examination there appeared to be no discoverable difference between the results for different hours of the day; and since that time the observation has been made in general only once each day. Subsequently, however, there appeared reason for believing that the variations of level have a close connexion with the variations of temperature, any sudden change of temperature being almost invariably accompanied by an abrupt change of the error of level. To verify this fact, observations of the level were made for a short period, in 1858 (see *Greenwich Observations*, 1858, Introduction, page xxiv), at the end of long night-watches, as well as at the commencement, so as to obtain a great change of temperature; and it appeared that every notable rise of temperature was accompanied with a diminution of error of level. There appears to be nothing whatever in the metallic structure of the instrument, at its mounting, which can explain this thermal change. The qualities of the stones of which the two piers are built are different; but I can scarcely imagine that such masses can so quickly receive the influence of change of temperature. In the observations of a single evening, something might be attributed to the radiation from the illuminating lamp; but this cannot explain the changes whose periods are long.

In 1876 the error of level was usually observed twice every day, and in some instances where there appeared to be a considerable change the separate results have been used for the morning and evening observations respectively.

*Error of Azimuth.*

This error is considered positive when the Eastern pivot is too far North. It is generally determined from observations of Polaris, of δ Ursæ Minoris, of Cephei 51, or of λ Ursæ Minoris, at consecutive passages above and below the pole; or from one observation of Polaris, or occasionally of λ Ursæ Minoris, combined with one observation of another star; or from observations of δ Ursæ Minoris and Cephei 51 in combination. The stars used are, however, always mentioned in the Notes; the method of using them is as follows:—

If two consecutive passages of Polaris have been observed, the second transit (as corrected for the error of collimation and level-error) is altered by the change of the star's R.A. and by the estimated clock-rate through $12^h$; and the difference, in seconds of time, between the first transit and the altered second transit (rejecting $12^h$) is divided by 3·519 to obtain the azimuthal error in seconds of space.

If three transits have been observed, the difference between the first and second is taken (rejecting $12^h$), and the difference between the second and third in like manner: and the mean between these is supposed to be independent of the change of R.A. and of the clock's rate, and is then divided by 3·519.

If several transits have been observed, the same process is used for every successive set of three, and the results are used separately, or the mean of the results is taken, accordingly as there appears reason to think that the position of the instrument has or has not undergone a change.

When only one observation of a circumpolar star can be obtained, the following process is used:—The letter $z$ being put for the azimuthal error; the time of true transit of any star consists of an observed time with an additional term multiplied by $z$; and, therefore, the clock-error as given by comparison of that transit with the star's tabular R.A., contains a term multiplied by $z$. The clock-error given thus by a star near the pole contains a large multiple of $z$. The clock-error given by a star far from the pole contains a small multiple of $z$. Equating these, with proper allowance for the rate of clock, $z$ is found. The combination of two stars, both near the pole, but one above and the other below the pole, is very favourable, as both factors of $z$ are large but have opposite signs.

The error is positive when the transit of the northern star above the pole is too late.

The numerical correction to the observed transit, in seconds of time, is,

$$\text{Azimuthal error} \times \frac{\text{sin zenith distance south}}{15 \text{ sin N.P.D.}}.$$

The numerical values of the three corrections for the errors of collimation, level, and azimuth, have been obtained throughout the year by means of sliding scales (one for each error) constructed by Mr. Simms, according to my directions. These scales give by simple inspection the numerical corrections in seconds of time for each transit; in the case of the stars in the Nautical Almanac, by means of their names which are written on cards attached to the scales; and, in the case of all other stars, by the North Polar Distances engraved on the scales. The value of the error in collimation, level, or azimuth, on the slider, is set to a brass pin which is let into the scale; and the value of the correction to transits, with its proper sign, is then taken out very readily at sight.

The following table of factors, however, for the three errors, having for argument the N.P.D. of the object, may be found convenient for the verification of the computed corrections.

| N.P.D. | Collimation. | Level. | Azimuth. | N.P.D. | Collimation. | Level. | Azimuth. |
|---|---|---|---|---|---|---|---|
| | $\frac{1}{15 \text{ Sin N.P.D.}}$ | $\frac{\text{Cos Z. D.}}{15 \text{ Sin N.P.D.}}$ | $\frac{\text{Sin Z. D.}}{15 \text{ Sin N.P.D.}}$ | | $\frac{1}{15 \text{ Sin N.P.D.}}$ | $\frac{\text{Cos Z. D.}}{15 \text{ Sin N.P.D.}}$ | $\frac{\text{Sin Z. D.}}{15 \text{ Sin N.P.D.}}$ |
| ° ′ | | | | ° ′ | | | |
| −45. 0 | −0·094 | −0·011 | +0·094 | − 7.30 | −0·511 | −0·355 | +0·368 |
| −44. 0 | −0·096 | −0·013 | +0·095 | − 7. 0 | −0·547 | −0·383 | +0·390 |
| −43. 0 | −0·098 | −0·014 | +0·096 | − 6.30 | −0·589 | −0·416 | +0·417 |
| −42. 0 | −0·100 | −0·016 | +0·098 | − 6. 0 | −0·638 | −0·455 | +0·447 |
| −41. 0 | −0·102 | −0·018 | +0·100 | | | | |
| −40. 0 | −0·104 | −0·021 | +0·102 | 6. 0 | +0·638 | +0·538 | −0·343 |
| −39. 0 | −0·106 | −0·023 | +0·104 | 6.30 | +0·589 | +0·499 | −0·312 |
| −38. 0 | −0·108 | −0·025 | +0·105 | 7. 0 | +0·547 | +0·466 | −0·286 |
| −37. 0 | −0·111 | −0·027 | +0·107 | 7.30 | +0·511 | +0·438 | −0·263 |
| −36. 0 | −0·113 | −0·030 | +0·109 | 8. 0 | +0·479 | +0·413 | −0·243 |
| −35. 0 | −0·116 | −0·033 | +0·111 | 8.30 | +0·451 | +0·391 | −0·226 |
| −34. 0 | −0·119 | −0·036 | +0·114 | 9. 0 | +0·426 | +0·371 | −0·210 |
| −33. 0 | −0·122 | −0·039 | +0·116 | 9.30 | +0·404 | +0·353 | −0·196 |
| −32. 0 | −0·126 | −0·042 | +0·119 | 10. 0 | +0·384 | +0·337 | −0·183 |
| −31. 0 | −0·129 | −0·045 | +0·121 | 10.30 | +0·366 | +0·323 | −0·172 |
| −30. 0 | −0·133 | −0·049 | +0·124 | 11. 0 | +0·349 | +0·310 | −0·161 |
| −29. 0 | −0·138 | −0·053 | +0·127 | 11.30 | +0·334 | +0·298 | −0·152 |
| −28. 0 | −0·142 | −0·057 | +0·130 | 12. 0 | +0·321 | +0·287 | −0·143 |
| −27. 0 | −0·147 | −0·061 | +0·133 | 12.30 | +0·308 | +0·277 | −0·135 |
| −26. 0 | −0·152 | −0·065 | +0·137 | 13. 0 | +0·296 | +0·267 | −0·128 |
| −25. 0 | −0·158 | −0·070 | +0·141 | 13.30 | +0·286 | +0·259 | −0·122 |
| −24. 0 | −0·164 | −0·076 | +0·145 | 14. 0 | +0·276 | +0·251 | −0·116 |
| −23. 0 | −0·171 | −0·082 | +0·150 | 14.30 | +0·266 | +0·244 | −0·111 |
| −22. 0 | −0·178 | −0·088 | +0·155 | 15. 0 | +0·257 | +0·236 | −0·105 |
| −21. 0 | −0·186 | −0·094 | +0·160 | 15.30 | +0·249 | +0·230 | −0·099 |
| −20. 0 | −0·195 | −0·102 | +0·166 | 16. 0 | +0·242 | +0·224 | −0·093 |
| −19.30 | −0·200 | −0·106 | +0·170 | 16.30 | +0·235 | +0·218 | −0·088 |
| −19. 0 | −0·205 | −0·110 | +0·173 | 17. 0 | +0·228 | +0·212 | −0·084 |
| −18.30 | −0·210 | −0·114 | +0·176 | 17.30 | +0·222 | +0·207 | −0·080 |
| −18. 0 | −0·216 | −0·119 | +0·180 | 18. 0 | +0·216 | +0·202 | −0·076 |
| −17.30 | −0·222 | −0·124 | +0·184 | 18.30 | +0·210 | +0·197 | −0·072 |
| −17. 0 | −0·228 | −0·129 | +0·188 | 19. 0 | +0·205 | +0·193 | −0·068 |
| −16.30 | −0·235 | −0·134 | +0·192 | 19.30 | +0·200 | +0·189 | −0·065 |
| −16. 0 | −0·242 | −0·140 | +0·197 | 20. 0 | +0·195 | +0·185 | −0·062 |
| −15.30 | −0·249 | −0·146 | +0·202 | 21. 0 | +0·186 | +0·177 | −0·056 |
| −15. 0 | −0·257 | −0·153 | +0·207 | 22. 0 | +0·178 | +0·171 | −0·051 |
| −14.30 | −0·266 | −0·160 | +0·213 | 23. 0 | +0·171 | +0·164 | −0·046 |
| −14. 0 | −0·276 | −0·168 | +0·219 | 24. 0 | +0·164 | +0·159 | −0·041 |
| −13.30 | −0·286 | −0·176 | +0·225 | 25. 0 | +0·158 | +0·153 | −0·037 |
| −13. 0 | −0·296 | −0·184 | +0·232 | 26. 0 | +0·152 | +0·148 | −0·033 |
| −12.30 | −0·308 | −0·194 | +0·240 | 27. 0 | +0·147 | +0·144 | −0·029 |
| −12. 0 | −0·321 | −0·204 | +0·248 | 28. 0 | +0·142 | +0·140 | −0·026 |
| −11.30 | −0·334 | −0·214 | +0·256 | 29. 0 | +0·138 | +0·136 | −0·023 |
| −11. 0 | −0·349 | −0·227 | +0·266 | 30. 0 | +0·133 | +0·131 | −0·020 |
| −10.30 | −0·366 | −0·240 | +0·276 | 31. 0 | +0·129 | +0·128 | −0·017 |
| −10. 0 | −0·384 | −0·254 | +0·288 | 32. 0 | +0·126 | +0·125 | −0·014 |
| − 9.30 | −0·404 | −0·270 | +0·300 | 33. 0 | +0·122 | +0·122 | −0·012 |
| − 9. 0 | −0·426 | −0·288 | +0·314 | 34. 0 | +0·119 | +0·119 | −0·009 |
| − 8.30 | −0·451 | −0·308 | +0·330 | 35. 0 | +0·116 | +0·116 | −0·007 |
| − 8. 0 | −0·479 | −0·330 | +0·348 | 36. 0 | +0·113 | +0·113 | −0·005 |
| − 7.30 | −0·511 | −0·355 | +0·368 | 37. 0 | +0·111 | +0·111 | −0·003 |

| N.P.D. | Collimation. $\frac{1}{15 \text{ Sin N.P.D.}}$ | Level. $\frac{\text{Cos Z.D.}}{15 \text{ Sin N.P.D.}}$ | Azimuth. $\frac{\text{Sin Z.D.}}{15 \text{ Sin N.P.D.}}$ | N.P.D. | Collimation. $\frac{1}{15 \text{ Sin N.P.D.}}$ | Level. $\frac{\text{Cos Z.D.}}{15 \text{ Sin N.P.D.}}$ | Azimuth. $\frac{\text{Sin Z.D.}}{15 \text{ Sin N.P.D.}}$ |
|---|---|---|---|---|---|---|---|
| ° ′ | | | | ° ′ | | | |
| 37. 0 | +0·111 | +0·111 | −0·003 | 82. 0 | +0·067 | +0·049 | +0·046 |
| 38. 0 | +0·108 | +0·108 | −0·001 | 83. 0 | +0·067 | +0·048 | +0·047 |
| 39. 0 | +0·106 | +0·106 | +0·001 | 84. 0 | +0·067 | +0·047 | +0·048 |
| 40. 0 | +0·104 | +0·104 | +0·003 | 85. 0 | +0·067 | +0·046 | +0·048 |
| 41. 0 | +0·102 | +0·101 | +0·004 | 86. 0 | +0·067 | +0·045 | +0·049 |
| 42. 0 | +0·100 | +0·099 | +0·006 | 87. 0 | +0·067 | +0·044 | +0·050 |
| 43. 0 | +0·098 | +0·097 | +0·007 | 88. 0 | +0·067 | +0·043 | +0·051 |
| 44. 0 | +0·096 | +0·096 | +0·009 | 89. 0 | +0·067 | +0·042 | +0·052 |
| 45. 0 | +0·094 | +0·094 | +0·011 | 90. 0 | +0·067 | +0·041 | +0·052 |
| 46. 0 | +0·093 | +0·092 | +0·012 | 91. 0 | +0·067 | +0·040 | +0·053 |
| 47. 0 | +0·091 | +0·090 | +0·013 | 92. 0 | +0·067 | +0·040 | +0·054 |
| 48. 0 | +0·090 | +0·088 | +0·015 | 93. 0 | +0·067 | +0·039 | +0·054 |
| 49. 0 | +0·088 | +0·087 | +0·016 | 94. 0 | +0·067 | +0·038 | +0·055 |
| 50. 0 | +0·087 | +0·085 | +0·017 | 95. 0 | +0·067 | +0·037 | +0·056 |
| 51. 0 | +0·086 | +0·084 | +0·018 | 96. 0 | +0·067 | +0·036 | +0·057 |
| 52. 0 | +0·085 | +0·082 | +0·020 | 97. 0 | +0·067 | +0·035 | +0·057 |
| 53. 0 | +0·083 | +0·081 | +0·021 | 98. 0 | +0·067 | +0·034 | +0·058 |
| 54. 0 | +0·082 | +0·080 | +0·022 | 99. 0 | +0·067 | +0·033 | +0·059 |
| 55. 0 | +0·081 | +0·078 | +0·023 | 100. 0 | +0·068 | +0·032 | +0·060 |
| 56. 0 | +0·080 | +0·077 | +0·024 | 101. 0 | +0·068 | +0·031 | +0·060 |
| 57. 0 | +0·080 | +0·075 | +0·025 | 102. 0 | +0·068 | +0·030 | +0·061 |
| 58. 0 | +0·079 | +0·074 | +0·026 | 103. 0 | +0·068 | +0·029 | +0·062 |
| 59. 0 | +0·078 | +0·073 | +0·027 | 104. 0 | +0·069 | +0·028 | +0·063 |
| 60. 0 | +0·077 | +0·072 | +0·028 | 105. 0 | +0·069 | +0·027 | +0·063 |
| 61. 0 | +0·076 | +0·070 | +0·029 | 106. 0 | +0·069 | +0·027 | +0·064 |
| 62. 0 | +0·076 | +0·069 | +0·030 | 107. 0 | +0·070 | +0·026 | +0·065 |
| 63. 0 | +0·075 | +0·068 | +0·031 | 108. 0 | +0·070 | +0·025 | +0·066 |
| 64. 0 | +0·074 | +0·067 | +0·032 | 109. 0 | +0·071 | +0·024 | +0·066 |
| 65. 0 | +0·073 | +0·066 | +0·033 | 110. 0 | +0·071 | +0·023 | +0·067 |
| 66. 0 | +0·073 | +0·065 | +0·034 | 111. 0 | +0·072 | +0·022 | +0·068 |
| 67. 0 | +0·072 | +0·064 | +0·035 | 112. 0 | +0·072 | +0·021 | +0·069 |
| 68. 0 | +0·072 | +0·063 | +0·035 | 113. 0 | +0·073 | +0·020 | +0·070 |
| 69. 0 | +0·071 | +0·061 | +0·036 | 114. 0 | +0·073 | +0·018 | +0·071 |
| 70. 0 | +0·071 | +0·060 | +0·037 | 115. 0 | +0·074 | +0·017 | +0·072 |
| 71. 0 | +0·071 | +0·059 | +0·038 | 116. 0 | +0·075 | +0·016 | +0·072 |
| 72. 0 | +0·070 | +0·058 | +0·039 | 117. 0 | +0·075 | +0·015 | +0·073 |
| 73. 0 | +0·070 | +0·057 | +0·039 | 118. 0 | +0·076 | +0·014 | +0·074 |
| 74. 0 | +0·069 | +0·056 | +0·040 | 119. 0 | +0·076 | +0·013 | +0·075 |
| 75. 0 | +0·069 | +0·055 | +0·041 | 120. 0 | +0·077 | +0·012 | +0·076 |
| 76. 0 | +0·069 | +0·054 | +0·042 | 121. 0 | +0·078 | +0·011 | +0·077 |
| 77. 0 | +0·068 | +0·053 | +0·043 | 122. 0 | +0·079 | +0·009 | +0·078 |
| 78. 0 | +0·068 | +0·053 | +0·043 | 123. 0 | +0·080 | +0·008 | +0·079 |
| 79. 0 | +0·068 | +0·052 | +0·044 | 124. 0 | +0·080 | +0·007 | +0·080 |
| 80. 0 | +0·068 | +0·051 | +0·045 | 125. 0 | +0·081 | +0·005 | +0·081 |
| 81. 0 | +0·067 | +0·050 | +0·045 | 126. 0 | +0·082 | +0·004 | +0·082 |
| 82. 0 | +0·067 | +0·049 | +0·046 | | | | |

The *sixteenth* column contains the seconds of every transit, as affected with the three preceding corrections; and is conceived to represent the clock-time at which each body passed the true astronomical meridian of Greenwich. The numbers to which a bracket is annexed are those resulting from the mean of the two limbs of the Sun or a planet.

The *seventeenth* column contains the seconds of the tabular R.A. of the stars which are used for determining clock-errors. In addition to the list of stars taken from the Nautical Almanac, whose North Polar Distances exceed 50°, there has been used, as in preceding years, another list, consisting in the year 1876 of 103 stars, selected and observed for this purpose, and lying beyond the same limit of Polar Distance. The tabular right ascensions of Polaris, Cephei 51 (Hev.), δ Ursæ Minoris, and λ Ursæ Minoris, are set down, whenever they have been actually used in determining the azimuthal error, to be used in conjunction with the numbers in the sixteenth column, in order to enable the reader to judge of the general state of adjustment of the instrument; but not to assist in determining clock-errors.

For the Nautical-Almanac-stars, the Right Ascensions are computed by applying, to the numbers given in the Nautical Almanac, corrections fundamentally deduced from the "New-Seven-Year Catalogue of 2760 Stars, deduced from Observations, " extending from 1861 to 1867, at the Royal Observatory, Greenwich, and reduced " to the Epoch 1864," which is printed as an Appendix to the volume for 1868. To bring up the Mean Right Ascensions from the epoch of the Catalogue, viz., 1864, to the year 1876, use has been made of the precessions of that Catalogue, and of the proper motions given by Mr. Main or by Mr. Stone. The corrections necessary to bring up the stars' Right Ascensions to the day of observation are computed by the formula $E e + F f + G g + H h + L + l - 300^s + \mu\, t$, to which further allusion will be made below. For stars near the pole, the additional correction depending on the place of the Moon is also taken into account. The following table gives the Mean Right Ascensions for 1876, January 1, of all the stars which have been used in 1876 for determining clock-errors, together with the constant corrections to the Right Ascensions of the Nautical-Almanac-stars; it gives also, in addition, the Right Ascensions of Polaris and other stars very near the pole, which have been observed for the determination of azimuthal error throughout the year 1876.

ASSUMED MEAN RIGHT ASCENSIONS OF CLOCK STARS AND CIRCUMPOLAR STARS, WITH THE CORRECTIONS TO THE NAUTICAL ALMANAC, FOR 1876, JANUARY 1.

| Star's Name. | Assumed Mean R. A. 1876, Jan. 1. | Correction to N.A. | Star's Name. | Assumed Mean R. A. 1876, Jan. 1. | Correction to N.A. |
|---|---|---|---|---|---|
| | h m s | s | | h m s | s |
| α Andromedæ | 0. 1.58·79 | − 0·03 | β Arietis | 1.47.47·47 | + 0·02 |
| γ Pegasi | 0. 6.51·07 | − 0·03 | α Arietis | 2. 0.11·11 | − 0·01 |
| ι Ceti | 0.13. 6·50 | | ξ¹ Ceti | 2. 6.25·74 | |
| 44 Piscium | 0.19. 2·74 | | 67 Ceti | 2.10.47·87 | − 0·01 |
| 12 Ceti | 0.23.42·56 | − 0·02 | ξ² Ceti | 2.21.34·02 | + 0·01 |
| ε Andromedæ | 0.32. 0·34 | | ν Ceti | 2.29.21·99 | |
| β Ceti | 0.37.21·82 | + 0·03 | δ Ceti | 2.33. 7·66 | |
| δ Piscium | 0.42.14·91 | | γ² Ceti | 2.36.52·55 | − 0·01 |
| 20 Ceti | 0.46.40·16 | | σ Arietis | 2.44.38·84 | |
| μ Andromedæ | 0.49.52·42 | | ε Arietis | 2.52. 7·45 | |
| ε Piscium | 0.56.30·53 | − 0·03 | α Ceti | 2.55.47·89 | + 0·01 |
| θ Andromedæ | 1. 2.47·60 | | δ Arietis | 3. 4.32·43 | + 0·01 |
| ζ¹ Piscium | 1. 7.15·19 | | τ¹ Arietis | 3.14. 4·19 | |
| Polaris | 1.13.19·88 | − 0·05 | ο Tauri | 3.18. 8·53 | |
| θ Ceti | 1.17.49·47 | 0·00 | *f* Tauri | 3.24. 1·71 | |
| η Piscium | 1.24.50·95 | 0·00 | ε Eridani | 3.27. 5·29 | − 0·03 |
| ν Piscium | 1.34.58·70 | + 0·02 | 11 Tauri | 3.33.22·00 | |
| ο Piscium | 1.38.50·78 | | δ Eridani | 3.37.18·48 | |

ASSUMED MEAN RIGHT ASCENSIONS OF CLOCK STARS AND CIRCUMPOLAR STARS, WITH THE CORRECTIONS TO THE NAUTICAL ALMANAC, FOR 1876, JANUARY 1—*cont.*

| Star's Name. | Assumed Mean R. A. 1876, Jan. 1. | Correction to N.A. | Star's Name. | Assumed Mean R. A. 1876, Jan. 1. | Correction to N.A. |
|---|---|---|---|---|---|
| | h m s | s | | h m s | s |
| η Tauri | 3. 40. 6·91 | 0·00 | Regulus | 10. 1. 45·97 | − 0·03 |
| γ$^1$ Eridani | 3. 52. 14·61 | + 0·01 | γ$^1$ Leonis | 10. 13. 7·99 | − 0·03 |
| A$^1$ Tauri | 3. 57. 21·95 | | μ Hydræ | 10. 20. 5·62 | |
| ω$^1$ Tauri | 4. 1. 56·61 | | ρ Leonis | 10. 26. 16·85 | − 0·03 |
| ο$^1$ Eridani | 4. 5. 48·74 | + 0·02 | 34 Sextantis | 10. 36. 13·23 | |
| γ Tauri | 4. 12. 44·27 | | *l* Leonis | 10. 42. 44·29 | + 0·03 |
| ε Tauri | 4. 21. 22·59 | 0·00 | *d* Leonis | 10. 54. 9·33 | |
| Aldebaran | 4. 28. 48·37 | − 0·02 | χ Leonis | 10. 58. 37·18 | 0·00 |
| τ Tauri | 4. 34. 48·19 | | δ Leonis | 11. 7. 30·69 | − 0·04 |
| μ Eridani | 4. 39. 18·15 | | δ Crateris | 11. 13. 8·52 | 0·00 |
| ι Aurigæ | 4. 48. 55·18 | + 0·01 | τ Leonis | 11. 21. 33·56 | |
| ε Leporis | 5. 0. 12·71 | + 0·03 | υ Leonis | 11. 30. 35·96 | + 0·02 |
| Rigel | 5. 8. 34·71 | 0·00 | β Leonis | 11. 42. 44·01 | 0·00 |
| β Tauri | 5. 18. 27·24 | − 0·05 | β Virginis | 11. 44. 14·12 | |
| δ Orionis | 5. 25. 40·30 | − 0·02 | π Virginis | 11. 54. 31·11 | |
| α Leporis | 5. 27. 15·68 | − 0·01 | ο Virginis | 11. 58. 53·56 | |
| ε Orionis | 5. 29. 55·25 | 0·00 | ε Corvi | 12. 3. 44·97 | − 0·02 |
| α Columbæ | 5. 35. 9·65 | 0·00 | η Virginis | 12. 13. 33·68 | 0·00 |
| κ Orionis | 5. 41. 52·50 | | δ$^2$ Corvi | 12. 23. 27·09 | |
| α Orionis | 5. 48. 27·51 | − 0·02 | β Corvi | 12. 27. 52·47 | + 0·04 |
| 1 Geminorum | 5. 56. 34·94 | | ρ Virginis | 12. 35. 36·49 | |
| ν Orionis | 6. 0. 29·51 | − 0·02 | 35 Virginis | 12. 41. 32·58 | |
| η Geminorum | 6. 7. 23·54 | | 31 Comæ | 12. 45. 39·50 | |
| μ Geminorum | 6. 15. 27·51 | − 0·03 | δ Virginis | 12. 49. 21·46 | |
| β Canis Majoris | 6. 17. 14·35 | | ε Virginis | 12. 56. 0·26 | |
| ν Geminorum | 6. 21. 35·97 | | θ Virginis | 13. 3. 31·80 | − 0·01 |
| γ Geminorum | 6. 30. 32·83 | − 0·04 | Spica | 13. 18. 39·67 | 0·00 |
| ξ Geminorum | 6. 38. 19·77 | | ζ Virginis | 13. 28. 22·50 | − 0·04 |
| Cephei 51 | 6. 41. 45·46 | − 0·44 | *m* Virginis | 13. 35. 6·26 | |
| θ Canis Majoris | 6. 48. 25·71 | | τ Boötis | 13. 41. 22·18 | |
| ε Canis Majoris | 6. 53. 45·13 | − 0·03 | η Boötis | 13. 48. 46·84 | − 0·01 |
| ζ Geminorum | 6. 56. 45·23 | | τ Virginis | 13. 55. 20·17 | − 0·03 |
| γ Canis Majoris | 6. 58. 8·91 | − 0·03 | 94 Virginis | 13. 59. 43·82 | |
| 51 Geminorum | 7. 6. 15·02 | | κ Virginis | 14. 6. 16·93 | |
| δ Geminorum | 7. 12. 42·99 | − 0·03 | Arcturus | 14. 10. 0·33 | − 0·03 |
| β Canis Minoris | 7. 20. 25·53 | | *f* Boötis | 14. 20. 41·38 | |
| Castor | 7. 26. 41·16 | − 0·03 | ρ Boötis | 14. 26. 29·14 | − 0·03 |
| Procyon | 7. 32. 48·60 | − 0·04 | ε$^2$ Boötis | 14. 39. 34·29 | 0·00 |
| Pollux | 7. 37. 43·54 | − 0·03 | α Libræ | 14. 44. 1·24 | + 0·01 |
| ξ Navis | 7. 44. 4·77 | | ξ$^2$ Libræ | 14. 50. 2·47 | |
| 6 Cancri | 7. 55. 54·00 | + 0·04 | ψ Boötis | 14. 59. 7·94 | − 0·04 |
| 15 Argûs | 8. 2. 15·76 | − 0·04 | ι$^1$ Libræ | 15. 5. 9·31 | |
| β Cancri | 8. 9. 47·36 | | β Libræ | 15. 10. 20·09 | − 0·01 |
| *d*$^1$ Cancri | 8. 16. 15·70 | | ο$^2$ Libræ | 15. 16. 6·88 | |
| η Cancri | 8. 25. 32·16 | + 0·02 | ζ$^1$ Libræ | 15. 21. 15·94 | |
| γ Cancri | 8. 36. 6·45 | | α Coronæ | 15. 29. 26·27 | − 0·04 |
| ε Hydræ | 8. 40. 12·49 | − 0·01 | α Serpentis | 15. 38. 9·63 | − 0·02 |
| α Cancri | 8. 51. 42·22 | | ε Serpentis | 15. 44. 38·10 | |
| κ Cancri | 9. 1. 1·77 | − 0·02 | γ Serpentis | 15. 50. 43·57 | |
| 83 Cancri | 9. 12. 3·46 | − 0·01 | β$^1$ Scorpii | 15. 58. 13·69 | − 0·01 |
| α Hydræ | 9. 21. 29·58 | − 0·01 | δ Ophiuchi | 16. 7. 50·83 | − 0·01 |
| ξ Leonis | 9. 25. 15·63 | | γ Herculis | 16. 16. 27·00 | |
| ο Leonis | 9. 34. 31·85 | | Antares | 16. 21. 48·37 | − 0·01 |
| ε Leonis | 9. 38. 48·60 | − 0·03 | λ Ophiuchi | 16. 24. 39·60 | |
| μ Leonis | 9. 45. 42·48 | | ζ Ophiuchi | 16. 30. 19·88 | |
| π Leonis | 9. 53. 39·57 | 0·00 | ζ Herculis | 16. 36. 36·76 | 0·00 |

ASSUMED MEAN RIGHT ASCENSIONS OF CLOCK STARS AND CIRCUMPOLAR STARS, WITH THE CORRECTIONS TO THE NAUTICAL ALMANAC, FOR 1876, JANUARY 1—*concl.*

| Star's Name. | Assumed Mean R.A. 1876, Jan. 1. | Correction to N.A. | Star's Name. | Assumed Mean R.A. 1876, Jan. 1. | Correction to N.A. |
|---|---|---|---|---|---|
| | h m s | s | | h m s | s |
| κ Ophiuchi | 16. 51. 47·92 | + 0·02 | β Capricorni | 20. 14. 2·53 | |
| ε Herculis | 16. 55. 32·74 | | ρ Capricorni | 20. 21. 47·09 | + 0·02 |
| η Ophiuchi | 17. 3. 16·01 | | ε Delphini | 20. 27. 17·28 | |
| α¹ Herculis | 17. 8. 59·59 | − 0·03 | α Delphini | 20. 33. 52·70 | |
| θ Ophiuchi | 17. 14. 23·67 | − 0·01 | ε Aquarii | 20. 40. 57·68 | |
| σ Ophiuchi | 17. 20. 21·73 | | μ Aquarii | 20. 45. 57·82 | |
| α Ophiuchi | 17. 29. 10·67 | − 0·01 | 32 Vulpeculæ | 20. 49. 16·50 | − 0·02 |
| β Ophiuchi | 17. 37. 20·78 | | θ Capricorni | 20. 58. 58·46 | |
| μ Herculis | 17. 41. 36·36 | 0·00 | ζ Cygni | 21. 7. 39·52 | + 0·01 |
| 89 Herculis | 17. 50. 25·05 | | α Equulei | 21. 9. 37·46 | |
| 72 Ophiuchi | 18. 1. 28·22 | | ι Capricorni | 21. 15. 20·38 | |
| μ¹ Sagittarii | 18. 6. 20·80 | + 0·02 | β Aquarii | 21. 25. 1·75 | + 0·02 |
| δ Ursæ Minoris | 18. 12. 20·10 | − 0·21 | ξ Aquarii | 21. 31. 8·91 | |
| η Serpentis | 18. 14. 53·58 | | ε Pegasi | 21. 38. 5·74 | − 0·03 |
| λ Sagittarii | 18. 20. 19·04 | | δ Capricorni | 21. 40. 11·64 | |
| α Lyræ | 18. 32. 44·38 | − 0·02 | 16 Pegasi | 21. 47. 25·22 | − 0·04 |
| 2 Aquilæ | 18. 35. 28·99 | | α Aquarii | 21. 59. 24·79 | 0·00 |
| β¹ Lyræ | 18. 45. 30·08 | − 0·02 | ι Pegasi | 22. 1. 14·32 | |
| ε Aquilæ | 18. 53. 59·61 | | θ Aquarii | 22. 10. 17·31 | 0·00 |
| ζ Aquilæ | 18. 59. 42·56 | + 0·01 | γ Aquarii | 22. 15. 15·02 | |
| ψ Sagittarii | 19. 7. 56·08 | | σ Aquarii | 22. 24. 4·98 | |
| ω Aquilæ | 19. 11. 59·71 | 0·00 | η Aquarii | 22. 28. 58·98 | + 0·01 |
| δ Aquilæ | 19. 19. 14·70 | + 0·02 | ζ Pegasi | 22. 35. 16·60 | + 0·01 |
| α Vulpeculæ | 19. 23. 32·73 | | μ Pegasi | 22. 44. 1·13 | |
| μ Aquilæ | 19. 28. 1·86 | | λ Aquarii | 22. 46. 8·58 | |
| h² Sagittarii | 19. 29. 9·58 | + 0·07 | Fomalhaut | 22. 50. 47·65 | + 0·02 |
| e¹ Sagittarii | 19. 33. 37·07 | | α Pegasi | 22. 58. 35·06 | 0·00 |
| ι Aquilæ | 19. 40. 21·83 | − 0·04 | γ Piscium | 23. 10. 44·15 | − 0·02 |
| α Aquilæ | 19. 44. 43·95 | − 0·02 | κ Piscium | 23. 20. 34·50 | − 0·01 |
| λ Ursæ Minoris | 19. 48. 15·97 | − 1·60 | ι Piscium | 23. 33. 34·33 | 0·00 |
| β Aquilæ | 19. 49. 13·30 | 0·00 | δ Sculptoris | 23. 42. 27·83 | + 0·01 |
| c Sagittarii | 19. 55. 1·83 | | ω Piscium | 23. 52. 56·62 | − 0·01 |
| θ Aquilæ | 20. 4. 54·33 | | 2 Ceti | 23. 57. 23·14 | |
| α² Capricorni | 20. 11. 10·36 | + 0·02 | | | |

The *eighteenth* column contains the error of the clock, found by subtracting the numbers in the sixteenth column from those in the seventeenth. The error is therefore positive when the clock is slow. The apparent clock-errors given by Polaris, Cephei 51, δ Ursæ Minoris, and λ Ursæ Minoris, as has been remarked above, are not employed in determining the clock-errors available for computations of Right Ascensions.

The *nineteenth* column contains the adopted losing rate, and the adopted error of the clock at $0^h$ sidereal, as found by the following process. The observations are divided into groups, defined by bars across this column (in all instances the same as the limits of the observations of each observer). The mean of the clock-errors given by all the clock-stars in each group is then taken, and this is considered to be the clock-error corresponding to the mean of all the times of transit of those stars. The next step is to investigate the clock-rate, making allowance for personal equation between the transits of successive observers; and it will be sufficient to explain the personal equation existing between any two observers, but more especially between Mr. Criswick and some other observer; for example, between Mr. Criswick and Mr. Lynn; since it has been the practice from the beginning of 1871 to reduce all the clock-times of observation with the Altazimuth to sidereal time by means of errors of the transit-clock referred to Mr. Criswick as the standard. Suppose then that transits have been observed on successive days by Mr. Criswick and Mr. Lynn, and that, for the set of observations on each day, the mean is taken as described above. It will be seen by one of the tables in the Introduction to the *Greenwich Observations*, 1875, page lvi, that the clock-error given by Mr. Lynn's observations is less than that given by Mr. Criswick's observations by $0^{s}\cdot25$, as deduced from observations suitable for the determination of this quantity in the year 1875; and this is the last determination of personal equation which is available for the daily reduction of observations in 1876. The quantity $0^{s}\cdot26$ is therefore added to Mr. Lynn's clock-errors, and it is then considered that we have two sets of clock-errors (namely, Mr. Criswick's as unaltered, and Mr. Lynn's as modified) justly comparable. Each mean clock-error, properly modified, is now compared with that which precedes and with that which follows; a preceding rate and a following rate are thus found, and by these the computer is guided in adopting the clock-rate to be used through the group of observations: this adopted clock-rate is set down in the nineteenth column. For facility of calculation, the proportional part of this rate, corresponding to the mean sidereal time or mean of all the times of transit for the group, is applied with changed sign to the mean clock-error; and thus the clock-error at $0^{h}$ sidereal is found. If it happen that any observations included in the same group are made in the sidereal day preceding or following that for which the mean error has been found, the whole adopted daily rate is subtracted from or added to the error found for $0^{h}$; and thus the error for $0^{h}$ of the preceding or the following sidereal day is obtained. These errors at $0^{h}$ for all the different sidereal days are also set down in the nineteenth column. It is to be remarked that, in the application of these errors, if the observations of small stars and planets have been made by the same person as the observations of the clock-stars (whether it be Mr. Criswick or Mr. Lynn), no further computation is necessary for obtaining the right ascensions of those objects than the application, to the time of transit, of the clock-error at $0^{h}$, and of a proportional part of the clock-rate corresponding to the right ascension of the object: but, if the clock-stars are observed by Mr. Lynn, and the other object by Mr. Criswick, a further correction $+0^{s}\cdot26$ must be applied: if the clock-stars are observed by Mr. Criswick, and the object by Mr. Lynn, $-0^{s}\cdot26$ must be applied. The personal equations are *not* applied in the column of *Apparent Right Ascensions from the Observations* in this Section.

In the preceding years, observations were exhibited which gave the relative personal equations of the different observers of transits, as far as means existed for determining them. In the year 1876 the following sets of observations have been found available for determining personal equations in the use of the galvanic method of recording transits. They have been treated in the same manner as in preceding years, by comparing the clock-error at the same sidereal hour given by two different groups of stars observed by different persons.

OBSERVATIONS FOR THE DETERMINATION OF THE PERSONAL EQUATIONS OF THE VARIOUS TRANSIT-OBSERVERS USING THE GALVANIC METHOD OF OBSERVING TRANSITS.

| Day, 1876. | | Observers in order of Seniority. | Interval between mean of Groups of Clock Stars. | Order of Observations. | | Clock Slow at 0h Sidereal by Senior Observer. | Clock Slow at 0h Sidereal by Junior Observer. | Excess of Clock Slow by Junior Observer. |
|---|---|---|---|---|---|---|---|---|
| | | | h | | | s | s | s |
| July | 10 | W C and L | 7 | L | W C | 30·46 | 30·09 | − 0·37 |
| September | 8 | W C and C | 5 | W C | C | 50·88 | 50·82 | − 0·06 |
| ,, | 11 | | 3 | W C | C | 49·29 | 49·11 | − 0·18 |
| July | 10 | W C and AD | 4 | A D | W C | 30·46 | 30·27 | − 0·19 |
| August | 30 | | 0 | W C | A D | 59·66 | 59·61 | − 0·05 |
| September | 8 | W C and T | 0 | W C | T | 51·72 | 51·78 | + 0·06 |
| September | 11 | W C and G | 2 | W C | G | 49·29 | 49·21 | − 0·08 |
| July | 15 | W C and P | 6 | P | W C | 27·26 | 27·14 | − 0·12 |
| September | 8 | W C and J B | 1 | W C | J B | 51·72 | 51·70 | − 0·02 |
| September | 11 | W C and K | 0 | W C | K | 49·29 | 49·18 | − 0·11 |
| January | 28 | L and C | 12 | C | L | 52·18 | 52·58 | + 0·40 |
| February | 17 | | 11 | L | C | 43·38 | 43·71 | + 0·33 |
| March | 2 | | 0 | L | C | 38·85 | 39·12 | + 0·27 |
| ,, | 4 | | 0 | L | C | 37·84 | 38·07 | + 0·23 |
| ,, | 6 | | 4 | L | C | 36·87 | 37·03 | + 0·16 |
| ,, | 11 | | 4 | C | L | 34·78 | 34·96 | + 0·18 |
| ,, | 30 | | 0 | C | L | 36·89 | 37·14 | + 0·25 |
| April | 1 | | 1 | L | C | 37·86 | 37·99 | + 0·13 |
| ,, | 3 | | 3 | L | C | 39·03 | 39·11 | + 0·08 |
| ,, | 7 | | 1 | L | C | 40·74 | 40·98 | + 0·24 |
| ,, | 9 | | 2 | C | L | 41·55 | 41·81 | + 0·26 |
| ,, | 11 | | 0 | C | L | 42·05 | 42·36 | + 0·31 |
| ,, | 26 | | 0 | L | C | 46·04 | 46·24 | + 0·20 |
| ,, | 28 | | 3 | L | C | 46·27 | 46·55 | + 0·28 |
| May | 2 | | 1 | L | C | 46·68 | 46·88 | + 0·20 |
| ,, | 6 | | 2 | L | C | 47·10 | 47·33 | + 0·23 |
| ,, | 8 | | 1 | C | L | 47·30 | 47·49 | + 0·19 |
| ,, | 10 | | 3 | C | L | 47·32 | 47·61 | + 0·29 |
| ,, | 12 | | 1 | C | L | 47·51 | 47·71 | + 0·20 |
| June | 24 | | 2 | L | C | 38·56 | 38·76 | + 0·20 |
| October | 29 | | 1 | C | L | 48·35 | 48·59 | + 0·24 |
| ,, | 31 | | 4 | L | C | 5·42 | 5·75 | + 0·33 |
| November | 2 | | 1 | L | C | 17·43 | 17·62 | + 0·19 |
| ,, | 26 | | 1 | C | L | 53·26 | 53·45 | + 0·19 |
| ,, | 28 | | 1 | C | L | 56·36 | 56·59 | + 0·23 |

OBSERVATIONS FOR PERSONAL EQUATIONS—*continued.*

| Day, 1876. | | Observers in order of Seniority. | Interval between mean of Groups of Clock Stars. | Order of Observations. | | Clock Slow at $0^h$ Sidereal by Senior Observer. | Clock Slow at $0^h$ Sidereal by Junior Observer. | Excess of Clock Slow by Junior Observer. |
|---|---|---|---|---|---|---|---|---|
| | | | h | | | s | s | s |
| December | 4 | L and C *cont.* | 1 | L | C | 5·47 | 5·63 | + 0·16 |
| ,, | 4 | | 1 | L | C | 5·50 | 5·56 | + 0·06 |
| ,, | 12 | | 8 | L | C | 12·77 | 13·20 | + 0·43 |
| January | 8 | L and A D | 4 | A D | L | 5·74 | 5·99 | + 0·25 |
| February | 2 | | 10 | L | A D | 49·20 | 49·42 | + 0·22 |
| ,, | 9 | | 11 | A D | L | 46·34 | 46·66 | + 0·32 |
| March | 15 | | 0 | A D | L | 34·57 | 34·81 | + 0·24 |
| June | 11 | | 3 | L | A D | 41·91 | 42·08 | + 0·17 |
| ,, | 26 | | 1 | L | A D | 38·01 | 38·14 | + 0·13 |
| July | 4 | | 1 | L | A D | 33·99 | 34·21 | + 0·22 |
| ,, | 10 | | 3 | L | A D | 30·09 | 30·27 | + 0·18 |
| ,, | 24 | | 2 | L | A D | 22·12 | 22·33 | + 0·21 |
| ,, | 28 | | 2 | A D | L | 20·04 | 20·35 | + 0·31 |
| ,, | 30 | | 1 | L | A D | 18·87 | 19·13 | + 0·26 |
| September | 28 | | 12 | A D | L | 36·09 | 36·29 | + 0·20 |
| October | 14 | | 12 | L | A D | 50·18 | 50·31 | + 0·13 |
| December | 4 | | 7 | L | A D | 5·50 | 5·78 | + 0·28 |
| ,, | 12 | | 10 | L | A D | 12·77 | 13·20 | + 0·43 |
| January | 26 | L and T | 10 | L | T | 53·77 | 54·24 | + 0·47 |
| ,, | 29 | | 0 | L | T | 51·65 | 52·13 | + 0·48 |
| ,, | 31 | | 1 | L | T | 50·42 | 50·93 | + 0·51 |
| February | 4 | | 1 | T | L | 48·38 | 48·84 | + 0·46 |
| ,, | 10 | | 1 | L | T | 45·98 | 46·39 | + 0·41 |
| ,, | 12 | | 1 | L | T | 45·41 | 45·86 | + 0·45 |
| May | 10 | | 12 | L | T | 47·42 | 47·85 | + 0·43 |
| June | 1 | | 2 | L | T | 44·39 | 44·84 | + 0·45 |
| August | 8 | | 12 | L | T | 12·96 | 13·38 | + 0·42 |
| September | 23 | | 2 | L | T | 39·56 | 39·96 | + 0·40 |
| ,, | 25 | | 1 | L | T | 37·59 | 38·00 | + 0·41 |
| ,, | 29 | | 0 | L | T | 36·02 | 36·47 | + 0·45 |
| October | 5 | | 6 | T | L | 15·80 | 16·27 | + 0·47 |
| ,, | 7 | | 1 | L | T | 59·44 | 59·74 | + 0·30 |
| November | 1 | | 11 | T | L | 17·46 | 18·06 | + 0·60 |
| June | 28 | L and G | 0 | L | G | 37·22 | 37·55 | + 0·33 |
| July | 13 | | 6 | G | L | 27·40 | 27·75 | + 0·35 |

OBSERVATIONS FOR PERSONAL EQUATIONS—*continued.*

| Day, 1876. | | Observers in order of Seniority. | Interval between mean of Groups of Clock Stars. | Order of Observations. | | Clock Slow at $0^h$ Sidereal by Senior Observer. | Clock Slow at $0^h$ Sidereal by Junior Observer. | Excess of Clock Slow by Junior Observer. |
|---|---|---|---|---|---|---|---|---|
| | | | h | | | s | s | s |
| August | 3 | L and G | 0 | L | G | 16·77 | 17·04 | + 0·27 |
| ,, | 8 | *cont.* | 1 | G | L | 13·63 | 13·93 | + 0·30 |
| October | 13 | | 8 | G | L | 50·19 | 50·48 | + 0·29 |
| February | 9 | L and P | 9 | P | L | 46·34 | 46·51 | + 0·17 |
| August | 10 | | 3 | P | L | 12·53 | 12·73 | + 0·20 |
| July | 13 | L and W L | 7 | W L | L | 27·40 | 27·90 | + 0·50 |
| August | 10 | | 12 | L | W L | 11·99 | 12·31 | + 0·32 |
| February | 2 | L and R P | 3 | R P | L | 49·23 | 49·68 | + 0·45 |
| March | 15 | | 7 | R P | L | 34·57 | 35·01 | + 0·44 |
| April | 15 | | 7 | R P | L | 43·73 | 44·12 | + 0·39 |
| May | 12 | | 6 | R P | L | 47·51 | 47·93 | + 0·42 |
| ,, | 30 | | 2 | R P | L | 44·72 | 45·16 | + 0·44 |
| July | 13 | L and H P | 4 | L | H P | 27·40 | 27·71 | + 0·31 |
| ,, | 21 | | 11 | H P | L | 23·37 | 23·64 | + 0·27 |
| August | 10 | | 6 | L | H P | 12·53 | 12·79 | + 0·26 |
| ,, | 14 | | 11 | L | H P | 9·50 | 9·87 | + 0·37 |
| November | 24 | | 1 | H P | L | 50·60 | 50·88 | + 0·28 |
| December | 21 | L and B | 1 | B | L | −23·17 | −23·05 | + 0·12 |
| July | 12 | L and B D | 1 | B D | L | 28·98 | 29·25 | + 0·27 |
| ,, | 24 | | 12 | L | B D | 22·12 | 22·43 | + 0·31 |
| August | 1 | | 2 | B D | L | 17·97 | 18·21 | + 0·24 |
| ,, | 14 | | 9 | B D | L | 10·11 | 10·46 | + 0·35 |
| December | 6 | L and F D | 5 | F D | L | 6·63 | 6·89 | + 0·26 |
| January | 28 | C and A D | 2 | A D | C | 52·53 | 52·51 | − 0·02 |
| February | 1 | | 1 | A D | C | 50·08 | 50·10 | + 0·02 |
| ,, | 3 | | 2 | C | A D | 48·89 | 48·91 | + 0·02 |
| ,, | 5 | | 0 | A D | C | 48·12 | 48·10 | − 0·02 |
| May | 31 | | 2 | C | A D | 44·90 | 44·73 | − 0·17 |
| June | 10 | | 2 | C | A D | 42·39 | 42·40 | + 0·01 |
| ,, | 19 | | 5 | C | A D | 39·92 | 39·90 | − 0·02 |
| ,, | 27 | | 0 | A D | C | 37·87 | 37·92 | + 0·05 |
| September | 5 | | 2 | A D | C | 54·53 | 54·66 | + 0·13 |
| ,, | 28 | | 2 | C | A D | 36·67 | 36·74 | + 0·07 |

## OBSERVATIONS FOR PERSONAL EQUATIONS—*continued.*

| Day, 1876. | | Observers in order of Seniority. | Interval between mean of Groups of Clock Stars. | Order of Observations. | | Clock Slow at 0h Sidereal by Senior Observer. | Clock Slow at 0h Sidereal by Junior Observer. | Excess of Clock Slow by Junior Observer. |
|---|---|---|---|---|---|---|---|---|
| | | | h | | | s | s | s |
| October | 2 | C and A D *cont.* | 1 | A D | C | 35·01 | 35·05 | + 0·04 |
| ,, | 4 | | 1 | A D | C | 17·19 | 17·14 | − 0·05 |
| ,, | 6 | | 2 | A D | C | 0·72 | 0·75 | + 0·03 |
| ,, | 14 | | 9 | A D | C | 49·14 | 49·02 | − 0·12 |
| November | 6 | | 8 | C | A D | 25·86 | 25·89 | + 0·03 |
| ,, | 11 | | 8 | C | A D | 32·29 | 32·34 | + 0·05 |
| December | 4 | | 7 | C | A D | 5·56 | 5·78 | + 0·22 |
| ,, | 8 | | 4 | C | A D | 7·90 | 7·90 | 0·00 |
| ,, | 12 | | 2 | C | A D | 13·20 | 13·20 | 0·00 |
| January | 3 | C and T | 0 | C | T | 9·49 | 9·66 | + 0·17 |
| February | 18 | | 11 | C | T | 43·39 | 43·51 | + 0·12 |
| May | 2 | | 11 | C | T | 47·05 | 47·27 | + 0·22 |
| ,, | 10 | | 10 | C | T | 47·74 | 47·85 | + 0·11 |
| June | 19 | | 4 | T | C | 39·92 | 40·11 | + 0·19 |
| ,, | 29 | | 4 | C | T | 37·10 | 37·27 | + 0·17 |
| July | 1 | | 1 | T | C | 35·99 | 36·20 | + 0·21 |
| ,, | 3 | | 1 | C | T | 34·69 | 34·87 | + 0·18 |
| ,, | 9 | | 1 | T | C | 30·80 | 31·03 | + 0·23 |
| September | 8 | | 5 | T | C | 31·66 | 31·78 | + 0·12 |
| October | 4 | | 9 | C | T | 16·03 | 16·20 | + 0·17 |
| November | 10 | | 8 | T | C | 32·29 | 32·43 | + 0·14 |
| ,, | 28 | | 12 | C | T | 58·34 | 58·53 | + 0·19 |
| December | 5 | | 6 | T | C | 6·27 | 6·45 | + 0·18 |
| April | 7 | C and G | 8 | C | G | 41·00 | 41·00 | 0·00 |
| September | 11 | | 1 | G | C | 49·11 | 49·21 | + 0·10 |
| June | 10 | C and P | 4 | C | P | 42·39 | 42·35 | − 0·04 |
| December | 5 | | 10 | P | C | 6·27 | 6·33 | + 0·06 |
| July | 17 | C and W | 5 | C | W | 25·99 | 26·10 | + 0·11 |
| January | 5 | C and R P | 4 | R P | C | 8·13 | 8·30 | + 0·17 |
| April | 15 | | 11 | C | R P | 43·95 | 44·21 | + 0·26 |
| May | 12 | | 6 | R P | C | 47·71 | 47·93 | + 0·22 |
| ,, | 29 | | 10 | C | R P | 44·98 | 45·12 | + 0·14 |

OBSERVATIONS FOR PERSONAL EQUATIONS—*continued.*

| Day, 1876. | | Observers in order of Seniority. | Interval between mean of Groups of Clock Stars. | Order of Observations. | | Clock Slow at 0h Sidereal by Senior Observer. | Clock Slow at 0h Sidereal by Junior Observer. | Excess of Clock Slow by Junior Observer. |
|---|---|---|---|---|---|---|---|---|
| | | | h | | | s | s | s |
| July | 11 | C and H P | 0 | H P | C | 29 ·68 | 29 ·75 | + 0 ·07 |
| December | 8 | | 5 | H P | C | 7 ·90 | 7 ·96 | + 0 ·06 |
| October | 11 | C and B | 7 | B | C | 53 ·09 | 53 ·14 | + 0 ·05 |
| July | 11 | C and B D | 10 | C | B D | 29 ·07 | 29 ·14 | + 0 ·07 |
| ,, | 17 | | 12 | C | B D | 25 ·99 | 26 ·11 | + 0 ·12 |
| September | 21 | | 9 | B D | C | 40 ·49 | 40 ·53 | + 0 ·04 |
| October | 11 | | 8 | B D | C | 53 ·09 | 53 ·14 | + 0 ·05 |
| September | 8 | C and J B | 5 | J B | C | 51 ·66 | 51 ·70 | + 0 ·04 |
| November | 6 | C and F D | 1 | F D | C | 25 ·86 | 25 ·94 | + 0 ·08 |
| ,, | 10 | | 6 | C | F D | 32 ·29 | 32 ·40 | + 0 ·11 |
| December | 5 | | 4 | C | F D | 6 ·27 | 6 ·39 | + 0 ·12 |
| September | 11 | C and K | 3 | K | C | 49 ·11 | 49 ·18 | + 0 ·07 |
| ,, | 22 | | 3 | C | K | 40 ·44 | 40 ·56 | + 0 ·12 |
| March | 3 | A D and T | 2 | T | A D | 38 ·58 | 38 ·74 | + 0 ·16 |
| ,, | 7 | | 2 | T | A D | 36 ·77 | 36 ·92 | + 0 ·15 |
| ,, | 29 | | 0 | A D | T | 36 ·77 | 36 ·92 | + 0 ·15 |
| ,, | 31 | | 3 | A D | T | 37 ·64 | 37 ·87 | + 0 ·23 |
| April | 2 | | 1 | A D | T | 38 ·54 | 38 ·78 | + 0 ·24 |
| ,, | 4 | | 0 | A D | T | 39 ·59 | 39 ·87 | + 0 ·28 |
| ,, | 10 | | 1 | T | A D | 41 ·93 | 42 ·15 | + 0 ·22 |
| ,, | 29 | | 0 | T | A D | 46 ·68 | 46 ·86 | + 0 ·18 |
| May | 1 | | 2 | T | A D | 46 ·86 | 47 ·05 | + 0 ·19 |
| ,, | 3 | | 2 | T | A D | 47 ·04 | 47 ·29 | + 0 ·25 |
| ,, | 5 | | 1 | A D | T | 47 ·31 | 47 ·54 | + 0 ·23 |
| ,, | 7 | | 4 | A D | T | 47 ·49 | 47 ·72 | + 0 23 |
| ,, | 9 | | 0 | A D | T | 47 ·51 | 47 ·84 | + 0 ·33 |
| June | 19 | | 10 | T | A D | 39 ·90 | 40 ·11 | + 0 ·21 |
| ,, | 23 | | 1 | T | A D | 39 ·11 | 39 ·38 | + 0 ·27 |
| October | 30 | | 3 | A D | T | 6 ·66 | 6 ·72 | + 0 ·06 |
| November | 1 | | 4 | A D | T | 17 ·64 | 17 ·94 | + 0 ·30 |
| ,, | 10 | | 11 | T | A D | 32 ·29 | 32 ·43 | + 0 ·14 |
| ,, | 27 | | 0 | A D | T | 56 ·66 | 56 ·81 | + 0 ·15 |
| ,, | 29 | | 1 | A D | T | 58 ·41 | 58 ·46 | + 0 ·05 |
| April | 8 | A D and G | 1 | A D | G | 41 ·30 | 41 ·45 | + 0 ·15 |
| July | 8 | | 2 | A D | G | 31 ·48 | 31 ·61 | + 0 ·13 |

OBSERVATIONS FOR PERSONAL EQUATIONS—*continued.*

| Day, 1876. | | Observers in order of Seniority. | Interval between mean of Groups of Clock Stars. | Order of Observations. | | Clock Slow at $0^h$ Sidereal by Senior Observer. | Clock Slow at $0^h$ Sidereal by Junior Observer. | Excess of Clock Slow by Junior Observer. |
|---|---|---|---|---|---|---|---|---|
| | | | h | | | s | s | s |
| February | 9 | A D and P | 3 | A D | P | 46·66 | 46·51 | − 0·15 |
| June | 10 | | 2 | A D | P | 42·40 | 42·35 | − 0·05 |
| ,, | 20 | | 11 | A D | P | 39·55 | 39·59 | + 0·04 |
| July | 14 | | 7 | A D | P | 27·17 | 27·19 | + 0·02 |
| September | 1 | | 2 | A D | P | 58·12 | 58·13 | + 0·01 |
| December | 20 | | 1 | P | A D | 25·37 | 25·38 | + 0·01 |
| July | 7 | A D and W | 9 | W | A D | 31·51 | 31·61 | + 0·10 |
| December | 30 | | 5 | A D | W | 56·81 | 56·84 | + 0·03 |
| February | 15 | A D and W L | 4 | W L | A D | 44·34 | 44·54 | + 0·20 |
| July | 19 | | 12 | W L | A D | 24·60 | 24·76 | + 0·16 |
| ,, | 26 | | 2 | W L | A D | 21·08 | 21·27 | + 0·19 |
| March | 15 | A D and R P | 6 | R P | A D | 34·81 | 35·01 | + 0·20 |
| June | 20 | | 9 | A D | R P | 39·70 | 39·86 | + 0·16 |
| July | 14 | A D and H P | 4 | H P | A D | 27·79 | 27·82 | + 0·03 |
| ,, | 20 | | 10 | A D | H P | 24·08 | 24·21 | + 0·13 |
| November | 6 | | 9 | A D | H P | 25·89 | 26·02 | + 0·13 |
| December | 8 | | 9 | H P | A D | 7·90 | 7·96 | + 0·06 |
| ,, | 22 | | 2 | A D | H P | −22·97 | −22·92 | + 0·05 |
| September | 14 | A D and B | 7 | B | A D | 45·96 | 46·15 | + 0·19 |
| June | 14 | A D and B D | 5 | B D | A D | 41·37 | 41·45 | + 0·08 |
| July | 24 | | 11 | A D | B D | 22·33 | 22·46 | + 0·13 |
| December | 18 | | 2 | B D | A D | 23·96 | 23·96 | 0·00 |
| November | 6 | A D and F D | 8 | F D | A D | 25·89 | 25·94 | + 0·05 |
| ,, | 11 | | 2 | F D | A D | 32·34 | 32·40 | + 0·06 |
| September | 15 | A D and K | 0 | K | A D | 45·99 | 46·24 | + 0·25 |
| August | 9 | M and T | 6 | T | M | 13·24 | 13·39 | + 0·15 |
| August | 9 | M and P | 12 | M | P | 12·67 | 12·76 | + 0·09 |
| August | 9 | M and B D | 5 | M | B D | 12·67 | 12·68 | + 0·01 |

OBSERVATIONS FOR PERSONAL EQUATIONS—*continued.*

| Day, 1876. | | Observers in order of Seniority. | Interval between mean of Groups of Clock Stars. | Order of Observations. | | Clock Slow at $0^h$ Sidereal by Senior Observer. | Clock Slow at $0^h$ Sidereal by Junior Observer. | Excess of Clock Slow by Junior Observer. |
|---|---|---|---|---|---|---|---|---|
| | | | h | | | s | s | s |
| July | 31 | T and G | 0 | G | T | 18·69 | 18·64 | − 0·05 |
| October | 1 | | 3 | G | T | 35·73 | 35·53 | − 0·20 |
| February | 18 | T and P | 6 | T | P | 43·51 | 43·32 | − 0·19 |
| August | 2 | | 2 | P | T | 17·81 | 17·65 | − 0·16 |
| September | 12 | | 2 | P | T | 47·77 | 47·32 | − 0·45 |
| December | 5 | | 3 | P | T | 6·45 | 6·33 | − 0·12 |
| July | 7 | T and W | 9 | T | W | 32·33 | 32·30 | − 0·03 |
| August | 7 | T and W L | 1 | T | W L | 14·70 | 14·67 | − 0·03 |
| ,, | 11 | | 4 | W L | T | 12·36 | 12·38 | + 0·02 |
| August | 11 | T and B | 10 | T | B | 11·76 | 11·67 | − 0·09 |
| September | 14 | | 6 | T | B | 46·12 | 46·15 | + 0·03 |
| May | 13 | T and B D | 4 | B D | T | 48·01 | 47·89 | − 0·12 |
| July | 25 | | 2 | B D | T | 21·97 | 21·93 | − 0·04 |
| ,, | 31 | | 11 | T | B D | 18·18 | 18·18 | 0·00 |
| August | 9 | | 10 | T | B D | 12·82 | 12·68 | − 0·14 |
| ,, | 25 | | 1 | B D | T | 3·37 | 3·14 | − 0·23 |
| ,, | 29 | | 2 | B D | T | 0·69 | 0·57 | − 0·12 |
| September | 6 | | 3 | B D | T | 53·64 | 53·57 | − 0·07 |
| September | 8 | T and J B | 0 | T | J B | 51·78 | 51·70 | − 0·08 |
| December | 5 | T and F D | 10 | T | F D | 6·45 | 6·39 | − 0·06 |
| May | 4 | G and P | 1 | P | G | 47·24 | 47·16 | − 0·08 |
| November | 7 | | 8 | P | G | 27·53 | 27·36 | − 0·17 |
| July | 13 | G and W L | 1 | W L | G | 28·40 | 28·55 | + 0·15 |
| March | 10 | G and B D | 0 | B D | G | 35·49 | 35·49 | 0·00 |
| July | 31 | | 11 | G | B D | 18·64 | 18·66 | + 0·02 |
| August | 13 | | 9 | G | B D | 10·45 | 10·51 | + 0·06 |
| September | 11 | G and K | 2 | K | G | 49·21 | 49·18 | − 0·03 |
| August | 10 | P and W L | 9 | P | W L | 12·25 | 12·31 | + 0·06 |

OBSERVATIONS FOR PERSONAL EQUATIONS—*continued.*

| Day, 1876. | | Observers in order of Seniority. | Interval between mean of Groups of Clock Stars. | Order of Observations. | | Clock Slow at $0^h$ Sidereal by Senior Observer. | Clock Slow at $0^h$ Sidereal by Junior Observer. | Excess of Clock Slow by Junior Observer. |
|---|---|---|---|---|---|---|---|---|
| | | | h | | | s | s | s |
| June | 20 | P and R P | 11 | R P | P | 39·57 | 39·86 | + 0·29 |
| July | 14 | P and H P | 11 | H P | P | 27·19 | 27·20 | + 0·01 |
| August | 10 | | 9 | P | H P | 12·19 | 12·26 | + 0·07 |
| November | 7 | | 8 | H P | P | 27·36 | 27·48 | + 0·12 |
| August | 9 | P and B D | 7 | B D | P | 12·76 | 12·68 | − 0·08 |
| October | 10 | | 12 | P | B D | 54·69 | 54·57 | − 0·12 |
| August | 23 | P and J B | 9 | J B | P | 3·83 | 3·78 | − 0·05 |
| August | 5 | W and B | 2 | B | W | 15·81 | 15·77 | − 0·04 |
| ,, | 12 | | 5 | B | W | 11·73 | 11·65 | − 0·08 |
| July | 17 | W and B D | 7 | W | B D | 26·10 | 26·11 | + 0·01 |
| August | 10 | W L and H P | 6 | H P | W L | 12·31 | 12·26 | − 0·05 |
| ,, | 15 | | 8 | H P | W L | 9·32 | 9·04 | − 0·28 |
| August | 11 | W L and B | 12 | W L | B | 11·80 | 11·67 | − 0·13 |
| July | 25 | W L and B D | 9 | B D | W L | 21·24 | 21·37 | + 0·13 |
| November | 6 | H P and F D | 11 | F D | H P | 26·04 | 25·94 | − 0·10 |
| October | 11 | B and B D | 7 | B D | B | 53·14 | 53·16 | + 0·02 |
| September | 21 | B D and K | 0 | K | B D | 41·35 | 41·29 | − 0·06 |

From these differences, if we form equations in which each observer's initial shall successively stand first, we obtain the following groups of equations:—

For W C.

| | | s |
|---|---|---|
| W C − L | = | + 0·37 |
| 2 (W C − C) | = | + 0·24 |
| 2 (W C − A D) | = | + 0·24 |
| W C − T | = | − 0·06 |
| W C − G | = | + 0·08 |
| W C − P | = | + 0·12 |
| W C − J B | = | + 0·02 |
| W C − K | = | + 0·11 |

For L.

| | | s |
|---|---|---|
| L − W C | = | − 0·37 |
| 28 (L − C) | = | − 6·46 |
| 15 (L − A D) | = | − 3·55 |
| 15 (L − T) | = | − 6·71 |
| 5 (L − G) | = | − 1·54 |
| 2 (L − P) | = | − 0·37 |
| 2 (L − W L) | = | − 0·82 |
| 5 (L − R P) | = | − 2·14 |
| 5 (L − H P) | = | − 1·49 |
| L − B | = | − 0·12 |
| 4 (L − B D) | = | − 1·17 |
| L − F D | = | − 0·26 |

**For C.**

| | | s |
|---|---|---|
| 2 (C − W C) | = | − 0·24 |
| 28 (C − L) | = | + 6·46 |
| 19 (C − A D) | = | − 0·27 |
| 14 (C − T) | = | − 2·40 |
| 2 (C − G) | = | − 0·10 |
| 2 (C − P) | = | − 0·02 |
| C − W | = | − 0·11 |
| 4 (C − R P) | = | − 0·79 |
| 2 (C − H P) | = | − 0·13 |
| C − B | = | − 0·05 |
| 4 (C − B D) | = | − 0·28 |
| C − J B | = | − 0·04 |
| 3 (C − F D) | = | − 0·31 |
| 2 (C − K) | = | − 0·19 |

**For A D.**

| | | |
|---|---|---|
| 2 (A D − W C) | = | − 0·24 |
| 15 (A D − L) | = | + 3·55 |
| 19 (A D − C) | = | + 0·27 |
| 20 (A D − T) | = | − 4·02 |
| 2 (A D − G) | = | − 0·28 |
| 6 (A D − P) | = | + 0·12 |
| 2 (A D − W) | = | − 0·13 |
| 3 (A D − W L) | = | − 0·55 |
| 2 (A D − R P) | = | − 0·38 |
| 5 (A D − H P) | = | − 0·40 |
| A D − B | = | − 0·19 |
| 3 (A D − B D) | = | − 0·21 |
| 2 (A D − F D) | = | − 0·11 |
| A D − K | = | − 0·25 |

**For M.**

| | | |
|---|---|---|
| M − T | = | − 0·15 |
| M − P | = | − 0·09 |
| M − B D | = | − 0·01 |

**For T.**

| | | |
|---|---|---|
| T − W C | = | + 0·06 |
| 15 (T − L) | = | + 6·71 |
| 14 (T − C) | = | + 2·40 |
| 20 (T − A D) | = | + 4·02 |
| T − M | = | + 0·15 |
| 2 (T − G) | = | + 0·25 |
| 4 (T − P) | = | + 0·92 |
| T − W | = | + 0·03 |
| 2 (T − W L) | = | + 0·01 |
| 2 (T − B) | = | + 0·06 |
| 7 (T − B D) | = | + 0·72 |
| T − J B | = | + 0·08 |
| T − F D | = | + 0·06 |

**For G.**

| | | s |
|---|---|---|
| G − W C | = | − 0·08 |
| 5 (G − L) | = | + 1·54 |
| 2 (G − C) | = | + 0·10 |
| 2 (G − A D) | = | + 0·28 |
| 2 (G − T) | = | − 0·25 |
| 2 (G − P) | = | + 0·25 |
| G − W L | = | − 0·15 |
| 3 (G − B D) | = | − 0·08 |
| G − K | = | + 0·03 |

**For P.**

| | | |
|---|---|---|
| P − W C | = | − 0·12 |
| 2 (P − L) | = | + 0·37 |
| 2 (P − C) | = | + 0·02 |
| 6 (P − A D) | = | − 0·12 |
| P − M | = | + 0·09 |
| 4 (P − T) | = | − 0·92 |
| 2 (P − G) | = | − 0·25 |
| P − W L | = | − 0·06 |
| P − R P | = | − 0·29 |
| 3 (P − H P) | = | − 0·20 |
| 2 (P − B D) | = | + 0·20 |
| P − J B | = | + 0·05 |

**For W.**

| | | |
|---|---|---|
| W − C | = | + 0·11 |
| 2 (W − A D) | = | + 0·13 |
| W − T | = | − 0·03 |
| 2 (W − B) | = | + 0·12 |
| W − B D | = | − 0·01 |

**For W L.**

| | | |
|---|---|---|
| 2 (W L − L) | = | + 0·82 |
| 3 (W L − A D) | = | + 0·55 |
| 2 (W L − T) | = | − 0·01 |
| W L − G | = | + 0·15 |
| W L − P | = | + 0·06 |
| 2 (W L − H P) | = | + 0·33 |
| W L − B | = | + 0·13 |
| W L − B D | = | − 0·13 |

**For R P.**

| | | |
|---|---|---|
| 5 (R P − L) | = | + 2·14 |
| 4 (R P − C) | = | + 0·79 |
| 2 (R P − A D) | = | + 0·38 |
| R P − P | = | + 0·29 |

For H P.

| | | |
|---|---|---|
| 5 (H P − L) | = | + 1·49 s |
| 2 (H P − C) | = | + 0·13 |
| 5 (H P − A D) | = | + 0·40 |
| 3 (H P − P) | = | + 0·20 |
| 2 (H P − W L) | = | − 0·33 |
| H P − F D | = | + 0·10 |

For B.

| | | |
|---|---|---|
| B − L | = | + 0·12 |
| B − C | = | + 0·05 |
| B − A D | = | + 0·19 |
| 2 (B − T) | = | − 0·06 |
| 2 (B − W) | = | − 0·12 |
| B − W L | = | − 0·13 |
| B − B D | = | − 0·02 |

For B D.

| | | |
|---|---|---|
| 4 (B D − L) | = | + 1·17 |
| 4 (B D − C) | = | + 0·28 |
| 3 (B D − A D) | = | + 0·21 |
| B D − M | = | + 0·01 |
| 7 (B D − T) | = | − 0·72 |
| 3 (B D − G) | = | + 0·08 |
| 2 (B D − P) | = | − 0·20 |

For B D—*continued.*

| | | |
|---|---|---|
| B D − W | = | + 0·01 s |
| B D − W L | = | + 0·13 |
| B D − B | = | + 0·02 |
| B D − K | = | + 0·06 |

For J B.

| | | |
|---|---|---|
| J B − W C | = | − 0·02 |
| J B − C | = | + 0·04 |
| J B − T | = | − 0·08 |
| J B − P | = | − 0·05 |

For F D.

| | | |
|---|---|---|
| F D − L | = | + 0·26 |
| 3 (F D − C) | = | + 0·31 |
| 2 (F D − A D) | = | + 0·11 |
| F D − T | = | − 0·06 |
| F D − H P | = | − 0·10 |

For K.

| | | |
|---|---|---|
| K − W C | = | − 0·11 |
| 2 (K − C) | = | + 0·19 |
| K − A D | = | + 0·25 |
| K − G | = | − 0·03 |
| K − B D | = | − 0·06 |

Now, since one of the quantities denoted by W C, L, C, &c. must evidently remain indeterminate, we will refer all the rest to C as a standard; and, putting C = 0, the initials W C, L, A D., &c. will represent the values of "clock slow," which would be given by the observations of Mr. Christie, Mr. Lynn, Mr. Downing, &c., when that given by the observation of Mr. Criswick = 0.

Then, adding all the equations in each group, we get the following equations, in which each observer's personal equation is successively affected by a large co-efficient:

| | | |
|---|---|---|
| 10 W C − L − 2 A D − T − G − P − J B − K | = | + 1·12 s |
| 84 L − W C − 15 A D − 15 T − 5 G − 2 P − 2 W L − 5 R P − 5 H P − B − 4 B D − F D | = | −25·00 |
| 83 A D − 2 W C − 15 L − 20 T − 2 G − 6 P − 2 W − 3 W L − 2 R P − 5 H P − B − 3 B D − 2 F D − K | = | − 2·82 |
| 3 M − T − P − B D | = | − 0·25 |
| 71 T − W C − 15 L − 20 A D − M − 2 G − 4 P − W − 2 W L − 2 B − 7 B D − J B − F D | = | +15·47 |
| 19 G − W C − 5 L − 2 A D − 2 T − 2 P − W L − 3 B D − K | = | + 1·64 |
| 26 P − W C − 2 L − 6 A D − M − 4 T − 2 G − W L − R P − 3 H P − 2 B D − J B | = | − 1·23 |
| 7 W − 2 A D − T − 2 B − B D | = | + 0·32 |

h 2

| | |
|---|---|
| 13 WL − 2 L − 3 AD − 2 T − G − P − 2 HP − B − BD | = + 1·90 s |
| 12 RP − 5 L − 2 AD − P | = + 3·60 |
| 18 HP − 5 L − 5 AD − 3 P − 2 WL − FD | = + 1·99 |
| 9 B − L − AD − 2 T − 2 W − WL − BD | = + 0·03 |
| 28 BD − 4 L − 3 AD − M − 7 T − 3 G − 2 P − W − WL − B − K | = + 1·05 |
| 4 JB − WC − T − P | = − 0·11 |
| 8 FD − L − 2 AD − T − HP | = + 0·52 |
| 6 K − WC − AD − G − BD | = + 0·24 |

Solving these equations by successive approximations, that is, by first substituting in each equation the approximately known values of all the personal equations, except that which has the largest co-efficient, thence deducing the value of that one personal equation, then using that deduced value for substitution in the other equations, and repeating the process, we get finally the following values:—

| | | | |
|---|---|---|---|
| WC = + 0·12 s | L = − 0·24 s | AD = − 0·01 s | M = 0·00 s |
| T = + 0·18 | G = + 0·07 | P = − 0·01 | W = + 0·10 |
| WL = + 0·16 | RP = + 0·20 | HP = + 0·06 | B = + 0·06 |
| BD = + 0·07 | JB = + 0·05 | FD = + 0·06 | K = + 0·08 |

or, restoring C:—

| | | | |
|---|---|---|---|
| C − WC = − 0·12 s | C − L = + 0·24 s | C − AD = + 0·01 s | C − M = 0·00 s |
| C − T = − 0·18 | C − G = − 0·07 | C − P = + 0·01 | C − W = − 0·10 |
| C − WL = − 0·20 | C − RP = − 0·20 | C − HP = − 0·06 | C − B = − 0·06 |
| C − BD = − 0·07 | C − JB = − 0·06 | C − FD = − 0·06 | C − K = − 0·08 |

The observations by eye and ear since 1859 are insufficient in number to give a trustworthy determination of the personal equations observed by that method. Those determined in 1858 and 1859 (Introduction to *Greenwich Observations*, 1858, page xl, and 1859, page xlii,) were the following:—

| | |
|---|---|
| D − E = + 0·03 s | D − L = + 0·38 s |
| D − C = + 0·01 | D − JC = + 0·14 |

None of these, however, have been applied in 1876.

The personal equations given above, as applicable to the chronographic method of observing, deduced from the observations made in 1876 and referred to Mr. Criswick as Standard Observer, have been applied to the collected results of transits for the Sun, Moon, and Planets, whenever they were needed throughout the year 1876.

But those used in the adoption of clock-rate as explained above, page xlviii, and in the reduction of Altazimuth Observations, also referred to Mr. Criswick as Standard, have been deduced from the observations in 1875. The investigation of these is given in the *Introduction to the Greenwich Astronomical Observations*, 1875, page xlviii.

In the standing foot-note on each page is given the duration of passage for the semidiameter of a planet when only one limb has been observed. It is found as follows:—

For the Sun, a correction of $-0^s{\cdot}04$, derived from the observations of several preceding years, is applied to the Nautical Almanac semidiameter.

For the Moon and Mercury, the duration is taken without alteration from the Nautical Almanac.

For Venus, a correction is applied to the Nautical-Almanac-semidiameter, determined from observations made with the Transit-Circle from 1851 to 1862. The investigation, by Mr. Stone, will be found in the *Monthly Notices of the Royal Astronomical Society*, Vol. XXV. No. 3. The correction which has been applied additively to the Nautical-Almanac-semidiameter during the year 1876, is

$$+ 0^s{\cdot}026 + 0{\cdot}027 \times \text{tabular duration of passage of semidiameter.}$$

For Jupiter and Saturn, both limbs are always observed, if possible; but if, through accident or necessity, only one limb is observed, the duration of passage of the semidiameter is obtained by applying to the value given in the Nautical Almanac a correction derived from a few of the neighbouring observations. The elements of computation are given in the notes.

The *twentieth* column contains the right ascension of the center of the body observed: it is formed by adding the time from the sixteenth column, the clock-error at $0^h$ next preceding from the nineteenth column, the proportional part of the rate in the same column corresponding to the right ascension, and the duration of the passage of the semidiameter from the foot-notes. No result is set down for a clock-star, unless at least four clock-stars, distributed over several hours of right ascension, have been observed; no result is set down for Polaris, δ Ursæ Minoris, Cephei 51, or λ Ursæ Minoris, unless Polaris, δ Ursæ Minoris, or Cephei 51, has been observed at opposite passages; and no result is set down for other close circumpolar stars, unless there has been a good determination of the azimuthal error on the day of observation.

The *twenty-first* column contains the correction with its proper sign, as it is to be applied for reducing the apparent right ascension of each star at the time of observation to the mean right ascension on the 1st of January, 1876. It is computed in the following manner.

For stars in the list of the Nautical Almanac, the mean R. A. of the Nautical Almanac is subtracted from the apparent R. A. of the Nautical Almanac: the sign of the quantity so found is changed.

For other stars, the corrections are computed by the formula

$$\mathrm{E\,e + F\,f + G\,g + H\,h + L + l} - 300^{s} + \mu\,\mathrm{t};$$

(where $\mu$ is the annual proper motion in R. A. taken from Mr. Main's or Mr. Stone's papers in the *Memoirs of the Royal Astronomical Society*, or from the *British Association Catalogue*, and t is the fraction of a year corresponding to the day of observation) which is derived from the well-known formula,

$$\mathrm{A}\,a + \mathrm{B}\,b + \mathrm{C}\,c + \mathrm{D}\,d + \mu\,\mathrm{t},$$

or its equivalent,

$$\begin{aligned} & \tfrac{\mathrm{A}}{15}\cos \mathrm{R.A.}\ \mathrm{cosec\ N.P.D.} \\ + & \tfrac{\mathrm{B}}{15}\sin \mathrm{R.A.}\ \mathrm{cosec\ N.P.D.} \\ + & \mathrm{C}\ \sin \mathrm{R.A.}\ \cot \mathrm{N.P.D.} \times \mathrm{numb.\ log.}\ 0{\cdot}1259 \\ + & \tfrac{\mathrm{D}}{15}\cos \mathrm{R.A.}\ \cot \mathrm{N.P.D.} \\ + & \mathrm{C} \times \mathrm{numb.\ log.}\ 0{\cdot}4869 \\ + & \mu\,\mathrm{t}, \end{aligned}$$

by a process which is explained with sufficient detail in the Introduction to the Twelve-Year Catalogue appended to the volume for 1847, in the Introduction to the Six-Year Catalogue of 1576 Stars for 1850, appended to the volume for 1854, in the Introduction to the Seven-Year Catalogue of 2022 Stars for 1860, appended to the volume for 1862, and in that of the New Seven-Year Catalogue for 1864, attached to the volume for 1868. It will be sufficient here to state that $\mathrm{E = A} + 25$, $\mathrm{F = B} + 25$, $\mathrm{G = C} + 1{\cdot}2$, $\mathrm{H = D} + 25$, $\mathrm{e} = a + 1{\cdot}2$, $\mathrm{f} = b + 1{\cdot}2$, $\mathrm{g} = c + 25$, $\mathrm{h} = d + 1{\cdot}2$, $\mathrm{L} = 210 - 1{\cdot}2 \times \mathrm{E} - 1{\cdot}2 \times \mathrm{F} - 25 \times \mathrm{G} - 1{\cdot}2 \times \mathrm{H}$, $\mathrm{l} = 210 - 25 \times \mathrm{e} - 25 \times \mathrm{f} - 1{\cdot}2 \times \mathrm{g} - 25 \times \mathrm{h}$. The values of the day-constants log. E, log. F, log. G, log. H, and L, are given in the Nautical Almanac. The values of the star-constants, log. e, log. f, log. g, log. h, and l, for stars contained in the Seven-Year Catalogue for 1860, and in the New Seven-Year Catalogue for 1864, are printed in those Catalogues. For other stars, the star-constants will be found in the annual Catalogues for the years 1868 to 1875, or in that included in the present volume.

The sign of the computed quantity is changed before application.

§ 2. *Observations of the Collimators, and of the Reflected Image of the Central Vertical Wire of the Transit-Circle, for the Determination of the Errors of Collimation, and Level*, page [91] to [103].

With regard to these tables, the following remarks, in addition to the explanation which has been given, in the description of the instrument, and in the account of the methods of determining the errors of collimation and level, will be sufficient.

### OBSERVATIONS FOR COINCIDENCE OF COLLIMATORS.

These observations are made on every week day. For those made on Monday, the Transit-Circle is raised to admit an uninterrupted view of the South Collimator or Reversed Telescope by the North Collimator. On other days, the view is taken through the pierced cube of the Transit-Circle Telescope.

By means of the micrometer of the North Collimator, the nearly vertical sides of the squares formed by the intersecting wires are made to cross at their middle points, and the readings of the micrometer-head of the North Collimator are taken six times. The wire is then left at a reading corresponding to the mean of the six. These means are printed in the table, and will give a satisfactory idea of the firmness of the collimators.

### OBSERVATIONS OF THE COLLIMATORS FOR DETERMINATION OF THE ERROR OF COLLIMATION.

The way in which these observations are made has been fully explained (pages vi and xli). The mean of the readings for the separate collimators, and the resulting reading for the line of collimation, are set down in consecutive columns; the next column gives the reading which has been adopted for the period of time limited by the bars above and below; and the last column gives the adopted reading for the line of collimation after the application of a correction of $+ 0^{r}\cdot 019$ to reduce the result to that which would have been obtained if the instrument had been raised when the observation for coincidence of the collimators was made. By comparing the numbers in this column with the *Readings of Transit-Micrometer* given in the foot-notes of the section *Transits observed*, &c., and applying $-0''\cdot 19$ for diurnal aberration, the errors of collimation actually used will be deduced. For determination of the sign of the error, it must be observed that the micrometer-head is East, and that the readings of the micrometer increase as the wire moves towards the head.

### DETERMINATION OF THE LEVEL ERROR.

The method of making these observations has been described (pages vii and xlii). A comparison of the transit-micrometer-reading for coincidence of the direct and reflected images of the central wire, with the adopted reading for the line of collimation set down in the contiguous column, gives the error of level in terms of revolutions of the micrometer; and the numbers in the next column exhibit the errors of level in arc. The last column gives the adopted values of the error, and the limits of time during which they have been used. The determination of the sign of the errors has been previously explained.

§ 3. *Observations of Zenith Distance with the Transit-Circle*, page (1) to (115).

In order to include the whole of the reductions belonging to a single observation on one page, the elements for those reductions which are not frequently changed, and which do not require tabular arrangement, are given in the foot-notes: these are;—correction for runs; formulæ used in computing micrometer-corrections, corrections for curvature of path, and inclination of wire; and Zenith-Point-corrections.

The corrections for planets, including change of N.P.D. for reduction to the meridian, parallax, and semidiameter, and also the corrections for reducing the apparent places of stars to mean places, are exhibited in tabular arrangement at the lower part of each page, opposite to the reference-numbers which correspond to the observations in the upper part of the page.

DAY.—The day of observation always begins with the Sun's transit.

NO. FOR REFERENCE.—This column requires no explanation.

NAME OF OBJECT.—The nomenclature of stars follows the same general rule as in the section of *Transits observed*, &c., except that, as a last resource, the place of the star is defined by its right ascension, which is generally accurate to $1^s$. The letters N.L. and S.L. denote north and south limbs of planets, and N.C. and S.C. the north and south cusps of Mercury or Venus. The words *Nadir Observation* indicate an observation of the image of the horizontal or zenith-distance wire as seen by reflexion in a trough of mercury, as is described in page x. For other objects, the letter R. denotes that the object is observed by reflexion in the trough of mercury.

READINGS OF THE MICROSCOPE-MICROMETERS.—The application of the letters for the six ordinary microscope-micrometers is the same as in the Observations of preceding years from 1836: the observer, beginning with the northern horizontal microscope, and passing the upper microscopes, the southern horizontal, and the lower ones, in the direction of the circle's circumference, reads them in the order A, C, E, B, D, F (see diagram, page viii.) These readings in the observing books are placed in the order $\frac{\text{A, C, E,}}{\text{B, D, F}}$; from which form they are easily changed into the order of printing. Each pair of adjacent readings, therefore, is the pair of readings at the opposite ends of a diameter. The number of integral revolutions is given in the fifth column only. Occasionally the number of revolutions expressed in this column does not apply unchanged to all the microscopes, on account of the difference of their readings; but since the readings never differ by more than four or five tenths of a revolution, and the order of the more conspicuous differences is noted at the bottom of the page, this will occasion no ambiguity. Occasionally the cross-wires fall on the negative side of the micrometer-zero; in such cases the fractional part of the reading given is positive, being that taken from the micrometer-head, but the integer 9 represents $-1$.

The reading of the pointer-microscope is omitted for the sake of economy of space, but it may be inferred from the Zenith-Point given in full at the bottom of each page, and from the deduced Zenith-Distance.

From 1876, January 18 to March 20, the four supplementary microscopes a, b, $\alpha$, $\beta$, were read together with the six ordinary microscopes, the order of the 10 microscopes being A, a, C, E, $\beta$, B, b, D, F, $\alpha$.

The pair of opposite microscopes a, b, are at a distance of 20°, and $\alpha$, $\beta$, at a distance of 25° from A, B, on opposite sides respectively.

From 1876, January 1 to 5, the four supplementary microscopes a, b, $\alpha$, $\beta$, alone were read.

It is proper now to explain how the revolutions and parts of revolutions of the microscope-micrometers are converted into arc, when the six ordinary microscopes are used.

First, it may be premised that, as one revolution of each microscope-micrometer does not differ extravagantly from 1′ on the limb of the circle, we may consider each revolution as a nominal minute. Next, supposing the number of integral revolutions, as shown by each microscope, to be the same for all, we ought, in order to obtain the mean of the fractions of a revolution, to add together the subdivisions as shown by the different micrometer-heads, and divide the sum by 6. Thirdly, as the subdivisions are in the decimal scale, we should then multiply this mean by 60, to reduce it to sexagesimal seconds. It is evident thus that the number of nominal seconds to be attached to the nominal minute will be found by simply adding together the subdivisions on the micrometer-heads, and shifting the decimal point.

When the four supplementary microscopes are used, the sub-divisions are added together; the sum is then multiplied by 3 and divided by 2; it is then only necessary to shift the decimal point.

From the ordinary observations of runs (those for the year 1876 being given at page (117) &c. of the present volume), it is known that the screws of the micrometers are so sensibly equal that, in the reduction of the observations, it is sufficient to take the mean of the six readings, and to apply to it the mean correction for runs. To do this, the following process is employed. The sum of the runs for the six microscopes never differs materially from $29^{r}\cdot3$. Now, if the correction, by the addition of which each revolution of a micrometer may be converted into a minute of arc, were exactly $\frac{1}{50}$ part of the reading, then the sum of the runs would be $\frac{50}{51} \times 30^{r}\cdot000$, or $29^{r}\cdot4118$. It is not likely that the sum of the runs will ever amount to this quantity; and the variable correction, after adding $\frac{1}{50}$ part to the mean of the readings of the microscopes, will therefore always be additive. To determine this quantity, let the sum of the runs be $29^{r}\cdot 412 - x$. Then the true reading in seconds of space, corresponding to a nominal reading of $r''$ (including the value both of the nominal minutes and of the subdivisions of the nominal minute) will be

$$r'' \times \frac{30\cdot 000}{29\cdot 412 - x}$$

or

$$r'' \left\{1 + \frac{1}{50} + 0\cdot 03468 \times x\right\}$$

Hence the correction, after adding $\frac{1}{50}$ part of the mean of readings, will be $+ r\,x \times 0''\cdot 03468$. For the purpose of calculating this quantity easily by the ordinary proportional scale, it is convenient, in the first place, to compute its value when $r = 100''$. This value, which is evidently $+ 3''\cdot 468 \times x$, is tabulated for different values of $x$. Let X be the number taken from this table; then, for any actual reading $r$, the correction will be $\frac{rX}{100}$: a quantity which can easily be taken from the ordinary sliding-rule.

For the four supplementary microscopes, the constant for the sum of the runs would be $\frac{50}{51} \times 20^{r}\cdot 000 = 19^{r}\cdot 608$. Hence the true reading in seconds of space will be

$$r'' \times \frac{20\cdot 000}{19\cdot 608 - x}$$

or

$$r'' \left\{1 + \frac{1}{50} + 0\cdot 05202 \times x\right\}$$

and the correction after adding $\frac{1}{50}$ part of the mean of readings, will be $+ r\,x \times 0''\cdot 05202$.

On a few occasions the cross-wires of one or more of the microscopes have fallen on the negative side of the micrometer zero: these cases are always mentioned in the notes.

CORRECTIONS FOR ERROR OF DIVISION AND FOR FLEXURE OF TELESCOPE.—The errors due to these causes were elaborately investigated in 1851 and 1852, and a full account of the processes employed in the investigations will be found in the detailed accounts of the instrument, printed as Appendixes to the volume for 1852, and to the volume for 1867. At the end of the year 1856 a new investigation of the division-corrections was made. It is not necessary to give any details of the work, as the method employed is precisely the same as that adopted in the computations made in 1851 and 1852. The means of the results of these independent investigations have been adopted for use during the year 1876. The following table contains the final result for errors of division for every degree: ($1^{r} = 61''\cdot 4$ nearly). The errors are always considered in the nature of reading too much.

| Degree. | Excess of Reading. | Degree. | Excess of Reading. | Degree. | Excess of Reading. | Degree. | Excess of Reading. | Degree. | Excess of Reading. | Degree. | Excess of Reading. | Degree. | Excess of Reading. | Degree. | Excess of Reading. | Degree. | Excess of Reading. | Degree. | Excess of Reading. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ° | r | ° | r | ° | r | ° | r | ° | r | ° | r | ° | r | ° | r | ° | r | ° | r |
| 0 | 0·052 | 36 | 0·057 | 72 | 0·054 | 108 | 0·059 | 144 | 0·084 | 180 | 0·053 | 216 | 0·041 | 252 | 0·047 | 288 | 0·054 | 324 | 0·082 |
| 1 | ·050 | 37 | ·053 | 73 | ·050 | 109 | ·064 | 145 | ·077 | 181 | ·055 | 217 | ·040 | 253 | ·051 | 289 | ·063 | 325 | ·079 |
| 2 | ·050 | 38 | ·051 | 74 | ·049 | 110 | ·060 | 146 | ·069 | 182 | ·053 | 218 | ·044 | 254 | ·057 | 290 | ·062 | 326 | ·078 |
| 3 | ·051 | 39 | ·056 | 75 | ·056 | 111 | ·055 | 147 | ·076 | 183 | ·053 | 219 | ·042 | 255 | ·063 | 291 | ·063 | 327 | ·072 |
| 4 | ·052 | 40 | ·057 | 76 | ·058 | 112 | ·058 | 148 | ·080 | 184 | ·053 | 220 | ·039 | 256 | ·067 | 292 | ·072 | 328 | ·075 |
| 5 | ·050 | 41 | ·059 | 77 | ·055 | 113 | ·059 | 149 | ·077 | 185 | ·044 | 221 | ·038 | 257 | ·066 | 293 | ·071 | 329 | ·076 |
| 6 | ·051 | 42 | ·062 | 78 | ·054 | 114 | ·067 | 150 | ·076 | 186 | ·038 | 222 | ·038 | 258 | ·066 | 294 | ·078 | 330 | ·068 |
| 7 | ·047 | 43 | ·062 | 79 | ·056 | 115 | ·069 | 151 | ·073 | 187 | ·044 | 223 | ·040 | 259 | ·064 | 295 | ·079 | 331 | ·062 |
| 8 | ·052 | 44 | ·056 | 80 | ·062 | 116 | ·071 | 152 | ·078 | 188 | ·047 | 224 | ·041 | 260 | ·073 | 296 | ·073 | 332 | ·066 |
| 9 | ·051 | 45 | ·051 | 81 | ·065 | 117 | ·074 | 153 | ·083 | 189 | ·045 | 225 | ·037 | 261 | ·080 | 297 | ·069 | 333 | ·071 |
| 10 | ·051 | 46 | ·055 | 82 | ·072 | 118 | ·071 | 154 | ·086 | 190 | ·035 | 226 | ·042 | 262 | ·077 | 298 | ·065 | 334 | ·081 |
| 11 | ·055 | 47 | ·060 | 83 | ·074 | 119 | ·074 | 155 | ·089 | 191 | ·031 | 227 | ·049 | 263 | ·087 | 299 | ·069 | 335 | ·075 |
| 12 | ·057 | 48 | ·069 | 84 | ·075 | 120 | ·078 | 156 | ·085 | 192 | ·035 | 228 | ·050 | 264 | ·085 | 300 | ·085 | 336 | ·074 |
| 13 | ·054 | 49 | ·067 | 85 | ·071 | 121 | ·083 | 157 | ·073 | 193 | ·039 | 229 | ·056 | 265 | ·084 | 301 | ·087 | 337 | ·069 |
| 14 | ·062 | 50 | ·056 | 86 | ·071 | 122 | ·086 | 158 | ·064 | 194 | ·037 | 230 | ·052 | 266 | ·085 | 302 | ·082 | 338 | ·065 |
| 15 | ·050 | 51 | ·053 | 87 | ·075 | 123 | ·090 | 159 | ·069 | 195 | ·036 | 231 | ·056 | 267 | ·086 | 303 | ·086 | 339 | ·064 |
| 16 | ·053 | 52 | ·058 | 88 | ·075 | 124 | ·096 | 160 | ·072 | 196 | ·039 | 232 | ·062 | 268 | ·085 | 304 | ·091 | 340 | ·069 |
| 17 | ·049 | 53 | ·075 | 89 | ·072 | 125 | ·088 | 161 | ·067 | 197 | ·035 | 233 | ·065 | 269 | ·081 | 305 | ·086 | 341 | ·066 |
| 18 | ·056 | 54 | ·068 | 90 | ·073 | 126 | ·093 | 162 | ·065 | 198 | ·036 | 234 | ·060 | 270 | ·078 | 306 | ·089 | 342 | ·075 |
| 19 | ·055 | 55 | ·073 | 91 | ·072 | 127 | ·088 | 163 | ·062 | 199 | ·043 | 235 | ·059 | 271 | ·072 | 307 | ·089 | 343 | ·069 |
| 20 | ·056 | 56 | ·070 | 92 | ·078 | 128 | ·086 | 164 | ·067 | 200 | ·039 | 236 | ·049 | 272 | ·063 | 308 | ·084 | 344 | ·063 |
| 21 | ·045 | 57 | ·067 | 93 | ·071 | 129 | ·082 | 165 | ·073 | 201 | ·044 | 237 | ·054 | 273 | ·062 | 309 | ·079 | 345 | ·070 |
| 22 | ·050 | 58 | ·071 | 94 | ·075 | 130 | ·076 | 166 | ·073 | 202 | ·047 | 238 | ·062 | 274 | ·060 | 310 | ·077 | 346 | ·067 |
| 23 | ·053 | 59 | ·073 | 95 | ·070 | 131 | ·082 | 167 | ·067 | 203 | ·047 | 239 | ·070 | 275 | ·068 | 311 | ·086 | 347 | ·064 |
| 24 | ·049 | 60 | ·070 | 96 | ·069 | 132 | ·072 | 168 | ·057 | 204 | ·044 | 240 | ·069 | 276 | ·069 | 312 | ·085 | 348 | ·068 |
| 25 | ·050 | 61 | ·068 | 97 | ·068 | 133 | ·070 | 169 | ·054 | 205 | ·045 | 241 | ·070 | 277 | ·073 | 313 | ·084 | 349 | ·063 |
| 26 | ·058 | 62 | ·067 | 98 | ·073 | 134 | ·076 | 170 | ·048 | 206 | ·046 | 242 | ·063 | 278 | ·082 | 314 | ·085 | 350 | ·051 |
| 27 | ·053 | 63 | ·064 | 99 | ·077 | 135 | ·080 | 171 | ·051 | 207 | ·047 | 243 | ·069 | 279 | ·078 | 315 | ·077 | 351 | ·053 |
| 28 | ·052 | 64 | ·071 | 100 | ·075 | 136 | ·084 | 172 | ·046 | 208 | ·043 | 244 | ·070 | 280 | ·074 | 316 | ·081 | 352 | ·051 |
| 29 | ·052 | 65 | ·062 | 101 | ·070 | 137 | ·087 | 173 | ·043 | 209 | ·045 | 245 | ·066 | 281 | ·073 | 317 | ·084 | 353 | ·054 |
| 30 | ·058 | 66 | ·060 | 102 | ·073 | 138 | ·081 | 174 | ·040 | 210 | ·054 | 246 | ·059 | 282 | ·076 | 318 | ·084 | 354 | ·047 |
| 31 | ·066 | 67 | ·058 | 103 | ·069 | 139 | ·079 | 175 | ·042 | 211 | ·056 | 247 | ·054 | 283 | ·077 | 319 | ·075 | 355 | ·041 |
| 32 | ·067 | 68 | ·059 | 104 | ·066 | 140 | ·078 | 176 | ·053 | 212 | ·047 | 248 | ·042 | 284 | ·072 | 320 | ·081 | 356 | ·045 |
| 33 | ·069 | 69 | ·063 | 105 | ·060 | 141 | ·080 | 177 | ·060 | 213 | ·043 | 249 | ·044 | 285 | ·065 | 321 | ·074 | 357 | ·055 |
| 34 | ·064 | 70 | ·063 | 106 | ·062 | 142 | ·083 | 178 | ·058 | 214 | ·041 | 250 | ·054 | 286 | ·063 | 322 | ·073 | 358 | ·054 |
| 35 | ·056 | 71 | ·061 | 107 | ·057 | 143 | ·089 | 179 | ·053 | 215 | ·037 | 251 | ·050 | 287 | ·054 | 323 | ·084 | 359 | ·052 |

A re-determination of these errors, agreeing sensibly with the preceding table, was made in 1871, June and July. In this determination the divisions 30°, 90°, 150°, &c. were taken as the primary divisions instead of 0°, 60°, 120°, &c. as in previous investigations.

On 1876, January 31 and February 1, observations were made for the determination of the Horizontal Astronomical Flexure of the Telescope of the Transit-Circle, in the following manner.

The nearly horizontal wire of the South Collimator, used in these observations, was brought upon the image of the corresponding wire of the North Collimator, by looking through the cube of the Transit-Circle; and the micrometer-head was set at the mean of 20 successive readings. After each complete set of 10 observations of the collimating wires the observations for coincidence of these wires were repeated. And a correction has been applied to the mean Circle-reading at bisection of the wire of South Collimator, for the half-difference in the two sets of observations for coincidence.

OBSERVATIONS FOR THE DETERMINATION OF THE ASTRONOMICAL FLEXURE OF THE TELESCOPE OF THE TRANSIT-CIRCLE.

| Month and Day, 1876. | Order of Observation. | Concluded Circle Reading at bisection of Wire of North Collimator. | | Order of Observation. | Concluded Circle Reading at bisection of Wire of South Collimator. | |
|---|---|---|---|---|---|---|
| | | Ordinary Microscopes. | Supplementary Microscopes. | | Ordinary Microscopes. | Supplementary Microscopes. |
| | | ° ′ ″ | ° ′ ″ | | ° ′ ″ | ° ′ ″ |
| Jan. 31 | 1 | 269. 40. 53·57 | 269. 40. 49·31 | 2 | 89. 40. 53·57 | 89. 40. 49·02 |
| | 3 | 53·49 | 48·81 | 4 | 53·55 | 49·62 |
| | 5 | 53·30 | 48·48 | 6 | 53·60 | 49·19 |
| | 7 | 53·22 | 48·82 | 8 | 53·70 | 49·48 |
| | 9 | 53·00 | 48·85 | 10 | 53·48 | 49·22 |
| | 11 | 53·22 | 49·08 | 12 | 53·60 | 49·57 |
| | 13 | 53·31 | 48·87 | 14 | 53·72 | 49·18 |
| | 15 | 53·10 | 48·49 | 16 | 53·72 | 49·20 |
| | 17 | 53·32 | 48·72 | 18 | 53·46 | 49·57 |
| | 19 | 53·04 | 49·29 | 20 | 53·73 | 49·63 |
| | Mean.......... | 53·26 | 48·87 | Mean.......... | 53·61 | 49·37 |
| | | | | Correction ..... | +0·11 | +0·11 |
| | | | | Corrected Mean . | 53·72 | 49·48 |
| | | ° ′ ″ | ° ′ ″ | | ° ′ ″ | ° ′ ″ |
| Feb. 1 | 1 | 269. 40. 52·54 | 269. 40. 51·50 | 2 | 89. 40. 52·36 | 89. 40. 50·99 |
| | 3 | 52·69 | 51·56 | 4 | 52·29 | 50·99 |
| | 5 | 52·58 | 50·84 | 6 | 52·32 | 50·67 |
| | 7 | 52·30 | 50·70 | 8 | 52·18 | 50·41 |
| | 9 | 52·32 | 50·45 | 10 | 52·17 | 50·74 |
| | 11 | 52·56 | 50·49 | 12 | 52·28 | 50·77 |
| | 13 | 52·56 | 50·81 | 14 | 52·36 | 51·00 |
| | 15 | 52·59 | 51·08 | 16 | 52·21 | 51·20 |
| | 17 | 52·44 | 50·88 | 18 | 52·36 | 51·15 |
| | 19 | 52·61 | 50·75 | 20 | 52·62 | 51·10 |
| | Mean.......... | 52·52 | 50·91 | Mean.......... | 52·32 | 50·90 |
| | | | | Correction...... | +0·10 | +0·10 |
| | | | | Corrected Mean . | 52·42 | 51·00 |

The observations of 1876, January 31 and February 1, give respectively the correction for Astronomical Horizontal Flexure $-0''\cdot23$ and $+0''\cdot05$ from the Ordinary Microscopes; and $-0''\cdot31$ and $-0''\cdot05$ from the Supplementary Microscopes. The mean of these determinations is $-0''\cdot13$.

The value $-0''\cdot12$, previously found, has been used throughout the year 1876.

The product of this quantity by the sine of the zenith-distance south has been incorporated with the mean of those numbers in the preceding table which apply to the six divisions that are viewed simultaneously under the six microscopes. The resulting corrections, which are contained in the following table, have been applied additively to all circle-readings for which the six Ordinary microscopes were used, throughout the year 1876. The argument in this table is the Zenith Distance South.

DIVISION CORRECTION + FLEXURE CORRECTION.

(*Always Additive.*)

| Pointer Reading. | Corr. | Pointer Reading. | Corr. | Pointer Reading. | Corr. | Pointer Reading. | Corr. | Pointer Reading. | Corr. | Pointer Reading. | Corr. | Pointer Reading. | Corr. | Pointer Reading. | Corr. | Pointer Reading. | Corr. | Pointer Reading. | Corr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ° | ″ | ° | ″ | ° | ″ | ° | ″ | ° | ″ | ° | ″ | ° | ″ | ° | ″ | ° | ″ | ° | ″ |
| 0 | 0·28 | 36 | 0·37 | 72 | 0·40 | 108 | 0·47 | 144 | 0·64 | 180 | 0·28 | 216 | 0·51 | 252 | 0·62 | 288 | 0·69 | 324 | 0·78 |
| 1 | 0·31 | 37 | 0·46 | 73 | 0·44 | 109 | 0·45 | 145 | 0·64 | 181 | 0·31 | 217 | 0·60 | 253 | 0·66 | 289 | 0·67 | 325 | 0·78 |
| 2 | 0·34 | 38 | 0·55 | 74 | 0·55 | 110 | 0·38 | 146 | 0·60 | 182 | 0·34 | 218 | 0·69 | 254 | 0·79 | 290 | 0·60 | 326 | 0·74 |
| 3 | 0·31 | 39 | 0·62 | 75 | 0·61 | 111 | 0·30 | 147 | 0·51 | 183 | 0·33 | 219 | 0·78 | 255 | 0·85 | 291 | 0·52 | 327 | 0·65 |
| 4 | 0·30 | 40 | 0·65 | 76 | 0·63 | 112 | 0·16 | 148 | 0·44 | 184 | 0·32 | 220 | 0·81 | 256 | 0·87 | 292 | 0·38 | 328 | 0·56 |
| 5 | 0·34 | 41 | 0·66 | 77 | 0·66 | 113 | 0·00 | 149 | 0·35 | 185 | 0·36 | 221 | 0·82 | 257 | 0·90 | 293 | 0·22 | 329 | 0·47 |
| 6 | 0·42 | 42 | 0·72 | 78 | 0·63 | 114 | 0·03 | 150 | 0·23 | 186 | 0·44 | 222 | 0·88 | 258 | 0·87 | 294 | 0·25 | 330 | 0·35 |
| 7 | 0·51 | 43 | 0·72 | 79 | 0·66 | 115 | 0·13 | 151 | 0·19 | 187 | 0·53 | 223 | 0·88 | 259 | 0·90 | 295 | 0·35 | 331 | 0·31 |
| 8 | 0·51 | 44 | 0·65 | 80 | 0·82 | 116 | 0·15 | 152 | 0·20 | 188 | 0·55 | 224 | 0·81 | 260 | 1·06 | 296 | 0·37 | 332 | 0·32 |
| 9 | 0·47 | 45 | 0·57 | 81 | 0·87 | 117 | 0·13 | 153 | 0·13 | 189 | 0·51 | 225 | 0·73 | 261 | 1·11 | 297 | 0·35 | 333 | 0·23 |
| 10 | 0·48 | 46 | 0·49 | 82 | 0·73 | 118 | 0·14 | 154 | 0·09 | 190 | 0·52 | 226 | 0·67 | 262 | 0·97 | 298 | 0·36 | 334 | 0·19 |
| 11 | 0·51 | 47 | 0·46 | 83 | 0·61 | 119 | 0·16 | 155 | 0·24 | 191 | 0·55 | 227 | 0·64 | 263 | 0·85 | 299 | 0·38 | 335 | 0·34 |
| 12 | 0·49 | 48 | 0·49 | 84 | 0·59 | 120 | 0·18 | 156 | 0·39 | 192 | 0·53 | 228 | 0·67 | 264 | 0·83 | 300 | 0·38 | 336 | 0·49 |
| 13 | 0·52 | 49 | 0·47 | 85 | 0·59 | 121 | 0·21 | 157 | 0·48 | 193 | 0·58 | 229 | 0·65 | 265 | 0·83 | 301 | 0·41 | 337 | 0·58 |
| 14 | 0·64 | 50 | 0·40 | 86 | 0·55 | 122 | 0·24 | 158 | 0·57 | 194 | 0·70 | 230 | 0·58 | 266 | 0·79 | 302 | 0·44 | 338 | 0·67 |
| 15 | 0·70 | 51 | 0·32 | 87 | 0·46 | 123 | 0·22 | 159 | 0·66 | 195 | 0·76 | 231 | 0·50 | 267 | 0·70 | 303 | 0·42 | 339 | 0·74 |
| 16 | 0·72 | 52 | 0·18 | 88 | 0·38 | 124 | 0·21 | 160 | 0·69 | 196 | 0·78 | 232 | 0·36 | 268 | 0·62 | 304 | 0·41 | 340 | 0·77 |
| 17 | 0·74 | 53 | 0·01 | 89 | 0·29 | 125 | 0·25 | 161 | 0·70 | 197 | 0·82 | 233 | 0·21 | 269 | 0·53 | 305 | 0·45 | 341 | 0·78 |
| 18 | 0·71 | 54 | 0·04 | 90 | 0·17 | 126 | 0·33 | 162 | 0·76 | 198 | 0·79 | 234 | 0·24 | 270 | 0·41 | 306 | 0·53 | 342 | 0·84 |
| 19 | 0·74 | 55 | 0·14 | 91 | 0·13 | 127 | 0·42 | 163 | 0·76 | 199 | 0·82 | 235 | 0·34 | 271 | 0·37 | 307 | 0·62 | 343 | 0·84 |
| 20 | 0·90 | 56 | 0·16 | 92 | 0·14 | 128 | 0·44 | 164 | 0·70 | 200 | 0·98 | 236 | 0·36 | 272 | 0·38 | 308 | 0·62 | 344 | 0·76 |
| 21 | 0·95 | 57 | 0·14 | 93 | 0·06 | 129 | 0·40 | 165 | 0·62 | 201 | 1·03 | 237 | 0·34 | 273 | 0·30 | 309 | 0·58 | 345 | 0·68 |
| 22 | 0·80 | 58 | 0·15 | 94 | 0·02 | 130 | 0·41 | 166 | 0·55 | 202 | 0·90 | 238 | 0·35 | 274 | 0·26 | 310 | 0·59 | 346 | 0·61 |
| 23 | 0·68 | 59 | 0·17 | 95 | 0·17 | 131 | 0·44 | 167 | 0·52 | 203 | 0·78 | 239 | 0·37 | 275 | 0·41 | 311 | 0·62 | 347 | 0·58 |
| 24 | 0·66 | 60 | 0·18 | 96 | 0·32 | 132 | 0·42 | 168 | 0·55 | 204 | 0·76 | 240 | 0·38 | 276 | 0·56 | 312 | 0·60 | 348 | 0·61 |
| 25 | 0·66 | 61 | 0·20 | 97 | 0·41 | 133 | 0·46 | 169 | 0·54 | 205 | 0·76 | 241 | 0·42 | 277 | 0·65 | 313 | 0·64 | 349 | 0·58 |
| 26 | 0·62 | 62 | 0·23 | 98 | 0·50 | 134 | 0·58 | 170 | 0·47 | 206 | 0·72 | 242 | 0·45 | 278 | 0·74 | 314 | 0·76 | 350 | 0·51 |
| 27 | 0·53 | 63 | 0·21 | 99 | 0·58 | 135 | 0·65 | 171 | 0·39 | 207 | 0·63 | 243 | 0·43 | 279 | 0·82 | 315 | 0·81 | 351 | 0·43 |
| 28 | 0·44 | 64 | 0·20 | 100 | 0·61 | 136 | 0·67 | 172 | 0·25 | 208 | 0·56 | 244 | 0·42 | 280 | 0·85 | 316 | 0·83 | 352 | 0·29 |
| 29 | 0·35 | 65 | 0·24 | 101 | 0·62 | 137 | 0·70 | 173 | 0·10 | 209 | 0·47 | 245 | 0·46 | 281 | 0·86 | 317 | 0·86 | 353 | 0·12 |
| 30 | 0·23 | 66 | 0·32 | 102 | 0·68 | 138 | 0·67 | 174 | 0·13 | 210 | 0·35 | 246 | 0·54 | 282 | 0·92 | 318 | 0·83 | 354 | 0·15 |
| 31 | 0·19 | 67 | 0·41 | 103 | 0·68 | 139 | 0·70 | 175 | 0·23 | 211 | 0·31 | 247 | 0·63 | 283 | 0·92 | 319 | 0·86 | 355 | 0·25 |
| 32 | 0·20 | 68 | 0·42 | 104 | 0·61 | 140 | 0·86 | 176 | 0·25 | 212 | 0·32 | 248 | 0·64 | 284 | 0·85 | 320 | 1·02 | 356 | 0·27 |
| 33 | 0·11 | 69 | 0·38 | 105 | 0·53 | 141 | 0·91 | 177 | 0·23 | 213 | 0·25 | 249 | 0·60 | 285 | 0·77 | 321 | 1·07 | 357 | 0·25 |
| 34 | 0·07 | 70 | 0·39 | 106 | 0·46 | 142 | 0·78 | 178 | 0·25 | 214 | 0·21 | 250 | 0·61 | 286 | 0·70 | 322 | 0·92 | 358 | 0·25 |
| 35 | 0·22 | 71 | 0·42 | 107 | 0·44 | 143 | 0·66 | 179 | 0·27 | 215 | 0·36 | 251 | 0·64 | 287 | 0·66 | 323 | 0·80 | 359 | 0·27 |

A similar table applying to the four divisions viewed simultaneously by the four Supplementary microscopes has been formed, and the corresponding corrections have been applied to all circle-readings with the four Supplementary microscopes.

In pages {22} and {25} of the detailed accounts of the Transit-Circle before cited, mention is made of an apparatus for the investigation of the errors of every 5′ of each degree of the circle. The apparatus itself consists simply of the insertion, in the micrometer with which the spaces of 1° were compared, of two wire-crosses at an interval corresponding nearly to 5′ on the graduated circle. By a small motion of the micrometer, these crosses can be used conveniently for the measure of every space of 5′, and after every twelve measures the divisions of the series of 1° (whose errors are known from the preceding operations) will be brought under the microscope, and the errors of the intermediate divisions can be ascertained. This investigation was in preceding years esteemed unnecessary; but on repeating the general investigation of the errors of divisions of single degrees of the circle at the end of the year 1856, it was thought prudent to examine the 5′ divisions of those degrees of the circle which are under the microscopes in the observations of the Nadir Point, Polaris, and Polaris S.P. This examination was made between 1857, June 30 and July 3; and, for the method employed, the formulæ of reduction, and the details of the results, reference may be made to the volume for 1857.

In this place it is sufficient to state that the corrections to circle-readings for the Nadir Point, for Polaris, and for Polaris S.P., are as follows:—

| | | | | | |
|---|---|---|---|---|---|
| For Nadir Point, the division under Microscope A being | | | ° ′<br>90. 5,<br>90. 10, | the correction is | ″<br>+0·37<br>+0·52 |
| For Polaris, | ,, | ,, | 233. 5, | ,, | +0·83 |
| For Polaris S.P. | ,, | ,, | 230. 10, | ,, | +1·19 |

In 1865, July, an examination was made of the 5′ divisions employed in the observations of δ Ursæ Minoris and Cephei 51 above and below the pole. The following are the resulting corrections:—

| | | | | | |
|---|---|---|---|---|---|
| For Cephei 51, the division under Microscope A being | | | ° ′<br>234. 20, | the correction is | ″<br>+0·91 |
| For Cephei 51 S.P. | ,, | ,, | 228. 50, | ,, | +0·68 |
| For δ Ursæ Minoris | ,, | ,, | 235. 0, | ,, | +0·81 |
| For δ Ursæ Minoris S.P. | | ,, | 228. 15, | ,, | +0·76 |

These corrections have been applied additively to the circle-readings whenever they were needed throughout the year 1876.

The differences between these numbers and those used from 1868 to 1870 arise from the use of a different constant of flexure.

READINGS OF TELESCOPE-MICROMETER.—This column contains the readings of the micrometer in the eyepiece of the telescope, corresponding to the several bisections of an object during its passage across the field of view. The instrument is furnished with two clamps, one north and the other south, for fixing the instrument, but with no slow-motion screw; the object must therefore be bisected by means of the micrometer-screw, and the micrometer must be read, for every observation. The reading of $20^r$ corresponds pretty nearly to the middle of the range of the screw, and the wire is then tolerably near the center of the field of view; observations are, therefore, generally made with a position of the wire not greatly different from this.

A new telescope-micrometer, prepared by Mr. James Simms, has been in use since 1867, July 10.

To determine the value of the micrometer-revolution; on 1867, July 12, the telescope was directed to the nearly horizontal wire of the southern Reversed Telescope, and was placed so as to give Circle Readings (approximately) alternately of 89°. 29′ and 89°. 34′; the microscope-micrometers were read and corrected as usual; and the reading of the telescope-micrometer was taken, which was required to produce coincidence of its wire with the image of the wire of the Reversed Telescope. The observations were made under the direction of Mr. Dunkin. The mean of 42 intervals thus measured gave one revolution of telescope-micrometer =34″·526.

On 1867, July 31, after relieving the micrometer from a very slight constraint, observations were made by Mr. Stone for ascertaining the validity of this revolution-value through several revolutions. It appeared that, with different indexes of micrometer-revolutions, the following corrections were necessary, to refer the complete results (in the form of Results of Zenith Distance Observations) to the same mean:—

| | | | | | |
|---|---|---|---|---|---|
| Micrometer-reading | | 14ʳ, | correction required | appeared to be | − 0″·19 |
| ” | ” | 19, | ” | ” | 0·00 |
| ” | ” | 22, | ” | ” | − 0·16 |
| ” | ” | 27, | ” | ” | + 0·35 |

The corrections apparently required are too small to be adopted for use.

On 1875, March 30, a redetermination of the value of one revolution was made by Mr. Downing, by observations of the reflected image of the wire in the Nadir position; the mean of 10 intervals of 5 thus measured gave a value 34″·559, sensibly agreeing with the preceding.

On 1868, March 11, observations were made by Mr. Dunkin to determine whether there is any appreciable difference of results, according as the screw is turned to increase readings or to diminish readings. The following are the results:—

| | Micrometer-head turned so that readings increase. | | Micrometer-head turned so that readings diminish. |
|---|---|---|---|
| | r | | r |
| Separate readings | 20·423 | .... | 20·421 |
| | ·420 | .... | ·420 |
| | ·420 | .... | ·415 |
| | ·417 | .... | ·418 |
| | ·419 | .... | ·417 |
| | ·414 | .... | ·413 |
| | ·411 | .... | ·412 |
| | ·409 | .... | ·412 |
| | ·409 | .... | ·410 |
| | ·410 | .... | ·412 |
| Means.. | 20·415 | .... | 20·415 |

Observations were also made by Mr. Dunkin to determine whether the separate portions of the screw's revolution are sensibly different. The means of the readings are as follows:—

| Readings of Collimator-micrometer. | Readings of Telescope-micrometer. | Intervals. | Readings of Collimator-micrometer. | Readings of Telescope-micrometer. | Intervals. |
|---|---|---|---|---|---|
| | r | r | | r | r |
| ·000 | 17·998 | 0·501 | ·000 | 18·295 | 0·501 |
| ·720 | 18·499 | | ·720 | 18·796 | |
| ·000 | 18·505 | 0·504 | ·000 | 18·781 | 0·501 |
| ·720 | 19·009 | | ·720 | 19·282 | |
| ·000 | 19·028 | 0·504 | ·000 | 19·289 | 0·501 |
| ·720 | 19·532 | | ·720 | 19·790 | |
| ·000 | 19·548 | 0·502 | ·000 | 19·791 | 0·504 |
| ·720 | 20·050 | | ·720 | 20·295 | |
| ·000 | 20·036 | 0·502 | ·000 | 20·297 | 0·501 |
| ·720 | 20·538 | | ·720 | 20·798 | |
| ·000 | 20·563 | 0·501 | ·000 | 20·802 | 0·505 |
| ·720 | 21·064 | | ·720 | 21·307 | |
| ·000 | 21·046 | 0·500 | ·000 | 21·277 | 0·502 |
| ·720 | 21·546 | | ·720 | 21·779 | |
| ·000 | 21·560 | 0·503 | ·000 | 21·799 | 0·500 |
| ·720 | 22·063 | | ·720 | 22·299 | |
| ·000 | 21·998 | 0·502 | ·000 | 22·303 | 0·504 |
| ·720 | 22·500 | | ·720 | 22·807 | |
| ·000 | 22·555 | 0·506 | ·000 | 22·791 | 0·503 |
| ·720 | 23·061 | | ·720 | 23·294 | |
| ·000 | 23·061 | 0·505 | ·000 | 23·307 | 0·504 |
| ·720 | 23·566 | | ·720 | 23·811 | |

The evidence against any appreciable drunkenness of screw is very strong.

CORRESPONDING VERTICAL WIRES.—Omitting, in this Section, all reference to the wires Q, R, S, U, V, W, (page xxxv) adapted to galvanic observation of transits, the telescope contains seven vertical or transit wires N, O, P, T, X, Y, Z, here called 1, 2, 3, 4, 5, 6, 7, placed at sensibly equal intervals of about $14^s$ for transit of an equatoreal star; and the central or 4th wire is so nearly in the meridian as to prevent the necessity of any correction to the observed circle-reading when the body is observed at the passage over that wire. In that case, the only corrections which are required to the mean of the microscope-micrometer-readings (when converted into arc and combined with the equivalent for the telescope-micrometer-reading) are those arising from errors of division of the graduated circle, and from astronomical flexure of the telescope.

When the object has not been observed at the central wire, corrections are required for reduction to the meridian. These consist of three, viz.:—First, for want of horizontality of the micrometer-wire; secondly, for curvature of path of the object, or for difference between the small circle described by the body and the great circle of which the horizontal wire forms a part; and thirdly, in the case of the Sun, Moon, and Planets, for the change of N.P.D. in the interval between the time of observation and the meridian passage.

The correction due to inclination of wire was found by bisections of stars (by the telescope-declination-micrometer) at the first and seventh vertical wires. Its numerical value, additive before transit and subtractive after transit, for stars above the pole, is given in the foot-notes.

The general formula for the correction for curvature is given also in the foot-notes; its value is easily interpolated from a table constructed for convenient intervals of N.P.D. In the case of stars very near the Pole, when the place of observation does not coincide with a vertical wire, the correction for curvature is computed from the formula, "correction for curvature = number (log = 6·43569) $\times$ sin 2 N. P. D. $\times$ $t^2$," $t$ being the interval between the time of meridian passage and the time of transit expressed in seconds of time.

The formulæ for correction for motion are the following. In the case of the Moon, the correction for the change of N.P.D. in passing from one wire to the next is computed from the formula, "Change of declination for one hour of terrestrial longitude (from the section of Moon-culminating stars in the Nautical Almanac) $\times$ sec. declination $\times \frac{\text{Sin. Geoc. Z.D.}}{\text{Sin. App. Z.D.}} \times \frac{14}{3600}$ (the logarithm of the last factor being 7·58983)"; this formula supposes the equatoreal interval of the wires to be $14^s$. In the case of the other planets, the correction for motion is deduced immediately from the hourly motion in declination given in the Nautical Almanac; or, in the case of newly discovered planets, from their peculiar Ephemerides.

SECONDS OF CONCLUDED MERIDIONAL CIRCLE-READING.—The numbers in this column are found by adding together the mean of the microscope-readings corrected for runs, the equivalent for the mean of the telescope-micrometer-readings, corrected for curvature and inclination of the wire, and the correction for motion in the case of the Sun, Moon, or Planets. The degrees and minutes may be ascertained, when required, by subtracting the "Correction for Zenith Point" given in the notes, from the Apparent Zenith Distance.

ZENITH-POINT-CORRECTION.—The observations for this purpose are those of the reflected image of the horizontal wire, and those of the direct and reflected images of stars made at the same transit (see page x). The zenith-points deduced from the reflected image of the wire are combined with those deduced from observations of stars, in the following manner:—It has been the practice to observe when possible two stars to the north and two to the south of the zenith on every evening, and, in combining them for zenith-point, to allow to the mean of each group of star-observations, north and south respectively, twice the weight of the mean of a group of nadir-point observations, lest too great weight should be given to the readings of those divisions of the circle which correspond to the nadir-point observations.

Since the application of new micrometer-screws to the six ordinary microscopes, the discordance found in former years between the results of the nadir observation and the mean of those of north and south stars, appears to have become insensible, and no correction has been applied to the former.

The details of the computation of zenith-point are given in a subsequent table, page (124) to (135). The adopted corrections for zenith-point, for the six ordinary and four supplementary microscopes respectively, are given in the foot notes to this Section.

APPARENT ZENITH-DISTANCE.—The numbers in this column are found by adding the Zenith-Point-Correction to the Concluded Meridional Circle-Reading for the ordinary and supplementary microscopes respectively; when the sum exceeds 270° (denoting that the object is between the zenith and the north horizon), the complement to 360° is taken, and the negative sign is attached to it; for stars observed by reflexion, the sum is subtracted from 180°, and the remainder, with its algebraical sign, is the apparent zenith-distance. When the object has been observed at several wires, the mean of all the concluded circle-readings is used to form the Zenith-Distance.

When both limbs of the Moon are observed, it usually happens that one of them is slightly defective from the failure of illumination by the Sun. The necessary correction (which is not applied in this column, but which must be applied with others in order to form the numbers in the column of *Geocentric N.P.D. of Center*) is ascertained by computation in the following manner:—When the Moon is horned, let $\theta$ be the angle which the great circle joining the cusps makes with the meridian; $\delta_s$ the Sun's declination, and $\delta_m$ the Moon's declination as seen at Greenwich: $P$ the Sun's hour angle at the Moon's Transit: then

$$\text{Tan}\ \theta = \text{Cosec}\ P.\ \text{Cos}\ \delta_m.\ \text{Tan}\ \delta_s - \text{Cot P. Sin}\ \delta_m\,;$$

and the correction required will be

$$\text{Moon's semidiameter} \times \text{versin}\ \theta.$$

For Mercury and Venus, when horned, the investigation of the correction for defective illumination assumes the same form as for the Moon.

If the Moon be gibbous, as is the case in the greater number of instances, draw a great circle through the center of the Moon, at right angles to the meridian passing through the Moon, and let it meet the meridian passing through the Sun; then the intersection of this circle with the Sun's meridian will determine the place of a fictitious Sun, which would equally illuminate both limbs of the Moon when on the meridian; and the elevation or depression of the true Sun above or below the great circle joining the Moon and fictitious Sun, measured in a plane at right angles to that circle, will represent the angle by which the lowest or highest part of the illuminated hemisphere is distant from the limb, and therefore the angle whose versed sine multiplied into the Moon's semi-diameter is the correction required.

Let then $P$ be the North Pole of the heavens, $M$ the Moon on the meridian of Greenwich, and $S$ and $S_1$ the true and fictitious Suns, and imagine the triangles formed by great circles joining these. Let also $\delta_1$ be the declination of the fictitious Sun, $\theta_1$ the arc joining the true and fictitious Suns, and $\theta$ the perpendicular arc before mentioned.

Then $$\text{Tan}\ \delta_1 = \text{Tan}\ \delta_m \cdot \text{Cos}\ MPS_1 \,.$$

And $$\theta_1 = \delta_s - \delta_1 \,.$$

Also $$\text{Sin}\ \theta = \text{Sin}\ \theta_1 \,.\, \text{Sin}\ MS_1P$$

$$= \text{Sin}\ \theta_1 \frac{\text{Sin}\ MP}{\text{Sin}\ S_1P}$$

$$= \text{Sin}\ \theta_1 \frac{\text{Cos}\ \delta_m}{\text{Cos}\ \delta} \,.$$

From which $\theta$ is found.

The correction required to Apparent Zenith Distance is

$$\text{Moon's semidiameter} \times \text{versin}\ \theta.$$

In either case the North limb is fully illuminated if $\theta$ is positive, and the South limb if $\theta$ is negative.

In the cases of Mercury and Venus when gibbous, or of Mars and other planets sensibly gibbous, the investigation takes the following form. The angle $\theta$ being found as above, the length of the straight line drawn from the Sun perpendicular to the plane represented by the great circle above mentioned, is equal to Distance of Earth from Sun $\times$ sin $\theta$; and therefore if $\phi$ be the apparent angular distance of the Sun from that plane as seen from the planet, the value of $\phi$ is determined by the equation

$$\text{Sin}\ \phi = \frac{\text{Length of perpendicular line}}{\text{Dist. of Planet from Sun}} = \frac{\text{Dist. of Earth from Sun}}{\text{Dist. of Planet from Sun}} \times \sin\theta.$$

The angle $\phi$ represents in this case the angle by which the lowest or highest point of the illuminated hemisphere is distant from the limb as viewed by an observer anywhere in the plane of this great circle, and the correction therefore will be

$$\text{Planet's semidiameter} \times \text{versin}\ \phi.$$

BAROMETER.—The barometer is by Newman. Its scale is divided by vernier to 0·002 inch; but it is not usually necessary to read it to a smaller quantity than

k 2

0·01 inch for the computation of refraction. The movement of the vernier displaces a plunger which enters into the cistern of mercury, and thus maintains it constantly at the same level. This construction is not well adapted to a merely meteorological instrument, which constantly requires a visible reference to the lower surface of the mercury, but it is exceedingly convenient for the barometer as an astronomical auxiliary, and entirely avoids the risk of error from inadvertent omission of the lower verification, or from friction of a floating index; and is, on the whole, the best that can be employed. From careful comparisons made between 1875, June 10 and 24, the reading of this barometer was found to be greater than that of the Standard Barometer by 0·05 inch, allowance being made for the difference of temperature of the two barometers.

A correction of −0·05 inch has therefore been applied, and the corrected readings are printed in the column headed "Barometer."

EXTERIOR THERMOMETER.—This thermometer is by Troughton and Simms. It is mounted on the north front of the Observatory, where it is carried by an arm projecting from the wall to a distance of 4½ feet, at a height of nearly seven feet from the ground.

The following are the results of comparisons with the Standard Thermometer, made on 1861, January 31 :—

| Temperatures. | Excess of Reading of Exterior Thermometer. |
|---|---|
| ° 32·0 | ° 0·0 |
| 34·0 | 0·0 |
| 36·3 | 0·0 |
| 40·0 | 0·0 |
| 45·1 | −0·1 |
| 48·4 | 0·0 |
| 53·5 | 0·0 |
| 57·0 | 0·0 |
| 60·0 | 0·0 |
| 63·1 | −0·1 |
| 67·7 | +0·1 |
| 72·0 | 0·0 |
| 76·6 | 0·0 |
| 83·6 | 0·0 |
| 88·6 | 0·0 |
| 94·7 | 0·0 |

INTERIOR THERMOMETER.—On 1868, July 14, the small interior thermometer which had been in use for many years was replaced by a thermometer, No. 12,264, by Negretti and Zambra. The readings of this thermometer are now regularly taken for comparison with those of the exterior thermometer.

No correction has been applied to the readings of either the exterior thermometer or the interior thermometer.

REFRACTION.—The refraction is computed as in former years fundamentally from Bessel's Tables in the *Tabulæ Regiomontanæ*. These Tables, altered in form (but so as to give in all cases the same result) and expanded, are given in the Appendix to the volume for 1836, and they are also given in a still more expanded form, including the Supplementary Table for Zenith Distances greater than 85°, in an Appendix to the volume for 1853. The exterior thermometer only is used in the computation, excepting in cases when the Zenith Distance exceeds 85°. For such cases the refraction is derived from Bessel's Fundamenta, the Supplementary Table being no longer used.

The mean refractions used are the mean refractions of Bessel's Tabulæ Regiomontanæ, diminished in the proportion of 1 : 0·99469, or those of Bessel's Fundamenta, diminished in the proportion of 1 : 0·99797.

This alteration has been made on the authority of an investigation by Mr. Stone, in the *Monthly Notices of the Royal Astronomical Society*, 1867, November 8.

PARALLAX.—The parallaxes of the Sun, Moon, and Planets actually employed are given in the lower part of the page, as previously stated; the assumed ellipticity of the Earth being $\frac{1}{300}$.

For the planets the formula is, log. parallax = log. sin. (zen. dist. − 11′. 12″) + ar. co. log. distance + 0·95045.

For the Moon, the horizontal equatoreal parallaxes are interpolated, without alteration, from the Nautical Almanac, for the time of observation. The formula employed for the computation of the parallax to be applied to the observed zenith distance, is—

Parallax = Hor. Equat. Par. from N.A. × Sin Dist. from Geoc. Zenith × Geocentric Radius (Log = 9·9991136) + Corr. derived from the following table :—

| Z. D. | Correction for South Limb. | Z. D. | Correction for South Limb. | Z. D. | Correction for North Limb. | Z. D. | Correction for North Limb. |
|---|---|---|---|---|---|---|---|
| ° | ″ | ° | ″ | ° | ″ | ° | ″ |
| 30 | − 0·01 | 60 | + 0·10 | 30 | − 0·08 | 60 | − 0·10 |
| 35 | 0·00 | 65 | + 0·11 | 35 | − 0·09 | 65 | − 0·10 |
| 40 | + 0·02 | 70 | + 0·13 | 40 | − 0·09 | 70 | − 0·10 |
| 45 | + 0·03 | 75 | + 0·15 | 45 | − 0·10 | 75 | − 0·10 |
| 50 | + 0·05 | 80 | + 0·16 | 50 | − 0·10 | 80 | − 0·09 |
| 55 | + 0·07 | | | 55 | − 0·10 | | |

The correction tabulated above is the sum of two corrections, viz.: of one peculiar to the Moon's limbs, for which the numbers may be inferred from the table of corrections given in a subsequent part of this Introduction for the Moon's parallax in occultations, by supposing V (the angle, from the vertical, of the point of the Moon's limb under observation) = 0° or 180°; and of another due to the employment of the arc of equatoreal parallax instead of its sine, for which the formula is,

$$\frac{(\text{Seconds of hor. parallax})^3}{6} \times \text{Sin Z. D.} \times \text{Cos}^2 \text{ Z. D.} \times \text{Sin}^2 1''.$$

For the computation of the parallaxes of the small planets, the distances are taken from the Supplement to the Nautical Almanac, or from the *Berliner Jahrbuch*, for planets given in those works.

SEMIDIAMETER.—The semidiameters of the Sun, Moon, and Planets are given in the lower part of the page. For the Moon, Mercury, and Uranus, they are taken unchanged from the Nautical Almanac. For the Sun, Venus, Mars, Jupiter, and Saturn, the semidiameters are also taken unchanged from the Nautical Almanac, except in cases where only one limb has been observed. In these cases, for the Sun, the correction − 0″·53, derived from the observations of several preceding years, has been applied to the tabular semidiameter; for Venus, the correction + 0″·392 + 0·027 × tabular semidiameter, derived from an investigation mentioned at page lxi above, has been applied to the semidiameter given in the Nautical Almanac; and, for Mars, Jupiter, and Saturn, a correction usually derived from neighbouring observations, and specified in the notes, has been similarly applied.

GEOCENTRIC N. P. D. OF CENTER.—The numbers in this column are found by combining the Apparent Zenith Distance with the Refraction, Parallax, Semidiameter, and Assumed Colatitude 38°. 31′. 21″·60.

CORRECTION TO MEAN N. P. D. OF STARS.—The corrections for reducing the Apparent N. P. D. of the stars to the Mean North Polar Distances for the beginning of 1876, are given at the lower part of the page. For the stars in the list of the Nautical Almanac, the correction is found by subtracting the mean declination of the Nautical Almanac from the apparent declination of the same. For stars not in the Nautical Almanac, the numbers required to change Mean N. P. D. to Apparent N. P. D. are computed by the formula,

$$\text{E e}' + \text{F f}' + \text{G g}' + \text{H h}' + \text{L} + \text{l}' - 300'' + \mu' \text{ t}$$

(where $\mu'$ is the annual proper motion in N. P. D. taken from Mr. Main's or Mr. Stone's papers in the *Memoirs of the Royal Astronomical Society*, or from the *British Association Catalogue*, and t is the fraction of a year corresponding to the day of observation) which is derived from the well-known formula

$$\text{A } a' + \text{B } b' + \text{C } c' + \text{D } d' + \mu' \text{ t}$$

or its equivalent

A . sin N. P. D. × numb. (log. = 9·6376)
− A . sin R. A. cos N. P. D.
+ B . cos R. A. cos N. P. D.
+ C . cos R. A. × numb. (log. = 1·3020)
− D . sin R. A. + $\mu'$ t.

The formulæ for E, F, G, H, L, have been already given (page lxii): e′ = $a'$ + 1·2, f′ = $b'$ + 1·2, g′ = $c'$ + 25, h′ = $d'$ + 1·2, l′ = 210 − 25 × e′ − 25 × f′ − 1·2 × g′ − 25 × h′. The values of the day-constants log. E, log. F, log. G, log. H, and L, are given in the Nautical Almanac. The values of the star-constants log. e′, log. f′, log. g′, log. h′, and l′, for the stars contained in the Seven-Year Catalogue for 1860, and in the New Seven-Year Catalogue for 1864, are printed in those Catalogues. For other stars the star-constants will be found in the annual Catalogues for the years 1868 to 1875, or in that included in the present volume.

The sign of the computed quantity is changed before application.

§ 4. *Runs of each Microscope Micrometer of the Transit-Circle; and Zenith Points of the Transit-Circle, in the Year* 1876, page (117), &c.

With regard to the *Runs of the Microscopes*, the columns under A, B, C, D, E, F, a, b, $\beta$, $\alpha$, contain respectively the number of revolutions of each micrometer which measures an arc of 5′ on the circle; and the last columns give the sums of these numbers for the six ordinary and four supplementary microscopes respectively, and exhibit the number of revolutions which, for the mean of the six or four microscopes, measures an arc of 30′ or 20′ respectively, on the supposition that the screws of the micrometers have sensibly equal values. In the first calculations for the reduction of the observations it is assumed that the space of 30′ corresponds approximately to $\frac{50}{51}$ × 30$^{r}$·000, or to 29$^{r}$·4118; and the space of 20′ to $\frac{50}{51}$ × 20$^{r}$·000 or to 19$^{r}$·608; and, the fiftieth part of the micrometer-reading for the mean of the microscopes being added to the micrometer-reading, the remaining correction, depending on the difference between the values in the last columns of the tables in question and 29$^{r}$·4118 or 19$^{r}$·608, is computed in the way that has been explained (page lxv).

With regard to the Table of *Zenith Points*, the following explanation will be sufficient.

Whenever observations of stars have been made by reflexion, the results for zenith point derived from them have been combined with those derived from the observations of the reflected image of the wire. The results are always divided into three groups, viz.: those resulting from north stars, those from south stars, and those from wire-observations, and the mean of each group is taken. In combining these a weight 2 is attributed to each of the means of the two groups of star-observations, and a weight 1 to the mean of the group of wire-observations, in order to prevent too much weight being given to those divisions of the circle which are always under the microscopes for the wire-observations. From the pains taken to equalize the number of observations of stars north and south of the Zenith, no undue weight is, on the average, given to either of these positions; and, on the whole, it is presumed that, by this method of combination, the best possible average result is obtained.

The zenith-points from the six ordinary and from the four supplementary microscopes are given under separate headings, the two sets of circle-readings being perfectly independent.

§ 5. *Apparent Right Ascensions of Polaris and δ Ursæ Minoris; and Mean Right Ascensions, and Mean North Polar Distances of Stars deduced from each day's observation in the Year* 1876, page {1} to {57}.

The observations of Right Ascension and North Polar Distance of Stars are made so frequently on the same days that it has been found convenient to combine them under one general arrangement.

The apparent right ascensions of Polaris and δ Ursæ Minoris are extracted without alteration from the *twentieth* column of the *Transits observed*, &c.

The mean right ascensions of stars are found by applying to the apparent right ascensions in the *twentieth* column the corrections in the *twenty-first* column.

The corrections for personal equation have been invariably applied in this section when the observations of stars for clock-error have been made by one observer, and those of any other object requiring reduction, on the same day, by another observer.

The rules for the nomenclature of stars are the same as those in the section of the *Transits observed*, detailed in page xxxiv, but they are more rigorously followed. The stars in Weisse's two Catalogues are referred to under the initials W.B., which stand for "Weisse's Bessel." The stars in Oeltzen's Catalogue of Argelander's Zones are referred to under the abbreviation Oeltz. Arg.

The Mean North Polar Distances are found by applying, to the North Polar Distances in Section 3, the corrections given for each star in the lower part of the page.

Where two results are set down for the same day, the second refers to the observation with the four supplementary microscopes.

§ 6. *Investigation of the Correction to North Polar Distance for Discordance between the Results of Direct Observation and Reflexion Observation, and Investigation of the Apparent Correction to Assumed Latitude of the Observatory.*

The results of the direct and reflexion observations have been kept separate, with a view of ascertaining whether there is discordance between them, as has been frequently observed in the results of other circles; and the results of observations above and below the pole have been kept separate in order to ascertain whether there is any sensible error in the assumed colatitude.

With regard to the first of these points, the means of the groups of Direct-results and Reflexion-results were taken for all the stars observed: and the algebraical excess of the Reflexion-result over the Direct-result is given in the subjoined table. The weights used, have been determined as follows:—Putting $m$ and $n$ for the number of Reflexion and Direct Observations respectively, $e$ for the probable error of one observation, and $e_0$ for the probable systematic error affecting all observations of the same star, the weight to be given to that star is proportional to $\frac{4\,m\,n}{m\,e^2 + n\,e^2 + 2\,m\,n\,e^2_0}$, or assuming $e^2_0 = \frac{1}{10}\,e^2$, which would make $e_0 = 0''{\cdot}16$, the weight becomes $\frac{4\,m\,n}{m + n + \frac{1}{5}\,m\,n}$, which has been adopted for use.

EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS, FOR OBSERVATIONS OF ZENITH DISTANCES WITH THE TRANSIT-CIRCLE, 1876.

| Name of Star. | Approximate N. P. D. | Seconds of R. | Seconds of D. | R.—D. | Number of Obs. R. | Number of Obs. D. | Weight. |
|---|---|---|---|---|---|---|---|
| | ° ′ | ″ | ″ | ″ | | | |
| Polaris S.P. .......... | −1. 21 | − 7·93 | − 6·89 | − 1·04 | 9 | 85 | 12 |
| λ Ursæ Minoris S.P. ... | −1. 4 | −58·67 | −59·28 | + 0·61 | 3 | 28 | 7 |
| Groombridge 1119 S.P.. | −1. 0 | −30·06 | −28·49 | − 1·57 | 1 | 3 | 3 |
| λ Ursæ Minoris ....... | 1. 4 | 59·93 | 59·43 | + 0·50 | 7 | 36 | 11 |
| Polaris.............. | 1. 21 | 8·26 | 7·25 | + 1·01 | 4 | 86 | 9 |
| Cephei 51 ........... | 2. 45 | 58·87 | 58·94 | − 0·07 | 6 | 43 | 10 |
| Bradley 3147 ......... | 3. 23 | 36·82 | 35·86 | + 0·96 | 2 | 2 | 3 |
| δ Ursæ Minoris........ | 3. 23 | 31·45 | 31·38 | + 0·07 | 8 | 41 | 11 |
| Bradley 1399 ......... | 5. 7 | 11·56 | 14·63 | − 3·07 | 1 | 1 | 2 |
| Groombridge 2213 ..... | 5. 34 | 28·67 | 29·88 | − 1·21 | 1 | 1 | 2 |
| Piazzi VI. 292 ........ | 7. 21 | 22·50 | 23·82 | − 1·32 | 1 | 1 | 2 |
| Bradley 3038 ......... | 7. 30 | 14·28 | 15·28 | − 1·00 | 1 | 3 | 3 |
| ε Ursæ Minoris ....... | 7. 46 | 42·81 | 45·08 | − 2·27 | 2 | 2 | 3 |
| Piazzi VI. 285 ........ | 8. 31 | 24·67 | 24·38 | + 0·29 | 1 | 1 | 2 |
| Piazzi VI. 334 ........ | 8. 51 | 28·15 | 27·89 | + 0·26 | 2 | 4 | 4 |
| Bradley 1439 ......... | 8. 52 | 4·34 | 4·56 | − 0·22 | 2 | 2 | 3 |
| Bradley 1458 ......... | 8. 55 | 40·53 | 38·50 | + 2·03 | 1 | 1 | 2 |
| Bradley 2749 ......... | 9. 55 | 50·08 | 50·69 | − 0·61 | 1 | 1 | 2 |
| Piazzi VI. 75 ......... | 10. 18 | 26·12 | 26·62 | − 0·50 | 2 | 3 | 4 |

EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS, FOR OBSERVATIONS OF ZENITH DISTANCES WITH THE TRANSIT-CIRCLE, 1876—*continued.*

| Name of Star. | Approximate N. P. D. | Seconds of R. | Seconds of D. | R.—D. | Number of Obs. R. | Number of Obs. D. | Weight. |
|---|---|---|---|---|---|---|---|
| | ° ′ | ″ | ″ | ″ | | | |
| Piazzi XIII. 133 ...... | 10. 43 | 55 ·94 | 54 ·80 | + 1 ·14 | 2 | 2 | 3 |
| Bradley 1634 ......... | 11. 42 | 40 ·53 | 40 ·59 | — 0 ·06 | 1 | 2 | 2 |
| 4 Ursæ Minoris ....... | 11. 52 | 11 ·88 | 11 ·52 | + 0 ·36 | 1 | 2 | 2 |
| $\kappa^1$ Cephei (1st Star) .... | 12. 40 | 46 ·71 | 48 ·26 | — 1 ·55 | 1 | 2 | 2 |
| $\gamma$ Cephei ............. | 13. 4 | 35 ·29 | 34 ·69 | + 0 ·60 | 3 | 4 | 5 |
| Bradley 2440 ......... | 13. 8 | 33 ·59 | 36 ·23 | — 2 ·64 | 1 | 1 | 2 |
| Bradley 6 ............ | 13. 44 | 18 ·38 | 19 ·19 | — 0 ·81 | 1 | 1 | 2 |
| 5 Ursæ Minoris ....... | 13. 45 | 9 ·84 | 10 ·52 | — 0 ·68 | 1 | 1 | 2 |
| 19 Ursæ Minoris ...... | 13. 49 | 39 ·85 | 39 ·69 | + 0 ·16 | 1 | 2 | 2 |
| Bradley 1650 ......... | 14. 9 | 3 ·92 | 3 ·06 | + 0 ·86 | 2 | 2 | 3 |
| 50 Draconis .......... | 14. 42 | 46 ·92 | 46 ·61 | + 0 ·31 | 1 | 1 | 2 |
| 3 Ursæ Minoris ....... | 14. 49 | 7 ·23 | 8 ·34 | — 1 ·11 | 2 | 2 | 3 |
| Groombridge 4154..... | 15. 8 | 47 ·92 | 47 ·58 | + 0 ·34 | 1 | 1 | 2 |
| $\pi$ Cephei ............. | 15. 17 | 57 ·50 | 57 ·83 | — 0 ·33 | 2 | 2 | 3 |
| $\beta$ Ursæ Minoris ....... | 15. 20 | 15 ·68 | 15 ·80 | — 0 ·12 | 4 | 10 | 7 |
| 73 Draconis .......... | 15. 28 | 15 ·04 | 15 ·56 | — 0 ·52 | 1 | 1 | 2 |
| Bradley 3085 ......... | 16. 27 | 39 ·91 | 40 ·64 | — 0 ·73 | 1 | 1 | 2 |
| Groombridge 771...... | 16. 46 | 13 ·24 | 14 ·73 | — 1 ·49 | 2 | 2 | 3 |
| $\tau$ Draconis .......... | 16. 52 | 29 ·35 | 31 ·12 | — 1 ·77 | 2 | 2 | 3 |
| 79 Draconis .......... | 16. 53 | 1 ·23 | 2 ·45 | — 1 ·22 | 1 | 1 | 2 |
| 31 Cephei ............ | 17. 0 | 0 ·56 | 1 ·25 | — 0 ·69 | 1 | 2 | 2 |
| Bradley 1160 ......... | 17. 13 | 41 ·48 | 40 ·64 | + 0 ·84 | 2 | 2 | 3 |
| 16 Cephei ............ | 17. 24 | 36 ·62 | 36 ·07 | + 0 ·55 | 1 | 1 | 2 |
| $\gamma$ Ursæ Minoris ....... | 17. 43 | 29 ·52 | 30 ·40 | — 0 ·88 | 2 | 2 | 3 |
| 11 Ursæ Minoris ...... | 17. 44 | 34 ·38 | 34 ·35 | + 0 ·03 | 2 | 4 | 4 |
| $\psi^1$ Draconis (2nd Star) . | 17. 47 | 26 ·99 | 27 ·15 | — 0 ·16 | 3 | 3 | 5 |
| $\psi^1$ Draconis (1st Star) .. | 17. 47 | 56 ·99 | 56 ·96 | + 0 ·03 | 1 | 1 | 2 |
| Groombridge 2029..... | 18. 7 | 35 ·81 | 36 ·11 | — 0 ·30 | 2 | 2 | 3 |
| 50 Cassiopeiæ......... | 18. 11 | 49 ·36 | 48 ·81 | + 0 ·55 | 1 | 1 | 2 |
| Bradley 2934 ......... | 18. 29 | 56 ·99 | 56 ·98 | + 0 ·01 | 2 | 2 | 3 |
| Groombridge 2917..... | 18. 40 | 14 ·90 | 14 ·47 | + 0 ·43 | 2 | 2 | 3 |
| Groombridge 3409..... | 19. 4 | 53 ·40 | 54 ·79 | — 1 ·39 | 1 | 1 | 2 |
| 11 Cephei ............ | 19. 16 | 33 ·45 | 33 ·51 | — 0 ·06 | 2 | 2 | 3 |
| $\kappa$ Draconis........... | 19. 31 | 41 ·45 | 39 ·08 | + 2 ·37 | 2 | 2 | 3 |
| $\beta^2$ Cephei............ | 19. 59 | 60 ·35 | 60 ·46 | — 0 ·11 | 3 | 7 | 6 |
| 4 Draconis ........... | 20. 7 | 41 ·70 | 42 ·79 | — 1 ·09 | 1 | 1 | 2 |
| Groombridge 3590..... | 20. 25 | 26 ·27 | 26 ·88 | — 0 ·61 | 2 | 2 | 3 |
| $\sigma$ Draconis ........... | 20. 33 | 60 ·34 | 60 ·37 | — 0 ·03 | 3 | 3 | 5 |
| $\omega$ Draconis............ | 21. 11 | 4 ·77 | 5 ·58 | — 0 ·81 | 1 | 2 | 2 |
| Piazzi VII. 67 ........ | 21. 17 | 3 ·62 | 3 ·71 | — 0 ·09 | 2 | 2 | 3 |
| Bradley 382 .......... | 21. 38 | 38 ·26 | 39 ·82 | — 1 ·56 | 1 | 1 | 2 |
| Groombridge 2105..... | 21. 39 | 59 ·91 | 60 ·81 | — 0 ·90 | 1 | 1 | 2 |
| *f* Draconis............ | 21. 47 | 10 ·36 | 10 ·56 | — 0 ·20 | 1 | 1 | 2 |
| Groombridge 2320..... | 21. 51 | 47 ·66 | 47 ·89 | — 0 ·23 | 1 | 1 | 2 |
| Groombridge 2214..... | 22. 11 | 55 ·26 | 56 ·32 | — 1 ·06 | 2 | 2 | 3 |
| 7 Draconis ........... | 22. 32 | 55 ·97 | 57 ·38 | — 1 ·41 | 1 | 1 | 2 |
| $\delta$ Draconis............ | 22. 33 | 23 ·59 | 23 ·62 | — 0 ·03 | 6 | 5 | 7 |
| $o$ Cephei.............. | 22. 34 | 60 ·11 | 60 ·62 | — 0 ·51 | 2 | 2 | 3 |
| $\sigma^1$ Ursæ Majoris....... | 22. 38 | 52 ·36 | 52 ·25 | + 0 ·11 | 6 | 6 | 8 |
| Piazzi V. 246 ......... | 23. 0 | 6 ·60 | 6 ·82 | — 0 ·22 | 2 | 2 | 3 |
| Piazzi XVIII. 23...... | 23. 4 | 14 ·14 | 15 ·92 | — 1 ·78 | 1 | 1 | 2 |
| Bradley 332 .......... | 23. 9 | 24 ·27 | 24 ·45 | — 0 ·18 | 1 | 1 | 2 |
| Bradley 3054 ......... | 23. 28 | 32 ·73 | 32 ·31 | + 0 ·42 | 2 | 2 | 3 |

EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS, FOR OBSERVATIONS OF ZENITH DISTANCES WITH THE TRANSIT-CIRCLE, 1876—*continued.*

| Name of Star. | Approximate N. P. D. | Seconds of R. | Seconds of D. | R.—D. | Number of Obs. R. | Number of Obs. D. | Weight. |
|---|---|---|---|---|---|---|---|
| | ° ′ | ″ | ″ | ″ | | | |
| Piazzi XIV. 260 | 23. 34 | 23·75 | 23·37 | + 0·38 | 1 | 1 | 2 |
| Groombridge 3760 | 23. 55 | 13·29 | 10·58 | + 2·71 | 1 | 1 | 2 |
| 55 Draconis | 24. 13 | 43·74 | 43·60 | + 0·14 | 6 | 5 | 7 |
| B. A. C. 1751 | 24. 22 | 23·54 | 23·89 | − 0·35 | 1 | 1 | 2 |
| A Ursæ Majoris | 24. 26 | 5·37 | 4·78 | + 0·59 | 3 | 3 | 5 |
| ι Cephei | 24. 27 | 4·79 | 5·46 | − 0·67 | 2 | 2 | 3 |
| 42 Draconis | 24. 31 | 47·32 | 48·12 | − 0·80 | 6 | 6 | 8 |
| Groombridge 120 | 24. 31 | 59·05 | 58·95 | + 0·10 | 1 | 1 | 2 |
| π Draconis | 24. 31 | 26·84 | 26·96 | − 0·12 | 7 | 6 | 8 |
| Piazzi XIII. 184 | 24. 33 | 3·76 | 3·90 | − 0·14 | 1 | 1 | 2 |
| ι Draconis | 24. 39 | 49·92 | 49·83 | + 0·09 | 2 | 2 | 3 |
| 6 Ursæ Majoris | 24. 55 | 25·83 | 26·64 | − 0·81 | 6 | 6 | 8 |
| α Draconis | 25. 2 | 52·56 | 52·46 | + 0·10 | 1 | 1 | 2 |
| g Draconis | 25. 11 | 33·09 | 33·12 | − 0·03 | 1 | 1 | 2 |
| π Ursæ Majoris | 25. 14 | 29·24 | 29·82 | − 0·58 | 3 | 3 | 5 |
| Piazzi XV. 136 | 25. 22 | 25·78 | 25·89 | − 0·11 | 2 | 2 | 3 |
| Groombridge 1888 | 25. 31 | 36·28 | 37·08 | − 0·80 | 2 | 4 | 4 |
| 19 Camelopardali | 25. 56 | 46·39 | 45·95 | + 0·44 | 2 | 2 | 3 |
| Piazzi XXI. 142 | 26. 18 | 20·01 | 19·83 | + 0·18 | 2 | 3 | 4 |
| h Ursæ Majoris | 26. 23 | 51·33 | 51·58 | − 0·25 | 1 | 1 | 2 |
| 76 Ursæ Majoris | 26. 36 | 21·84 | 22·23 | − 0·39 | 1 | 1 | 2 |
| 49 Camelopardali | 26. 52 | 24·02 | 24·96 | − 0·94 | 4 | 2 | 4 |
| ε Cassiopeiæ | 26. 57 | 31·04 | 30·08 | + 0·96 | 1 | 1 | 2 |
| 17 Camelopardali | 27. 2 | 22·30 | 23·15 | − 0·85 | 1 | 1 | 2 |
| Piazzi III. 177 | 27. 18 | 37·49 | 37·73 | − 0·24 | 2 | 2 | 3 |
| Piazzi XV. 110 | 27. 18 | 42·13 | 42·17 | − 0·04 | 1 | 1 | 2 |
| θ Cephei | 27. 25 | 20·42 | 21·13 | − 0·71 | 4 | 4 | 6 |
| α Ursæ Majoris | 27. 34 | 48·01 | 48·34 | − 0·33 | 1 | 2 | 2 |
| b Ursæ Majoris | 27. 35 | 32·62 | 33·61 | − 0·99 | 1 | 3 | 3 |
| κ Cassiopeiæ | 27. 45 | 10·86 | 10·56 | + 0·30 | 1 | 1 | 2 |
| Groombridge 2742 | 27. 46 | 16·50 | 15·54 | + 0·96 | 1 | 1 | 2 |
| α Cephei | 27. 56 | 21·25 | 21·84 | − 0·59 | 2 | 12 | 5 |
| c Ursæ Majoris | 28. 4 | 2·55 | 4·22 | − 1·67 | 1 | 5 | 3 |
| 3 Lyncis | 28. 11 | 10·19 | 11·48 | − 1·29 | 1 | 1 | 2 |
| η Draconis | 28. 12 | 15·92 | 17·05 | − 1·13 | 1 | 2 | 2 |
| 68 Draconis | 28. 18 | 47·59 | 47·24 | + 0·35 | 1 | 1 | 2 |
| 66 Draconis | 28. 21 | 51·27 | 51·37 | − 0·10 | 1 | 1 | 2 |
| 9 Cephei | 28. 29 | 37·60 | 37·51 | + 0·09 | 1 | 2 | 2 |
| η Cephei | 28. 39 | 32·60 | 32·46 | + 0·14 | 4 | 4 | 6 |
| 12 Cassiopeiæ | 28. 51 | 22·95 | 22·27 | + 0·68 | 1 | 2 | 2 |
| ο Ursæ Majoris | 28. 52 | 10·05 | 10·84 | − 0·79 | 1 | 1 | 2 |
| Groombridge 2433 | 29. 12 | 49·81 | 50·61 | − 0·80 | 1 | 1 | 2 |
| Groombridge 2642 | 29. 24 | 14·52 | 14·56 | − 0·04 | 1 | 1 | 2 |
| γ Cassiopeiæ | 29. 57 | 19·25 | 18·79 | + 0·46 | 3 | 4 | 6 |
| 31 Camelopardali | 30. 9 | 34·77 | 34·81 | − 0·04 | 3 | 3 | 5 |
| 15 Lacertæ | 47. 21 | 47·17 | 46·35 | + 0·82 | 2 | 2 | 3 |
| 10 Canum Venaticûm | 50. 3 | 49·82 | 49·04 | + 0·78 | 3 | 3 | 5 |
| τ Andromedæ | 50. 3 | 6·15 | 5·65 | + 0·50 | 1 | 1 | 2 |
| γ Cygni | 50. 8 | 21·92 | 21·73 | + 0·19 | 5 | 4 | 6 |
| Groombridge 3919 | 50. 17 | 2·53 | 1·88 | + 0·65 | 1 | 1 | 2 |
| μ Lyræ | 50. 34 | 35·18 | 32·46 | + 2·72 | 1 | 1 | 2 |
| ν Aurigæ | 50. 53 | 25·07 | 25·58 | − 0·51 | 2 | 4 | 5 |
| Piazzi XX. 452 | 50. 59 | 45·50 | 44·86 | + 0·64 | 1 | 1 | 2 |

EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS, FOR OBSERVATIONS OF ZENITH DISTANCES WITH THE TRANSIT-CIRCLE, 1876—*continued.*

| Name of Star. | Approximate N. P. D. | Seconds of R. | Seconds of D. | R.—D. | Number of Obs. R. | Number of Obs. D. | Weight. |
|---|---|---|---|---|---|---|---|
| | ° ′ | ″ | ″ | ″ | | | |
| α Canum Venaticûm ... | 51. 0 | 42·40 | 41·39 | + 1·01 | 4 | 7 | 7 |
| Piazzi VIII. 245 ...... | 51. 3 | 12·38 | 11·97 | + 0·41 | 2 | 6 | 5 |
| α Lyræ.............. | 51. 19 | 50·66 | 49·60 | + 1·06 | 5 | 23 | 10 |
| 14 Andromedæ........ | 51. 26 | 41·91 | 41·89 | + 0·02 | 1 | 1 | 2 |
| 10 Lacertæ .......... | 51. 36 | 40·13 | 39·80 | + 0·33 | 2 | 2 | 3 |
| ρ Persei ............ | 51. 38 | 29·60 | 30·95 | − 1·35 | 1 | 1 | 2 |
| μ Aurigæ............ | 51. 40 | 51·43 | 52·76 | − 1·33 | 2 | 2 | 3 |
| 40 Cygni............ | 51. 58 | 59·10 | 58·24 | + 0·86 | 1 | 1 | 2 |
| 72 Cygni............ | 52. 1 | 17·04 | 16·84 | + 0·20 | 1 | 1 | 2 |
| τ Cygni ............ | 52. 29 | 61·24 | 59·12 | + 2·12 | 1 | 1 | 2 |
| σ Aurigæ............ | 52. 44 | 58·25 | 57·98 | + 0·27 | 2 | 3 | 4 |
| ρ Herculis ........... | 52. 44 | 20·84 | 19·93 | + 0·91 | 1 | 1 | 2 |
| 1 Lacertæ ........... | 52. 52 | 6·05 | 3·94 | + 2·11 | 1 | 1 | 2 |
| π Herculis........... | 53. 3 | 60·75 | 59·93 | + 0·82 | 1 | 1 | 2 |
| Piazzi XVI. 25........ | 53. 15 | 12·53 | 14·30 | − 1·77 | 1 | 5 | 3 |
| $b^2$ Cygni ............ | 53. 31 | 28·70 | 28·58 | + 0·12 | 1 | 1 | 2 |
| ι Lyræ .............. | 54. 6 | 35·31 | 35·56 | − 0·25 | 3 | 3 | 5 |
| 46 Leonis Minoris ..... | 55. 7 | 1·53 | 1·76 | − 0·23 | 1 | 1 | 2 |
| 47 Cygni............ | 55. 10 | 22·06 | 21·76 | + 0·30 | 2 | 2 | 3 |
| B. A. C. 516.......... | 55. 23 | 52·65 | 52·22 | + 0·43 | 2 | 2 | 3 |
| 35 Cygni............ | 55. 24 | 14·01 | 14·18 | − 0·17 | 1 | 1 | 2 |
| δ Boötis ............ | 56. 13 | 18·49 | 16·91 | + 1·58 | 2 | 2 | 3 |
| ν Ursæ Majoris........ | 56. 14 | 46·89 | 45·55 | + 1·34 | 2 | 2 | 3 |
| 59 Cancri ........... | 56. 36 | 51·16 | 50·34 | + 0·82 | 1 | 4 | 3 |
| u Herculis........... | 56. 46 | 54·73 | 55·86 | − 1·13 | 2 | 2 | 3 |
| π Andromedæ......... | 56. 57 | 48·77 | 48·32 | + 0·45 | 2 | 4 | 5 |
| 20 Leonis Minoris ..... | 57. 28 | 3·73 | 2·34 | + 1·39 | 1 | 1 | 2 |
| γ Lyræ ............. | 57. 29 | 46·15 | 44·91 | + 1·24 | 4 | 4 | 6 |
| Castor .............. | 57. 50 | 29·46 | 29·38 | + 0·08 | 4 | 8 | 3 |
| 37 Comæ............ | 58. 33 | 45·53 | 44·61 | + 0·92 | 2 | 2 | 3 |
| A Herculis .......... | 58. 37 | 28·49 | 27·59 | + 0·90 | 1 | 2 | 2 |
| $σ^1$ Piscium........... | 58. 51 | 43·35 | 42·94 | + 0·41 | 1 | 1 | 2 |
| 64 Pegasi ........... | 58. 52 | 59·62 | 60·52 | − 0·90 | 1 | 1 | 2 |
| 19 Lyræ ............ | 58. 55 | 20·19 | 20·19 | 0·00 | 4 | 5 | 6 |
| $σ^2$ Cancri........... | 58. 57 | 9·86 | 8·21 | + 1·65 | 1 | 3 | 3 |
| ρ Boötis ............ | 59. 5 | 0·96 | 1·06 | − 0·10 | 1 | 3 | 3 |
| Piazzi XVII. 176...... | 59. 8 | 14·59 | 14·12 | + 0·47 | 2 | 2 | 3 |
| 32 Herculis.......... | 59. 14 | 21·94 | 22·61 | − 0·67 | 1 | 2 | 2 |
| τ Geminorum ........ | 59. 33 | 12·94 | 12·33 | + 0·61 | 4 | 4 | 6 |
| ο Coronæ........... | 59. 56 | 58·81 | 58·13 | + 0·68 | 1 | 3 | 3 |
| φ Cygni............ | 60. 8 | 53·13 | 54·63 | − 1·50 | 1 | 1 | 2 |
| ζ Cygni............ | 60. 17 | 51·16 | 50·64 | + 0·52 | 3 | 6 | 6 |
| Piazzi XXI. 1 ........ | 60. 18 | 40·02 | 40·65 | − 0·63 | 1 | 1 | 2 |
| χ Boötis ............ | 60. 22 | 28·08 | 28·28 | − 0·20 | 1 | 1 | 2 |
| η Pegasi............. | 60. 26 | 35·93 | 36·90 | − 0·97 | 1 | 1 | 2 |
| β Coronæ............ | 60. 28 | 56·83 | 56·59 | + 0·24 | 1 | 1 | 2 |
| υ Coronæ............ | 60. 32 | 31·04 | 31·10 | − 0·06 | 1 | 2 | 2 |
| 12 Trianguli.......... | 60. 53 | 6·91 | 7·23 | − 0·32 | 2 | 2 | 3 |
| 28 Andromedæ........ | 60. 55 | 56·11 | 55·91 | + 0·20 | 1 | 1 | 2 |
| γ Comæ............. | 61. 3 | 31·76 | 30·80 | + 0·96 | 2 | 3 | 4 |
| 78 Pegasi ........... | 61. 20 | 31·15 | 30·72 | + 0·43 | 1 | 1 | 2 |
| β Tauri ............. | 61. 30 | 56·90 | 57·85 | − 0·95 | 1 | 5 | 3 |
| α Andromedæ......... | 61. 36 | 39·80 | 39·33 | + 0·47 | 1 | 5 | 3 |

EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS, FOR OBSERVATIONS OF ZENITH DISTANCES WITH THE TRANSIT-CIRCLE, 1876—*continued.*

| Name of Star. | Approximate N. P. D. | Seconds of R. | Seconds of D. | R.—D. | Number of Obs. R. | Number of Obs. D. | Weight. |
|---|---|---|---|---|---|---|---|
| | ° ′ | ″ | ″ | ″ | | | |
| Pollux | 61. 40 | 33 ·20 | 33 ·91 | − 0 ·71 | 2 | 12 | 5 |
| 30 Comæ | 61. 46 | 18 ·31 | 18 ·49 | − 0 ·18 | 2 | 2 | 3 |
| 9 Boötis | 61. 54 | 56 ·43 | 56 ·23 | + 0 ·20 | 1 | 1 | 2 |
| ι Geminorum | 61. 57 | 25 ·59 | 26 ·19 | − 0 ·60 | 4 | 5 | 6 |
| 11 Boötis | 62. 0 | 50 ·16 | 49 ·26 | + 0 ·90 | 2 | 2 | 3 |
| μ Herculis | 62. 12 | 19 ·99 | 19 ·82 | + 0 ·17 | 1 | 3 | 3 |
| β¹ Cygni | 62. 18 | 58 ·32 | 59 ·18 | − 0 ·86 | 2 | 2 | 3 |
| χ Cancri | 62. 23 | 56 ·79 | 56 ·41 | + 0 ·38 | 2 | 2 | 3 |
| ε² Boötis | 62. 24 | 7 ·14 | 7 ·51 | − 0 ·37 | 2 | 6 | 5 |
| 136 Tauri | 62. 25 | 9 ·17 | 8 ·40 | + 0 ·77 | 1 | 3 | 3 |
| 32 Vulpeculæ | 62. 25 | 47 ·38 | 46 ·25 | + 1 ·13 | 1 | 2 | 2 |
| 61 Pegasi | 62. 26 | 39 ·46 | 40 ·26 | − 0 ·80 | 1 | 1 | 2 |
| β Pegasi | 62. 35 | 22 ·37 | 21 ·35 | + 1 ·02 | 2 | 2 | 3 |
| 15 Vulpeculæ | 62. 35 | 20 ·13 | 18 ·44 | + 1 ·69 | 1 | 1 | 2 |
| φ² Cancri (1st Star) | 62. 40 | 43 ·89 | 43 ·86 | + 0 ·03 | 1 | 1 | 2 |
| φ² Cancri (2nd Star) | 62. 40 | 39 ·57 | 39 ·54 | + 0 ·03 | 1 | 1 | 2 |
| α Coronæ | 62. 52 | 0 ·00 | 0 ·47 | − 0 ·47 | 1 | 7 | 3 |
| 35 Vulpeculæ | 62. 56 | 48 ·34 | 49 ·11 | − 0 ·77 | 2 | 2 | 3 |
| *b* Boötis | 63. 13 | 21 ·73 | 21 ·07 | + 0 ·66 | 1 | 1 | 2 |
| μ Leonis | 63. 25 | 37 ·30 | 38 ·68 | − 1 ·38 | 1 | 1 | 2 |
| 12 Comæ | 63. 27 | 55 ·98 | 56 ·58 | − 0 ·60 | 1 | 1 | 2 |
| 19 Vulpeculæ | 63. 34 | 35 ·43 | 34 ·55 | + 0 ·88 | 1 | 1 | 2 |
| 3 Boötis | 63. 40 | 29 ·70 | 29 ·73 | − 0 ·03 | 1 | 1 | 2 |
| 39 Geminorum | 63. 46 | 30 ·10 | 28 ·85 | + 1 ·25 | 2 | 2 | 3 |
| λ Herculis | 63. 48 | 40 ·84 | 40 ·26 | + 0 ·58 | 1 | 1 | 2 |
| 3 Vulpeculæ | 63. 58 | 27 ·90 | 27 ·65 | + 0 ·25 | 1 | 1 | 2 |
| 139 Tauri | 64. 3 | 49 ·91 | 48 ·31 | + 1 ·60 | 1 | 1 | 2 |
| ψ² Cancri | 64. 7 | 4 ·63 | 5 ·11 | − 0 ·48 | 2 | 2 | 3 |
| *d* Boötis | 64. 19 | 12 ·71 | 12 ·21 | + 0 ·50 | 3 | 3 | 5 |
| ω Boötis | 64. 30 | 2 ·94 | 1 ·41 | + 1 ·53 | 1 | 1 | 2 |
| 10 Vulpeculæ | 64. 31 | 25 ·62 | 25 ·80 | − 0 ·18 | 1 | 1 | 2 |
| 16 Pegasi | 64. 39 | 26 ·69 | 26 ·90 | − 0 ·21 | 1 | 4 | 3 |
| 9 Leonis | 64. 46 | 25 ·49 | 24 ·71 | + 0 ·78 | 1 | 1 | 2 |
| κ Pegasi | 64. 55 | 27 ·02 | 26 ·98 | + 0 ·04 | 2 | 2 | 3 |
| 11 Tauri | 65. 4 | 23 ·33 | 23 ·42 | − 0 ·09 | 2 | 2 | 3 |
| B. F. 1857 (1st Star) | 65. 8 | 33 ·77 | 34 ·62 | − 0 ·85 | 1 | 2 | 2 |
| B. F. 1857 (2nd Star) | 65. 8 | 24 ·24 | 22 ·20 | + 2 ·04 | 1 | 1 | 2 |
| κ Geminorum | 65. 18 | 23 ·07 | 23 ·19 | − 0 ·12 | 4 | 4 | 5 |
| Bradley 2459 | 65. 19 | 35 ·26 | 35 ·11 | + 0 ·15 | 1 | 1 | 2 |
| 7 Comæ | 65. 22 | 54 ·10 | 54 ·32 | − 0 ·22 | 2 | 2 | 3 |
| 70 Herculis | 65. 22 | 32 ·18 | 32 ·32 | − 0 ·14 | 1 | 1 | 2 |
| Piazzi XII. 75 | 65. 23 | 7 ·03 | 8 ·74 | − 1 ·71 | 1 | 1 | 2 |
| υ³ Cancri | 65. 30 | 8 ·14 | 7 ·66 | + 0 ·48 | 2 | 4 | 4 |
| α Vulpeculæ | 65. 35 | 4 ·29 | 5 ·17 | − 0 ·88 | 1 | 2 | 2 |
| ε Leonis | 65. 39 | 20 ·88 | 20 ·66 | + 0 ·22 | 1 | 2 | 2 |
| 64 Arietis | 65. 43 | 59 ·78 | 59 ·48 | + 0 ·30 | 2 | 2 | 3 |
| 121 Tauri | 66. 3 | 41 ·00 | 41 ·38 | − 0 ·38 | 1 | 1 | 2 |
| Bradley 1485 | 66. 10 | 47 ·41 | 47 ·24 | + 0 ·17 | 1 | 1 | 2 |
| 39 Leonis | 66. 16 | 21 ·93 | 21 ·78 | + 0 ·15 | 1 | 1 | 2 |
| 2 Geminorum | 66. 21 | 7 ·33 | 7 ·76 | − 0 ·43 | 1 | 2 | 2 |
| ζ Andromedæ | 66. 24 | 27 ·45 | 28 ·83 | − 1 ·38 | 2 | 2 | 3 |
| Piazzi XVIII. 116 | 66. 28 | 27 ·43 | 26 ·94 | + 0 ·49 | 1 | 1 | 2 |
| Piazzi XVIII. 132 | 66. 30 | 36 ·91 | 37 ·45 | − 0 ·54 | 2 | 2 | 3 |
| 1 Geminorum | 66. 44 | 55 ·68 | 55 ·70 | − 0 ·02 | 3 | 3 | 5 |

EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS, FOR OBSERVATIONS OF ZENITH DISTANCES WITH THE TRANSIT-CIRCLE, 1876—*concluded.*

| Name of Star. | Approximate N.P.D. | Seconds of R. | Seconds of D. | R.—D. | Number of Obs. R. | Number of Obs. D. | Weight. |
|---|---|---|---|---|---|---|---|
| π Serpentis | 66° 51′ | 1″·52 | 0″·57 | + 0″·95 | 2 | 2 | 3 |
| 2 Boötis | 66. 52 | 32·36 | 31·54 | + 0·82 | 1 | 2 | 2 |
| τ Pegasi | 66. 56 | 17·52 | 16·90 | + 0·62 | 1 | 1 | 2 |
| 6 Geminorum | 67. 4 | 56·39 | 56·46 | − 0·07 | 1 | 1 | 2 |
| λ Pegasi | 67. 5 | 11·03 | 11·11 | − 0·08 | 1 | 1 | 2 |
| 1 Comæ | 67. 12 | 53·79 | 53·91 | − 0·12 | 2 | 2 | 3 |
| υ Pegasi | 67. 16 | 41·27 | 42·50 | − 1·23 | 1 | 1 | 2 |
| Piazzi IX. 230 | 67. 27 | 12·64 | 14·10 | − 1·46 | 1 | 1 | 2 |
| 113 Herculis | 67. 31 | 38·45 | 37·99 | + 0·46 | 3 | 3 | 5 |
| 92 Leonis | 67. 58 | 30·84 | 30·81 | + 0·03 | 1 | 1 | 2 |
| 35 Comæ | 68. 5 | 49·69 | 48·58 | + 1·11 | 3 | 3 | 5 |
| γ Cancri | 68. 5 | 13·78 | 12·98 | + 0·80 | 3 | 11 | 6 |
| 33 Vulpeculæ | 68. 9 | 9·54 | 8·96 | + 0·58 | 2 | 2 | 3 |
| 39 Comæ | 68. 11 | 50·97 | 50·96 | + 0·01 | 1 | 3 | 3 |
| 26 Comæ | 68. 15 | 18·95 | 19·73 | − 0·78 | 1 | 1 | 2 |
| ν Arietis | 68. 35 | 34·12 | 33·46 | + 0·66 | 1 | 4 | 3 |
| ζ Arietis | 69. 25 | 59·74 | 58·60 | + 1·14 | 1 | 1 | 2 |
| β Arietis | 69. 48 | 55·92 | 55·31 | + 0·61 | 2 | 3 | 4 |
| 51 Pegasi | 69. 53 | 44·84 | 44·77 | + 0·07 | 1 | 1 | 2 |
| 101 Herculis | 69. 58 | 21·80 | 21·47 | + 0·33 | 2 | 3 | 4 |
| Arcturus | 70. 10 | 14·50 | 15·66 | − 1·16 | 2 | 13 | 5 |
| f Boötis | 70. 12 | 52·93 | 53·22 | − 0·29 | 1 | 1 | 2 |
| $\chi^3$ Orionis | 70. 19 | 34·27 | 33·38 | + 0·89 | 1 | 4 | 3 |
| ξ Boötis | 70. 23 | 1·98 | 0·98 | + 1·00 | 1 | 1 | 2 |
| γ Herculis | 70. 33 | 14·27 | 15·13 | − 0·86 | 1 | 1 | 2 |
| θ Arietis | 70. 40 | 24·99 | 24·10 | + 0·89 | 1 | 2 | 2 |
| Piazzi XVII. 255 | 70. 42 | 13·86 | 12·08 | + 1·78 | 2 | 2 | 3 |
| 86 Leonis | 70. 54 | 27·08 | 26·41 | + 0·67 | 1 | 1 | 2 |
| $d^1$ Cancri | 71. 16 | 15·92 | 18·11 | − 2·19 | 1 | 1 | 2 |
| 83 Cancri | 71. 46 | 11·87 | 11·60 | + 0·27 | 2 | 6 | 5 |
| α Comæ | 71. 49 | 50·54 | 50·69 | − 0·15 | 1 | 1 | 2 |
| r Herculis | 71. 50 | 16·69 | 15·80 | + 0·89 | 2 | 2 | 3 |
| 36 Comæ | 71. 55 | 17·62 | 17·92 | − 0·30 | 2 | 2 | 3 |
| 3 Comæ | 72. 30 | 2·39 | 1·58 | + 0·81 | 1 | 1 | 2 |
| 111 Tauri | 72. 44 | 1·48 | 0·86 | + 0·62 | 2 | 2 | 3 |
| Piazzi XIV. 226 | 73. 7 | 41·69 | 41·76 | − 0·07 | 1 | 1 | 2 |
| γ Geminorum | 73. 30 | 49·08 | 48·10 | + 0·98 | 2 | 5 | 4 |
| $\tau^6$ Serpentis | 73. 34 | 27·81 | 26·21 | + 1·60 | 1 | 1 | 2 |
| ο Leonis | 73. 40 | 47·47 | 47·04 | + 0·43 | 1 | 1 | 2 |
| Piazzi XVII. 203 | 73. 59 | 19·89 | 20·14 | − 0·25 | 1 | 1 | 2 |
| β Serpentis | 74. 11 | 19·46 | 19·46 | 0·00 | 1 | 1 | 2 |
| α Delphini | 74. 31 | 27·63 | 27·61 | + 0·02 | 1 | 1 | 2 |
| β Leonis | 74. 44 | 5·21 | 4·92 | + 0·29 | 2 | 3 | 4 |
| ε Aquilæ | 75. 5 | 55·15 | 54·50 | + 0·65 | 3 | 4 | 5 |
| ρ Aquilæ | 75. 11 | 43·21 | 43·83 | − 0·62 | 1 | 2 | 2 |
| η Piscium | 75. 17 | 39·18 | 38·70 | + 0·48 | 1 | 7 | 3 |
| δ Delphini | 75. 22 | 10·02 | 7·66 | + 2·36 | 1 | 1 | 2 |
| α Pegasi | 75. 28 | 42·39 | 41·38 | + 1·01 | 2 | 5 | 4 |
| 37 Leonis | 75. 39 | 14·91 | 16·03 | − 1·12 | 1 | 1 | 2 |
| ζ Aquilæ | 76. 19 | 10·02 | 9·81 | + 0·21 | 1 | 2 | 2 |
| α Ophiuchi | 77. 20 | 53·53 | 53·09 | + 0·44 | 3 | 8 | 6 |
| Regulus | 77. 25 | 40·62 | 38·20 | + 2·42 | 1 | 8 | 3 |
| 20 Pegasi | 77. 28 | 22·83 | 24·60 | − 1·77 | 1 | 1 | 2 |
| 60 Cancri | 77. 54 | 4·60 | 5·78 | − 1·18 | 1 | 1 | 2 |

EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS FROM GROUPS OF STARS OBSERVED WITH THE TRANSIT-CIRCLE.

| Extent of Group, 1876. | Weight. | Mean N. P. D. | Mean Value of R−D. |
|---|---|---|---|
| | | ° ′ | ″ |
| Polaris S.P. to δ Ursæ Minoris....... | 66 | 1. 6 | + 0·07 |
| Bradley 1399 to Piazzi XIII. 133 .... | 32 | 8. 30 | − 0·49 |
| Bradley 1634 to 73 Draconis ........ | 41 | 14. 5 | − 0·24 |
| Bradley 3085 to κ Draconis ......... | 50 | 17. 52 | − 0·18 |
| $\beta^2$ Cephei to $\sigma^1$ Ursæ Majoris........ | 52 | 21. 35 | − 0·37 |
| Piazzi V. 246 to α Draconis......... | 64 | 24. 17 | − 0·14 |
| *g* Draconis to *b* Ursæ Majoris ....... | 49 | 26. 29 | − 0·37 |
| κ Cassiopeiæ to 31 Camelopardali .... | 47 | 28. 47 | − 0·17 |
| 15 Lacertæ to μ Aurigæ............ | 59 | 50. 43 | + 0·48 |
| 40 Cygni to π Andromedæ.......... | 53 | 54. 36 | + 0·38 |
| 20 Leonis Minoris to υ Coronæ....... | 64 | 59. 12 | + 0·33 |
| 12 Trianguli to 35 Vulpeculæ ....... | 72 | 62. 2 | + 0·02 |
| *b* Boötis to 64 Arietis .............. | 71 | 64. 40 | + 0·16 |
| 121 Tauri to ν Arietis.............. | 68 | 67. 18 | + 0·13 |
| ζ Arietis to Piazzi XIV. 226 ........ | 55 | 70. 57 | + 0·24 |
| γ Geminorum to 60 Cancri ......... | 51 | 75. 27 | + 0·45 |

This table indicates with tolerable clearness, the law of the values of R − D the mean numbers being, with one exception, negative for stars north of the Zenith, and, without exception, positive for stars south of the Zenith; so that a positive correction is required for Direct Observations, and a negative correction to Reflexion Observations south of the Zenith. Assuming that the correction can be represented by—

$$x + y \cos^2 \text{Z.D. south} \times \sin \text{Z.D. south},$$

it is found by calculation, that the following expressions, when tabulated, will give the values which best agree with the errors in the table above, namely:—

For direct observations

$$+ 0''\cdot004 + 0''\cdot386 \sin \text{Z.D.} \cos^2 \text{Z.D.}$$

For reflexion-observations

$$- 0''\cdot004 - 0''\cdot386 \sin \text{Z.D.} \cos^2 \text{Z.D.}$$

For use, these formulæ have been tabulated as follows; and the corrections have been applied to the mean result for N.P.D. of each star, and to every N.P.D. of Sun, Moon, and Planets in the section of Planetary Results, throughout the year.

CORRECTION FOR DISCORDANCE OF DIRECT AND REFLEXION RESULTS, 1876.

| N. P. D. | Corrections to Results of Direct-Observations. | Corrections to Results of Reflexion-Observations. |
|---|---|---|
| ° | ″ | ″ |
| − 40 | − 0·01 | + 0·01 |
| 30 | 0·04 | 0·04 |
| 20 | 0·09 | 0·09 |
| − 10 | 0·12 | 0·12 |
| 0 | 0·14 | 0·14 |
| + 10 | 0·14 | 0·14 |
| 20 | 0·11 | 0·11 |
| 30 | − 0·05 | + 0·05 |
| 40 | + 0·01 | − 0·01 |
| 50 | 0·08 | 0·08 |
| 60 | 0·13 | 0·13 |
| 70 | 0·15 | 0·15 |
| 80 | 0·15 | 0·15 |
| 90 | 0·12 | 0·12 |
| 100 | 0·08 | 0·08 |
| 110 | 0·04 | 0·04 |
| + 120 | + 0·01 | − 0·01 |

The law assumed for these numbers, it will be remarked, is different from that of the years preceding 1862.

The general system of corrections for R − D which has been followed for many years has been retained in the present volume. A careful examination of the different values obtained in different years has convinced me that the quantity is real, but I am still unable to explain perfectly its origin.

The observations of circumpolar stars have been reduced for the determination of latitude in the same manner as in preceding years. The computations below are directed to the determination of the quantity $z$ which ought to be added to the colatitude assumed in the reduction of the observations, namely, 38°. 31′. 21″·60.

The weights used in the following table are determined by use of the "Probable Errors of Greenwich Observations in Zenith Distance," given by Mr. Stone in the *Monthly Notices of the Royal Astronomical Society* for 1869, June 11, page 324. Putting $n$ for the number of observations of a star above the pole, $e$ for the probable error of one observation; $n_1$ and $e_1$, the similar quantities for the observations below the pole; $e_0$ the probable systematic error affecting all observations of the same star, and depending on outstanding division error and uncertainty in the constant of refraction; the formula employed to determine the weight to be given to that star is

$\frac{n\,n_1}{n_1\,e^2 + n\,e_1^2 + 2\,n\,n_1\,e_0^2}$; or, assuming $e_0^2 = \frac{1}{10}\,e^2$, which would make $e_0 = 0''\cdot16$, the weight becomes $\frac{n\,n_1}{n_1\,e^2 + n\,e_1^2 + \frac{1}{5}\,n\,n_1\,e^2}$, which has been adopted for use in the following investigation:—

CORRECTION TO ASSUMED LATITUDE, 1876.

| Star's Name, and Mode of Observation. | Number of Obs. | N. P. D. Uncorrected. | Result corrected for Discordance of R–D. | Number of Obs. | Concluded N. P. D. on assumed Latitude. | Number of Obs. | Algebraic Sum of Determinations. | Weight. | Product. |
|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ ″ | ″ | | ″ | | ″ | | ″ |
| λ Ursæ Minoris...D. | 36 | 1. 3. 59·43 | 59·29 | 43 | 59·42 | 74 | + 0·09 | 13 | + 1·17 |
| R. | 7 | 1. 3. 59·93 | 60·07 | | | | | | |
| S.P....D. | 28 | – 1. 3. 59·28 | –59·42 | 31 | – 59·33 | | | | |
| R. | 3 | – 1. 3. 58·67 | –58·53 | | | | | | |
| Polaris ..........D. | 86 | 1. 21. 7·25 | 7·11 | 90 | 7·17 | 184 | + 0·07 | 24 | + 1·68 |
| R. | 4 | 1. 21. 8·26 | 8·40 | | | | | | |
| S.P....D. | 85 | – 1. 21. 6·89 | – 7·03 | 94 | – 7·10 | | | | |
| R. | 9 | – 1. 21. 7·93 | – 7·79 | | | | | | |
| Cephei 51 .......D. | 43 | 2. 45. 58·94 | 58·80 | 49 | 58·83 | 88 | – 0·33 | 14 | – 4·62 |
| R. | 6 | 2. 45. 58·87 | 59·01 | | | | | | |
| S.P....D. | 39 | – 2. 45. 59·02 | –59·16 | 39 | – 59·16 | | | | |
| δ Ursæ Minoris...D. | 41 | 3. 23. 31·38 | 31·24 | 49 | 31·30 | 85 | – 0·54 | 14 | – 7·56 |
| R. | 8 | 3. 23. 31·45 | 31·59 | | | | | | |
| S.P....D. | 36 | – 3. 23. 31·70 | –31·84 | 36 | – 31·84 | | | | |
| Groombridge 1892 D. | 1 | 5. 53. 3·03 | 2·89 | 1 | 2·89 | 3 | + 0·32 | 2 | + 0·64 |
| S.P....D. | 2 | – 5. 53. 2·44 | – 2·57 | 2 | – 2·57 | | | | |
| Piazzi XIII. 263..D. | 1 | 6. 37. 32·51 | 32·37 | 4 | 32·37 | 7 | + 0·32 | 4 | + 1·28 |
| S.P....D. | 3 | – 6. 37. 31·93 | –32·05 | 3 | – 32·05 | | | | |
| Groombridge 774 .D. | 1 | 6. 57. 51·54 | 51·40 | 1 | 51·40 | 3 | – 0·47 | 2 | – 0·94 |
| S.P....D. | 2 | – 6. 57. 51·75 | –51·87 | 2 | – 51·87 | | | | |
| Groombridge 1927 D. | 2 | 8. 41. 56·98 | 56·84 | 2 | 56·84 | 4 | + 0·94 | 3 | + 2·82 |
| S.P....D. | 2 | – 8. 41. 55·78 | –55·90 | 2 | – 55·90 | | | | |
| Piazzi II. 60 .....D. | 2 | 8. 54. 25·31 | 25·17 | 2 | 25·17 | 3 | – 0·78 | 2 | – 1·56 |
| S.P....D. | 1 | – 8. 54. 25·83 | –25·95 | 1 | – 25·95 | | | | |
| Groombridge 1909 D. | 2 | 9. 3. 56·87 | 56·73 | 2 | 56·73 | 3 | + 0·27 | 2 | + 0·54 |
| S.P....D. | 1 | – 9. 3. 56·34 | –56·46 | 1 | – 56·46 | | | | |

## CORRECTION TO ASSUMED LATITUDE, 1876—*continued.*

| Star's Name, and Mode of Observation. | Number of Obs. | N. P. D. Uncorrected. | Result corrected for Discordance of R−D. | Number of Obs. | Concluded N. P. D. on assumed Latitude. | Number of Obs. | Algebraic Sum of Determinations. | Weight. | Product. |
|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ ″ | ″ | | ″ | | ″ | | ″ |
| Groombridge 1562 D. | 1 | 10. 17. 49·18 | 49·04 | 1 | 49·04 | 3 | + 0·52 | 2 | + 1·04 |
| S.P....D. | 2 | −10. 17. 48·40 | −48·52 | 2 | − 48·52 | | | | |
| Groombridge 2053 D. | 1 | 11. 18. 52·75 | 52·61 | 1 | 52·61 | 3 | + 1·25 | 2 | + 2·50 |
| S.P....D. | 2 | −11. 18. 51·24 | −51·36 | 2 | − 51·36 | | | | |
| γ Cephei ........D. | 4 | 13. 3. 34·69 | 34·56 | 7 | 34·93 | 11 | − 0·06 | 5 | − 0·30 |
| R. | 3 | 13. 3. 35·29 | 35·42 | | | | | | |
| S.P....D. | 4 | −13. 3. 34·88 | −34·99 | 4 | − 34·99 | | | | |
| 59 Draconis......D. | 1 | 13. 38. 50·85 | 50·72 | 1 | 50·72 | 3 | + 0·94 | 2 | + 1·88 |
| S.P....D. | 2 | −13. 38. 49·67 | −49·78 | 2 | − 49·78 | | | | |
| Bradley 1446 ....D. | 1 | 13. 38. 58·48 | 58·35 | 1 | 58·35 | 4 | + 1·12 | 2 | + 2·24 |
| S.P....D. | 3 | −13. 38. 57·12 | −57·23 | 3 | − 57·23 | | | | |
| Groombridge 784. D. | 1 | 14. 12. 12·36 | 12·23 | 1 | 12·23 | 3 | + 1·18 | 2 | + 2·36 |
| S.P....D. | 2 | −14. 12. 10·94 | −11·05 | 2 | − 11·05 | | | | |
| 3 Ursæ Minoris...D. | 2 | 14. 49. 8·34 | 8·22 | 4 | 7·79 | 5 | − 0·02 | 2 | − 0·04 |
| R. | 2 | 14. 49. 7·23 | 7·35 | | | | | | |
| S.P....D. | 1 | −14. 49. 7·71 | − 7·81 | 1 | − 7·81 | | | | |
| β Ursæ Minoris...D. | 10 | 15. 20. 15·80 | 15·68 | 14 | 15·71 | 15 | − 1·31 | 2 | − 2·62 |
| R. | 4 | 15. 20. 15·68 | 15·80 | | | | | | |
| S.P....D. | 1 | −15. 20. 16·92 | −17·02 | 1 | − 17·02 | | | | |
| Piazzi IV. 254 ...D. | 2 | 16. 13. 3·11 | 2·99 | 2 | 2·99 | 3 | − 1·62 | 2 | − 3·24 |
| S.P....D. | 1 | −16. 13. 4·51 | − 4·61 | 1 | − 4·61 | | | | |
| Groombridge 215 .D. | 2 | 16. 17. 39·65 | 39·53 | 2 | 39·53 | 3 | + 0·14 | 2 | + 0·28 |
| S.P....D. | 1 | −16. 17. 39·29 | −39·39 | 1 | − 39·39 | | | | |
| Groombridge 2337 D. | 3 | 16. 18. 9·62 | 9·50 | 3 | 9·50 | 5 | − 0·08 | 2 | − 0·16 |
| S.P....D. | 2 | −16. 18. 9·48 | − 9·58 | 2 | − 9·58 | | | | |
| Piazzi IV. 204 ...D. | 1 | 16. 25. 28·23 | 28·11 | 1 | 28·11 | 2 | + 0·91 | 1 | + 0·91 |
| S.P....D. | 1 | −16. 25. 27·10 | −27·20 | 1 | − 27·20 | | | | |
| τ Draconis .......D. | 2 | 16. 52. 31·12 | 31·00 | 4 | 30·24 | 7 | − 0·59 | 3 | − 1·77 |
| R. | 2 | 16. 52. 29·35 | 29·47 | | | | | | |
| S.P....D. | 3 | −16. 52. 30·73 | −30·83 | 3 | − 30·83 | | | | |

CORRECTION TO ASSUMED LATITUDE, 1876—*continued.*

| Star's Name, and Mode of Observation. | Number of Obs. | N. P. D. Uncorrected. | Result corrected for Discordance of R−D. | Number of Obs. | Concluded N. P. D. on assumed Latitude. | Number of Obs. | Algebraic Sum of Determinations. | Weight. | Product. |
|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ ″ | ″ | | ″ | | ″ | | ″ |
| 79 Draconis .....D. | 1 | 16. 53. 2·45 | 2·33 | 2 | 1·84 | 4 | − 0·48 | 2 | − 0·96 |
| R. | 1 | 16. 53. 1·23 | 1·35 | | | | | | |
| S.P....D. | 2 | −16. 53. 2·22 | − 2·32 | 2 | − 2·32 | | | | |
| 16 Cephei .......D. | 1 | 17. 24. 36·07 | 35·95 | 2 | 36·35 | 3 | − 0·72 | 2 | − 1·44 |
| R. | 1 | 17. 24. 36·62 | 36·74 | | | | | | |
| S.P....D. | 1 | −17. 24. 36·97 | −37·07 | 1 | − 37·07 | | | | |
| 50 Cassiopeiæ ....D. | 1 | 18. 10. 48·81 | 48·70 | 2 | 49·09 | 3 | + 1·03 | 2 | + 2·06 |
| R. | 1 | 18. 10. 49·36 | 49·47 | | | | | | |
| S.P....D. | 1 | −18. 10. 47·97 | −48·06 | 1 | − 48·06 | | | | |
| Bradley 2934.....D. | 2 | 18. 29. 56·98 | 56·87 | 4 | 56·99 | 6 | + 0·38 | 3 | + 1·14 |
| R. | 2 | 18. 29. 56·99 | 57·10 | | | | | | |
| S.P....D. | 2 | −18. 29. 56·52 | −56·61 | 2 | − 56·61 | | | | |
| Bradley 3135 ....D. | 2 | 18. 40. 58·89 | 58·78 | 2 | 58·78 | 5 | + 0·95 | 2 | + 1·90 |
| S.P....D. | 3 | −18. 40. 57·92 | −57·83 | 3 | − 57·83 | | | | |
| Groombridge 3409 D. | 1 | 19. 3. 54·79 | 54·68 | 2 | 54·10 | 4 | + 1·41 | 2 | + 2·82 |
| R. | 1 | 19. 3. 53·40 | 53·51 | | | | | | |
| S.P....D. | 2 | −19. 3. 52·60 | −52·69 | 2 | − 52·69 | | | | |
| Groombridge 1863 D. | 2 | 19. 6. 33·94 | 33·83 | 2 | 33·83 | 4 | − 0·25 | 2 | − 0·50 |
| S.P....D. | 2 | −19. 6. 33·99 | −34·08 | 2 | − 34·08 | | | | |
| Bradley 2854.....D. | 1 | 19. 15. 4·67 | 4·56 | 1 | 4·56 | 2 | + 1·02 | 1 | + 1·02 |
| S.P....D. | 1 | −19. 15. 3·45 | − 3·54 | 1 | − 3·54 | | | | |
| $\beta^2$ Cephei ........D. | 7 | 19. 59. 0·46 | 0·35 | 10 | 0·38 | 11 | − 0·53 | 2 | − 1·06 |
| R. | 3 | 19. 59. 0·35 | 0·46 | | | | | | |
| S.P....D. | 1 | − 19. 59. 0·82 | − 0·91 | 1 | − 0·91 | | | | |
| B. F. 1343.......D. | 2 | 20. 11. 59·48 | 59·37 | 2 | 59·37 | 3 | + 1·83 | 1 | + 1·83 |
| S.P....D. | 1 | −20. 11. 57·45 | −57·54 | 1 | − 57·54 | | | | |
| Piazzi VIII. 52 ...D. | 2 | 20. 15. 60·83 | 60·72 | 2 | 60·72 | 4 | + 1·35 | 2 | + 2·70 |
| S.P....D. | 2 | −20. 15. 59·28 | −59·37 | 2 | − 59·37 | | | | |
| A Cassiopeiæ.....D. | 2 | 20. 22. 28·42 | 28·31 | 2 | 28·31 | 3 | − 0·03 | 1 | − 0·03 |
| S.P....D. | 1 | −20. 22. 28·25 | −28·34 | 1 | − 28·34 | | | | |

CORRECTION TO ASSUMED LATITUDE, 1876—*continued.*

| Star's Name, and Mode of Observation. | Number of Obs. | N. P. D. Uncorrected. | Result corrected for Discordance of R−D. | Number of Obs. | Concluded N. P. D. on assumed Latitude. | Number of Obs. | Algebraic Sum of Determinations. | Weight. | Product. |
|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ ″ | ″ | | ″ | | ″ | | ″ |
| Groombridge 2952 D. | 3 | 20. 57. 57 ·40 | 57 ·30 | 3 | 57 ·30 | 4 | − 1 ·04 | 2 | − 2 ·08 |
| S.P....D. | 1 | −20. 57. 58 ·25 | −58 ·34 | 1 | − 58 ·34 | | | | |
| Bradley 382......D. | 1 | 21. 37. 39 ·82 | 39 ·73 | 2 | 39 ·04 | 4 | + 3 ·22 | 2 | + 6 ·44 |
| R. | 1 | 21. 37. 38 ·26 | 38 ·35 | | | | | | |
| S.P....D. | 2 | −21. 37. 35 ·73 | −35 ·82 | 2 | − 35 ·82 | | | | |
| Piazzi VIII. 46 ...D. | 2 | 22. 17. 50 ·31 | 50 ·22 | 2 | 50 ·22 | 3 | + 2 ·38 | 1 | + 2 ·38 |
| S.P....D. | 1 | −22. 17. 47 ·76 | −47 ·84 | 1 | − 47 ·84 | | | | |
| 7 Draconis.......D. | 1 | 22. 31. 57 ·38 | 57 ·29 | 2 | 56 ·68 | 3 | + 0 ·73 | 1 | + 0 ·73 |
| R. | 1 | 22. 31. 55 ·97 | 56 ·06 | | | | | | |
| S.P....D. | 1 | −22. 31. 55 ·87 | −55 ·95 | 1 | − 55 ·95 | | | | |
| Piazzi XIV. 260 ..D. | 1 | 23. 34. 23 ·37 | 23 ·29 | 2 | 23 ·56 | 3 | + 0 ·94 | 1 | + 0 ·94 |
| R. | 1 | 23. 34. 23 ·75 | 23 ·83 | | | | | | |
| S.P....D. | 1 | −23. 34. 22 ·55 | −22 ·62 | 1 | − 22 ·62 | | | | |
| Groombridge 3594 D. | 1 | 25. 20. 45 ·78 | 45 ·70 | 1 | 45 ·70 | 2 | + 0 ·36 | 1 | + 0 ·36 |
| S.P....D. | 1 | −25. 20. 45 ·27 | −45 ·34 | 1 | − 45 ·34 | | | | |
| Bradley 1363.....D. | 3 | 26. 10. 37 ·79 | 37 ·72 | 3 | 37 ·72 | 5 | − 0 ·34 | 2 | − 0 ·68 |
| S.P....D. | 2 | −26. 10. 38 ·00 | −38 ·06 | 2 | − 38 ·06 | | | | |
| Groombridge 1804 D. | 2 | 27. 7. 4 ·30 | 4 ·24 | 2 | 4 ·24 | 3 | + 2 ·26 | 1 | + 2 ·26 |
| S.P....D. | 1 | −27. 7. 1 ·92 | − 1 ·98 | 1 | − 1 ·98 | | | | |
| θ Cephei.........D. | 4 | 27. 25. 21 ·13 | 21 ·07 | 8 | 20 ·78 | 9 | + 1 ·22 | 1 | + 1 ·22 |
| R. | 4 | 27. 25. 20 ·42 | 20 ·48 | | | | | | |
| S.P....D. | 1 | −27. 25. 19 ·50 | −19 ·56 | 1 | − 19 ·56 | | | | |
| α Ursæ Majoris ..D. | 2 | 27. 34. 48 ·34 | 48 ·28 | 3 | 48 ·21 | 4 | + 2 ·10 | 1 | + 2 ·10 |
| R. | 1 | 27. 34. 48 ·01 | 48 ·07 | | | | | | |
| S.P....D. | 1 | −27. 34. 46 ·06 | −46 ·11 | 1 | − 46 ·11 | | | | |
| Groombridge 234 .D. | 1 | 27. 54. 9 ·07 | 9 ·01 | 1 | 9 ·01 | 4 | + 1 ·02 | 2 | + 2 ·04 |
| S.P....D. | 3 | −27. 54. 7 ·94 | − 7 ·99 | 3 | − 7 ·99 | | | | |
| α Cephei ........D. | 12 | 27. 56. 21 ·84 | 21 ·78 | 14 | 21 ·71 | 16 | + 1 ·40 | 3 | + 4 ·20 |
| R. | 2 | 27. 56. 21 ·25 | 21 ·31 | | | | | | |
| S.P....D. | 2 | −27. 56. 20 ·26 | −20 ·31 | 2 | − 20 ·31 | | | | |

CORRECTION TO ASSUMED LATITUDE, 1876—*continued.*

| Star's Name, and Mode of Observation. | Number of Obs. | N. P. D. Uncorrected. | Result corrected for Discordance of R−D. | Number of Obs. | Concluded N. P. D. on assumed Latitude. | Number of Obs. | Algebraic Sum of Determinations. | Weight. | Product. |
|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ ″ | ″ | | ″ | | ″ | | ″ |
| η Draconis .......D. | 2 | 28. 12. 17 ·05 | 16 ·99 | 3 | 16 ·65 | 5 | − 0·85 | 2 | − 1 ·70 |
| R. | 1 | 28. 12. 15 ·92 | 15 ·98 | | | | | | |
| S.P....D. | 2 | −28. 12. 17 ·45 | −17 ·50 | 2 | − 17 ·50 | | | | |
| 9 Cephei .......D. | 2 | 28. 28. 37 ·51 | 37 ·45 | 3 | 37 ·52 | 5 | + 0·70 | 2 | + 1 ·40 |
| R. | 1 | 28. 28. 37 ·60 | 37 ·66 | | | | | | |
| S.P....D. | 2 | −28. 28. 36 ·77 | −36 ·82 | 2 | − 36 ·82 | | | | |
| Bradley 3028.....D. | 2 | 28. 57. 43 ·24 | 43 ·19 | 2 | 43 ·19 | 3 | − 0·13 | 1 | − 0·13 |
| S.P....D. | 1 | −28. 57. 43 ·27 | −43 ·32 | 1 | − 43 ·32 | | | | |
| Groombridge 4222 D. | 3 | 29. 22. 35 ·09 | 35 ·04 | 3 | 35 ·04 | 5 | + 0·21 | 2 | + 0·42 |
| S.P....D. | 2 | −29. 22. 34 ·78 | −34 ·83 | 2 | − 34 ·83 | | | | |
| ν Cephei.........D. | 2 | 29. 27. 3 ·71 | 3 ·66 | 2 | 3 ·66 | 3 | − 0·11 | 1 | − 0·11 |
| S.P....D. | 1 | −29. 27. 3 ·72 | − 3 ·77 | 1 | − 3 ·77 | | | | |
| Groombridge 3274 D. | 1 | 29. 50. 42 ·51 | 42 ·46 | 1 | 42 ·46 | 3 | + 0·42 | 1 | + 0·42 |
| S.P....D. | 2 | −29. 50. 42 ·00 | −42 ·04 | 2 | − 42 ·04 | | | | |
| Radcliffe 3714 ....R. | 1 | 29. 50. 49 ·95 | 50 ·00 | 1 | 50 ·00 | 2 | − 1 ·69 | 1 | − 1 ·69 |
| S.P....D. | 1 | −29. 50. 51 ·65 | −51 ·69 | 1 | − 51 ·69 | | | | |
| 29 Lyncis........D. | 2 | 30. 3. 4 ·15 | 4 ·10 | 2 | 4 ·10 | 3 | + 0·29 | 1 | + 0·29 |
| S.P....D. | 1 | −30. 3. 3 ·77 | − 3 ·81 | 1 | − 3 ·81 | | | | |
| η Persei .........D. | 3 | 34. 37. 13 ·99 | 13 ·97 | 3 | 13 ·97 | 4 | − 1 ·13 | 1 | − 1 ·13 |
| S.P....D. | 1 | −34. 37. 15 ·07 | −15 ·10 | 1 | − 15 ·10 | | | | |
| γ Draconis .......D. | 5 | 38. 29. 44 ·22 | 44 ·22 | 5 | 44 ·22 | 9 | + 0·73 | 3 | + 2 ·19 |
| S.P....D. | 4 | −38. 29. 43 ·47 | −43 ·49 | 4 | − 43 ·49 | | | | |
| η Ursæ Majoris ..D. | 6 | 40. 4. 1 ·08 | 1 ·09 | 6 | 1 ·09 | 9 | − 0·50 | 2 | − 1 ·00 |
| S.P....D. | 3 | −40. 4. 1 ·58 | − 1 ·59 | 3 | − 1 ·59 | | | | |
| Capella..........D. | 4 | 44. 7. 49 ·97 | 50 ·01 | 4 | 50 ·01 | 5 | + 0·92 | | |
| S.P....D. | 1 | −44. 7. 49 ·08 | −49 ·09 | 1 | − 49 ·09 | | | | |
| α Cygni .........D. | 13 | 45. 9. 42 ·70 | 42 ·74 | 13 | 42 ·74 | 17 | + 1 ·12 | | |
| S.P....D. | 4 | −45. 9. 41 ·61 | −41 ·62 | 4 | − 41 ·62 | | | | |

If $z$ be the correction to the assumed colatitude, $2z +$ the algebraical sum of determinations ought to be equal to 0. Combining the whole with the weights above attached to them, $2z + 0''{\cdot}150 = 0$, or $z = -0''{\cdot}075$. The colatitude determined from the observations made in 1876 is therefore 38°. 31′. 21″·52.

The diminution in the colatitude below that found in former years (about 38°. 31′. 21″·80) appears to have been caused to a great extent by the diminution in the beginning of 1868 of the adopted tabular refraction.

## § 7. *Observations of Azimuth with the Altazimuth*, page [i] to [li].

The first *eleven* columns, on the left-hand page, require little explanation, except that by "Horizontal Transit" is meant the resolved horizontal part of the inclined movement of the object in passing through the field of the telescope. In making the observation, the instrument is clamped in azimuth, and the moderately-slow-motion screw of the Vertical Circle is used to make the transit of the object take place over the middle of each vertical wire. The observations have in general been made by the chronographic method, excepting at times when the galvanic apparatus has been out of order. Such cases are always distinctly marked whenever they occur.

The *twelfth* column is occupied by the personal equation of each observer, referred to Mr. Criswick as a standard, deduced from the observations of transits in the year 1875 (see Introduction to Greenwich Observations 1875, page xlviii), as the observations of 1876 are not available for the daily reductions of 1876. This personal equation is applied to the mean of observed transits (without application of any correction for omitted wires, if the transit is imperfect) to form the "Concluded Clock Time" in the *thirteenth* column.

The column *following* the "Concluded Clock Time" contains the error of the clock; that is, of the Sidereal Standard Clock, when the observations are made by galvanic contact; or of Graham 1, when they are made by eye and ear. The number of seconds by which the Sidereal Standard is slow is, before application, corrected by the quantity $-0^{s}{\cdot}03$ for the difference of longitude between the position of the Transit-Circle and that of the Altazimuth. This difference of longitude has been obtained by measurement on the plan of the Observatory, of which a reduced copy is attached to the volume for 1862.

By the application of the Clock Error to the Clock Time, the Sidereal Time in the *next* column is formed.

The last *four* columns contain the readings of the micrometers of the four microscopes of the Horizontal Circle. Occasionally the cross-wires fall on the negative-side of the micrometer-zero; in such cases the fractional part of the reading given is positive, being taken from the micrometer-head, but the integer 9 represents $-1$. The designations $a$, $b$, $c$, $d$, are so distributed among these microscopes that the observer, walking round the pier in the direction of the Sun's diurnal movement, passes them in the order $a$, $b$, $c$, $d$.

From the readings of the microscope-micrometers in the *last four* columns on the left-hand page, together with the pointer-reading (which is not inserted in the printed columns), the Concluded Reading of Horizontal Circle in the *first* column of the right-hand page is formed in this manner:—Suppose it is found, on examining the runs, that an arc of 5′ requires $7^{\text{rev}}\cdot7 - p$ of micrometer $a$, $7^{\text{rev}}\cdot6 - q$ of micrometer $b$, $7^{\text{rev}}\cdot8 - r$ of micrometer $c$, and $7^{\text{rev}}\cdot9 - s$ of micrometer $d$. Then $p$, $q$, $r$, $s$, are very small quantities. Now, suppose that the micrometer-readings in any observation are $w$, $x$, $y$, $z$: these four quantities being very nearly equal. Then the Concluded Circle-Reading ought to be

$$\frac{5'}{4} \times \left\{\frac{w}{7\cdot7-p} + \frac{x}{7\cdot6-q} + \frac{y}{7\cdot8-r} + \frac{z}{7\cdot9-s}\right\}$$

or

$$\frac{5'}{4} \times \left\{\frac{w}{7\cdot7} + \frac{x}{7\cdot6} + \frac{y}{7\cdot8} + \frac{z}{7\cdot9}\right\} + \frac{5'}{4} \times \left\{\frac{w}{7\cdot7}\cdot\frac{p}{7\cdot7} + \frac{x}{7\cdot6}\cdot\frac{q}{7\cdot6} + \frac{y}{7\cdot8}\cdot\frac{r}{7\cdot8} + \frac{z}{7\cdot9}\cdot\frac{s}{7\cdot9}\right\}.$$

From the near equality of $\frac{w}{7\cdot7}$, $\frac{x}{7\cdot6}$, &c., and the smallness of $p$, $q$, &c., the factors of $p$, $q$, $r$, $s$, may be considered equal: and the whole expression then becomes

$$w \times \frac{5'}{4 \times 7\cdot7} + x \times \frac{5'}{4 \times 7\cdot6} + y \times \frac{5'}{4 \times 7\cdot8} + z \times \frac{5'}{4 \times 7\cdot9}$$
$$+ \frac{1}{4}\left\{w \times \frac{5'}{4 \times 7\cdot7} + x \times \frac{5'}{4 \times 7\cdot6} + y \times \frac{5'}{4 \times 7\cdot8} + z \times \frac{5'}{4 \times 7\cdot9}\right\} \times \frac{p+q+r+s}{7\cdot75}$$

If the quantity $\frac{1}{4} \times \frac{100''}{7\cdot75} \times (p+q+r+s)$ be called *Correction for Runs for* 100″, then the expression is

$$w \times \frac{5'}{4 \times 7\cdot7} + x \times \frac{5'}{4 \times 7\cdot6} + y \times \frac{5'}{4 \times 7\cdot8} + z \times \frac{5'}{4 \times 7\cdot9}$$
$$+ \frac{1}{100}\left\{w \times \frac{5'}{4 \times 7\cdot7} + x \times \frac{5'}{4 \times 7\cdot6} + y \times \frac{5'}{4 \times 7\cdot8} + z \times \frac{5'}{4 \times 7\cdot9}\right\} \times \text{Correction for Runs for } 100''.$$

The separate terms of the first line are taken from four separate tables, entered with the respective arguments $w$, $x$, $y$, $z$; and, when they are added together, the value of the second line is rapidly computed by a short multiplication (usually effected by Crelle's *Rechen-tafeln*).

Another correction is occasionally necessary. When the transit of the object has not been observed across every one of the six vertical wires, the mean of the times actually observed is retained unaltered; but a correction is applied to the circle-reading, representing the difference between the azimuth of the mean of the wires actually observed and the azimuth of the mean of the six vertical wires. This correction is equal to the angular distance between the mean of the wires observed and the mean of the six wires, multiplied by the cosecant of zenith distance. The following are the angular distances from the several wires to the mean, which have been used throughout 1876, the designations of wires being the same as in preceding years: the signs given suppose the Face of the Vertical Circle to be to the Right, and are changed when the Face is left.

For wires used in chronographic observations:

| | ″ |
|---|---|
| Wire *s* | − 120·42 |
| *t* | − 77·11 |
| *u* | − 31·19 |
| *v* | + 31·46 |
| *w* | + 76·41 |
| *x* | + 120·86 |

For wires used in observations by eye and ear:

| | ″ |
|---|---|
| Wire *q* | − 598·77 |
| *r* | − 360·76 |
| *s* | − 121·77 |
| *x* | + 119·81 |
| *y* | + 361·50 |
| *z* | + 600·01 |

For daily observation of the image of the collimator, which is now in the horizontal plane, it is necessary to make use of a single wire, and the wire *v* has generally been employed for this purpose. The correction to be made to the Circle Reading in chronographic observations is ± 31″·46. This value is applicable for reduction to the mean of wires *s*, *t*, *u*, &c.; but, when the transits are observed by eye and ear, over the wires *q*, *r*, *s*, &c., the correction to be made to the Circle Reading is ± 30″·26.

By the application of this final correction, when necessary, the Concluded Reading in the *first* column on the right-hand page is formed.

The *second* column on the right-hand page contains the Approximate Apparent Zenith Distance taken from the Tabular Computations.

The *third* column contains the corrections to be applied to the Concluded Circle Reading on account of the error of collimation (the term having the same meaning as for a transit instrument) of the imaginary point in the field of view, which corresponds to the mean of the six vertical wires. The amount to be applied is, Horizontal Correction for Collimation × cosecant of Zenith Distance. The sign will change according as the Face of the Vertical Circle is Right or Left. The value of Horizontal Correction or Coefficient of Correction for Collimation, Face Right, is given at the bottom of the page; the method by which it is obtained will be explained in a subsequent section.

The next eight columns (from the *fourth* to the *eleventh*) contain the readings of the level-scales of the four levels which are parallel to the axis of the Vertical Circle, $e$ and $f$ being the readings of the two ends of one of the lower levels, $g$ and $h$ those of the other lower level, $i$ and $k$, $l$ and $m$, those of the two upper levels. As the reading of each level-scale proceeds in continuous order from the end next the Graduated Face of the Vertical Circle to the other end, it follows that the equivalents for the scale-values of both end-readings must be added; and that, when their mean is diminished by the reading corresponding to the horizontal position of the Horizontal Axis, the excess must be used (multiplied by the appropriate factor, viz., the cotangent of Zenith Distance) with its proper sign when the Graduated Face is Right, and with sign changed when the Graduated Face is Left.

The *twelfth* column contains the Concluded Level Indication. It is assumed from a careful determination with a level-prover on 1874, November 11, that for the mean of the four levels, each division represents one second of arc exactly; and the process for forming the Concluded Level Indication has been, to add together the eight numbers from the eight preceding columns, omitting 1000 from that sum, and to divide the remainder by 8.

From this Concluded Level Indication is subtracted the Level Indication for Horizontal Position of Axis of Vertical Circle given at the foot of every page (the method of obtaining which will be explained in a subsequent section); and the remainder, which represents the angular elevation of that end of the Horizontal Axis which is farthest from the Graduated Face, is multiplied by the cotangent of Zenith Distance. When the Graduated Face is Left the sign of the product is changed. The resulting number is given in the *thirteenth* column as the Correction for Level.

The *fourteenth* column contains the Corrected Reading of Horizontal Circle, as affected by all these corrections.

The *fifteenth* column contains the Concluded Azimuth, measuring from the South towards the West, which is formed by merely subtracting, from the Corrected

Reading of Horizontal Circle, the Zero of Azimuth given at the bottom of the page. The method of determining the Zero of Azimuth will be explained in a subsequent section.

In cases wherein both limbs of the Moon have been observed, one of the limbs is usually defective through want of illumination. A correction to the Azimuth (always mentioned in the foot-notes) is applied in all such cases; this correction is computed by finding first the azimuth of a point opposite the Sun, and then multiplying the distance between the azimuth of this point and that of the Moon's limb by the sine of the Sun's zenith distance; the correction is, Versed Sine of this difference multiplied by the Moon's azimuthal semidiameter.

§ 8. *Observations of Zenith Distance with the Altazimuth*, page [liii] to [lxxxvii].

The *first eleven* columns require no explanation, except that by "Vertical Transit" is meant the resolved vertical part of the inclined movement of the object in passing through the field of the telescope. The Vertical Circle is clamped, and the moderately-slow-motion of the Horizontal Circle is used to make the transit of the object take place over the middle of each horizontal wire. The methods of observing and recording the times of transit are the same as for the Horizontal Transits.

The *twelfth* column contains a correction which exists theoretically in all cases, but which in the Azimuths is practically insensible, although for the Zenith Distances, more especially those which are observed near the Meridian, it sometimes becomes important. The nature of it is this: In the subsequent calculations it is tacitly assumed that at the mean of the observed times of passage across the six horizontal wires (supposed free from error of observation), the body was at the point which represents the mean of all the six wires. This, however, is true only on the supposition that the vertical movement of the body is uniform. The correction is investigated in the following manner. In the spherical triangle whose sides are $a$, $b$, $c$, and where $C$ is the angle opposite to $c$, let $a$ and $b$ be respectively the co-latitude of the zenith, and the north polar distance of the object; then $C$ is the hour-angle, and $c$ the zenith distance. Suppose these letters to correspond truly to the position of the object when it passes the geometrical mean of the six horizontal wires: then if $\delta C$ be the addition (expressed in parts of the radius), or $\delta C_s \times 15 \sin 1''$ ($\delta C_s$ being expressed in seconds of time), which must be made to $C$ in order to express the hour-angle when the object passses one wire, and if $\delta c$ (expressed in parts of the radius), or $\delta c_{''} \times \sin 1''$ ($\delta c_{''}$ being expressed in seconds of arc), be the addition which must be made to $c$ in order to give the zenith distance of the same wire, we have

$$C+\delta C_{,} \times 15 \sin 1'' = C + \frac{d\,C}{d\,c} \cdot \delta c + \frac{d^2\,C}{d\,c^2} \cdot \frac{(\delta c)^2}{2}.$$

Now $\cos a \,.\, \cos b + \sin a \,.\, \sin b \,.\, \cos C = \cos c$.

Therefore $\sin a \,.\, \sin b \,.\, \sin C \,.\, \frac{d\,C}{d\,c} = \sin c$.

And $\sin a \,.\, \sin b \left\{ \cos C \,.\, \left(\frac{d\,C}{d\,c}\right)^2 + \sin C \,.\, \frac{d^2 C}{d\,c^2} \right\} = \cos c$.

Whence $\frac{d\,C}{d\,c} = \frac{\sin c}{\sin a \,.\, \sin b \,.\, \sin C}$

and $\frac{d^2 C}{d\,c^2} = - \frac{\cos C}{\sin C} \left(\frac{\sin c}{\sin a \,.\, \sin b \,.\, \sin C}\right)^2 + \frac{\cos c}{\sin a \,.\, \sin b \,.\, \sin C}$.

In the case before us $C$ is a small quantity, but no other quantity is small. Hence the first term of $\frac{d^2\,C}{d\,c^2}$ is the principal term, and the second may be neglected in comparison with it. And thus the equation becomes,

$$C + \delta C_{s} \times 15 \sin 1'' = C + \frac{\sin c}{\sin a \,.\, \sin b \,.\, \sin C} \delta c - \frac{\cos C}{\sin C} \left(\frac{\sin c}{\sin a \,.\, \sin b \,.\, \sin C}\right)^2 \frac{(\delta c)^2}{2}.$$

An approximate solution gives $\delta C_{,} \times 15 \sin 1'' = \frac{\sin c}{\sin a \,.\, \sin b \,.\, \sin C} \delta c$.

Substituting this in the last term, we have

$$C + \delta C_{,} \times 15 \sin 1'' = C + \frac{\sin c}{\sin a \,.\, \sin b \,.\, \sin C} \delta c - \frac{\cot C}{2} \,.\, (\delta C_{,})^2 \,.\, (15 \sin 1'')^2;$$

or, putting $C_{,}$ for the value of $C$ in seconds of time,

$$C_{,} + \delta C_{,} = C_{,} + \frac{\sin c}{\sin a \,.\, \sin b \,.\, \sin C \,.\, 15 \sin 1''} \delta c - \frac{\cot C}{2} \,.\, (\delta C_{,})^2 \,.\, 15 \sin 1'';$$

and, taking the mean of both sides, attributing successively to each the value which it obtains for each of the six wires, we have,

Mean of observed hour-angles in seconds of time =

$$C_{,} + \frac{\sin c}{6 \sin a \,.\, \sin b \,.\, \sin C \,.\, 15 \sin 1''} \Sigma \,.\, \delta c - \frac{\cot C \,.\, 15 \sin 1''}{12} \,.\, \Sigma \,.\, (\delta C_{,})^2.$$

As $c$ refers to the point which is the mean of the six wires, $\Sigma \,.\, \delta = 0$. For the convenient expression of the last term, let I be the interval in seconds of time from the first wire to the last. Then, for the first wire, $\delta C_{,} = -\frac{1}{2}$ I; for the second, $\delta C_{,} = -\frac{1}{3}$ I;

n 2

for the third, $\delta\ C_s = -\frac{1}{6}\ \mathrm{I}$; for the fourth, $\delta\ C_s = +\frac{1}{6}\ \mathrm{I}$; for the fifth it is $+\frac{1}{3}\ \mathrm{I}$; for the sixth, $+\frac{1}{2}\ \mathrm{I}$. Hence the equation becomes,

Mean of observed hour-angles in seconds of time =

$$C_s - \frac{\cot C.\ 15 \sin 1''}{12} \cdot \frac{28}{36} \times \mathrm{I}^2,$$

$$= C_s - \frac{35}{36} \sin 1'' \times \cot C \times \mathrm{I}^2.$$

Hence the correction to be applied to the mean of the observed hour-angles, in order to obtain the true hour-angle corresponding to the zenith distance at the mean of the wires, is:—

$$+\frac{35}{36} \sin 1'' \times \cot C \times \mathrm{I}^2.$$

If the transit be imperfect, but the wires observed be consecutive, the following corrections will be applicable, being easily deduced from the preceding investigation:—

When the first or last three wires are observed, if $\mathrm{I}_3$ be the interval in seconds of time from the first to the third, the correction in seconds of time will be $+\frac{5}{4} \sin 1'' \times \cot C \times (\mathrm{I}_3)^2$.

When the first or last four wires are observed, if $\mathrm{I}_4$ be the interval from the first to the fourth, the correction will be $+\frac{525}{512} \sin 1'' \times \cot C \times (\mathrm{I}_4)^2$.

When five consecutive wires are observed, if $\mathrm{I}_5$ be the interval from the first to the fifth, the correction will be $+\frac{129}{125} \sin 1'' \times \cot C \times (\mathrm{I}_5)^2$.

If the wires are not consecutive, the corresponding correction will be found, on the same principles, with little difficulty.

This correction will be subtractive from the mean of times when the hour-angle is diminishing, or before the object has passed the meridian, and additive to the mean of times when the object has passed the meridian. A small table of double entry is prepared with arguments $C$ and I, and from this the correction is readily taken.

The *thirteenth* column is occupied by the personal equation (referred to Mr. Criswick as standard), and this is applied to the mean of wires, corrected as above mentioned, to form the concluded Clock-time in the *fourteenth* column. The *two last* columns require no explanation beyond that in the section of Azimuths.

The *first four* columns on the right-hand side give the readings of the four microscope-micrometers, which are converted into arc by the aid of the numbers given at the bottom of the page, in the same manner as the similar numbers in the section of Azimuths.

When the observer views the graduated face of the vertical circle, the microscopes are seen in the position $\frac{\text{A D}}{\text{B C}}$.

When the transits over any number of wires are omitted, the time of transit retained is the mean of the transits actually observed, corrected if necessary for personal equation; but a correction in arc is applied to the circle-reading, corresponding to the interval between the mean of the wires actually observed and the mean of the six wires. Calling the whole system of wires (including both the eye-and-ear and the galvanic wires) in the order in which a star on the West side of the meridian passes them when the Graduated Face of the Vertical Circle is Right, *Q*, *R*, *S*, *T*, *U*, *V*, *W*, *X*, *Y*, *Z*, then the correction to reduce each of the wires to the mean of either system of wires used throughout the year 1876 is:—

For wires used in chronographic observations, and in eye-and-ear observations of objects near the meridian,

| | | |
|---|---|---|
| Wire *S* | − | 62″·62 |
| *T* | − | 41·03 |
| *U* | − | 18·14 |
| *V* | + | 19·33 |
| *W* | + | 41·99 |
| *X* | + | 60·44 |

For wires used exclusively in observations by eye and ear:

| | | |
|---|---|---|
| Wire *Q* | − | 298″·63 |
| *R* | − | 180·82 |
| *S* | − | 62·60 |
| *X* | + | 61·73 |
| *Y* | + | 178·43 |
| *Z* | + | 301·92 |

The Concluded Reading in the *fifth* column is formed; in the instances when the celestial body's transit has been observed over all the wires, by the simple mean of the equivalents for readings of microscope-micrometers (duly corrected for runs); in the instances in which the transits over a part only of the wires are obtained, by applying to the mean of equivalents the correction (stated in the foot-notes) for the difference between the mean of all the wires and the mean of the wires observed; and in observations of the collimator, by applying to the mean of equivalents the entire correction corresponding to the single wire employed.

The four columns from the *sixth* to the *ninth* give the readings of the two ends of the two levels which are parallel to the plane of the Vertical Circle, *E* and *F* being the readings of the two ends of the lower level, and *G* and *H* those of the two ends of the upper level. As, when the Graduated Face is Right, the Circle-Readings increase with the increasing Zenith Distance, and as in the same case the numeration of the levels increases from the end next the object to the end next the observer, it follows that the indication of the levels is in all cases additive to the Circle-Reading: and that the equivalents for the two ends of each level are to be combined additively. For the mean of the two levels, one division of the scale is assumed (from a careful determination with a level-prover on 1874, November 11,) to be equal to 1″·075 (the zeros of *E* and *G* being 0$^{\text{div.}}$, and those of *F* and *H* being respectively 200$^{\text{div.}}$ and 250$^{\text{div.}}$), and then the mean of the four readings increased by $\frac{3}{40}$ of its amount is taken to form the Level-Indication in the *tenth* column.

The Barometer, whose reading is contained in the *eleventh* column, is by Simms, with adjustible bag and float: it is placed in a small recess of the dome. Comparisons with the Standard Barometer made between 1863, January 28 and 31, and 1874, November 20 and 30, appeared to indicate that the readings of the Altazimuth Barometer require a correction −0$^{\text{in.}}$072; a further correction of −0$^{\text{in.}}$028 is required on account of difference of altitude, to obtain the excess of the readings of the Altazimuth over the Standard Barometer, if placed side by side. A correction of −0$^{\text{in.}}$10 has therefore been applied to the readings of the Barometer throughout the year, the corrected readings thus representing the readings of the Standard Barometer at the level of the Altazimuth.

The Thermometer, whose reading is contained in the *twelfth* column, is by Simms: it is placed on the East side of the tower carrying the dome, where its case is carried by long iron rods attached to the brickwork; it is mounted with its bulb inclosed by a double case, which is silvered by electro-plating, allowing a perfectly free passage for the air; it is read from a new window pierced in the eastern side of the Altazimuth observing room. The corrections required for its errors, ascertained by comparison with the Standard Thermometer, are as follows:—

CORRECTION TO ALTAZIMUTH (PORCELAIN) THERMOMETER.

| Temperature. | Correction. | Temperature. | Correction. |
|---|---|---|---|
| ° 28 | +0·1 | ° 66 | +0·1 |
| 30 | 0·0 | 68 | +0·2 |
| 32 | 0·0 | 70 | +0·2 |
| 34 | 0·0 | 72 | +0·2 |
| 36 | −0·1 | 74 | +0·3 |
| 38 | −0·1 | 76 | +0·2 |
| 40 | −0·1 | 78 | +0·2 |
| 42 | −0·2 | 80 | +0·1 |
| 44 | −0·2 | 82 | 0·0 |
| 46 | −0·2 | 84 | 0·0 |
| 48 | −0·2 | 86 | 0·0 |
| 50 | −0·1 | 88 | 0·0 |
| 52 | −0·1 | 90 | +0·1 |
| 54 | −0·1 | 92 | +0·1 |
| 56 | 0·0 | 94 | +0·1 |
| 58 | 0·0 | 96 | +0·2 |
| 60 | 0·0 | 98 | +0·2 |
| 62 | +0·1 | 100 | +0·2 |
| 64 | +0·1 | 102 | +0·2 |

An approximate Zenith Distance being obtained by the use of an approximate zenith-point, the refraction in the *thirteenth* column is computed by the use of the tables printed in the Appendix to the Greenwich Observations, 1836, and reprinted (with an addition, including Bessel's supplementary table for Zenith-Distances exceeding 85°, which, however, is no longer used,) as an Appendix to the Volume for 1853, giving the same results as the tables in the *Tabulæ Regiomontanæ;* the mean refractions being diminished in the proportion of 1 : 0·99469, which is equivalent to a reduction of the mean refraction of Bessel's Fundamenta in the proportion of 1 : 0·99797. This refraction is always additive to the observed Zenith Distance, and therefore it is added to the Reading of the Vertical Circle when the Graduated Face is Right, and subtracted when it is Left.

By the combination of these various quantities, the Corrected Reading in the *fourteenth* column is formed. It is to be remarked that this Corrected Reading contains implicitly a constant depending on the assumed zeros of the Level-Scales, and equal to the Level-Indication when the axis of azimuthal rotation is vertical. In this respect it differs from the Corrected Reading of the Horizontal Circle, which contains no such constant.

The Zenith-Point, whose value is given at the foot of each page, is obtained by a process which will be explained hereafter: it is sufficient here to state that it also contains implicitly the same constant depending on the assumed zeros of the Level-Scales. The concluded Zenith-Distance therefore in the *fifteenth* column, which is formed by subtracting the Zenith-Point from the Corrected Reading when the Graduated Face is Right, and by subtracting the Corrected Reading from the Zenith-Point when the Graduated Face is Left, is freed from this constant.

In cases wherein both the upper and the lower limb of the Moon have been observed, one limb is usually defective through want of illumination. A correction for this defect is applied, computed by a method analogous to that used for correcting the Zenith Distance of the defective limb of the Moon when observed on the meridian (see page lxxiv). The corrections for defect of illumination are always mentioned in the notes.

### § 9. *Comparison of Tabular Azimuths and Zenith Distances with Azimuths and Zenith Distances observed*, page [lxxxix] to [cxxxv].

The *first three* columns need no explanation.

The Mean Solar Time in the *fourth* column is formed from the Sidereal Time in the two preceding sections, by the same process as in the formation of Mean Time for the observations of Planets (which will be described hereafter).

The Tabular R.A. of Center in the *fifth* column is thus formed. For stars in the list of the Nautical Almanac, there are applied, to the places given in the Nautical Almanac, corrections fundamentally deduced from the Right Ascensions given in the Greenwich New Seven-year Catalogue of 2760 Stars for the epoch 1864 (see page xlvi). For the Moon, the Tabular R.A. of Center is formed by interpolating with second differences between the hourly places of the Moon given in the Nautical Almanac, using as argument the Mean Solar Time of the *fourth* column.

The Hour Angle in the *sixth* column is the difference (without respect of sign, but taken less than 180°) between the Tabular R. A. and the Sidereal Time in the two preceding sections. The East or West side of the Meridian is indicated by the letter E or W in the *seventh* column.

The *eighth* column contains the Tabular Geocentric N.P.D. of Center. It is thus formed. For stars, the places in N.P.D. are derived from the same sources as those in R.A. For the Moon, the N.P.D. is formed by interpolating with second differences between the hourly places of the Nautical Almanac.

It may be proper here to describe the method which has been adopted since the beginning of 1862 for the computation of Interpolations with second differences, with the view of avoiding all changes of sign. Up to that time the practice had been as follows. If we took from the Ephemeris the values $x_1$, $x_2$, $x_3$, corresponding to the equidistant times $T_1$, $T_2$, $T_3$, and if we wished to compute the value of $x$ for the time $T_2 + \tau$ (where $\tau$ is expressed by a number whose unit is $T_2 - T_1$ or $T_3 - T_2$, and is always less than $\pm 1$, and practically always less than $\pm \frac{1}{2}$ ), we begin by taking the differences, thus:—

| | | First difference. | Second difference. |
|---|---|---|---|
| $T$ | $x_1$ | | |
| | | $\Delta'(1)$ | |
| $T_2$ | $x_2$ | | $\Delta(2)$ |
| | | $\Delta''(1)$ | |
| $T$ | $x_3$ | | |

Then, forming the coefficients $\frac{1}{2}\left\{\Delta'(1) + \Delta''(1)\right\}$ and $\frac{1}{2}\Delta(2)$ numerically, the required quantity $x$ is:—

$$x_2 + \frac{1}{2}\left\{\Delta'(1) + \Delta''(1)\right\} \times \tau + \frac{1}{2}\Delta(2) \times \tau^2.$$

This formula is very conveniently adapted to logarithmic computation, but it is subject to the very serious inconvenience of numerous changes of sign. For all elements, $\tau$ and $\Delta(2)$ may be $+$ or $-$; for all elements except the Moon's R. A., $\Delta'(1)$ and $\Delta''(1)$ may be $+$ or $-$, and may even have different signs.

The formula of interpolation may be varied; but in every form, without a radical change in the character of the numbers between which the interpolation is to be effected, there will be a great number of changes of sign.

In order to escape these difficulties, the following process has been devised:—

First: although it is usual still to select, for the middle tabular time $T_2$, that tabular time which is nearest to the time for which interpolation is required, whether before it or after it, yet, in the formula of interpolation, the adopted tabular number (to which the results of the interpolation-formula are added) is the first of the three, or $x_1$. Call the time for which the interpolation is made, $T_1 + t$. It will be easily seen that the formula for $x$ now is,

$$x_1 + \left\{ \Delta'(1) - \frac{1}{2}\Delta(2) \right\} \times t + \frac{1}{2}\Delta(2) \times t^2.$$

As $t$ is the measure of the interval by which the time for interpolation follows $T_1$, $t$ is always positive, and therefore in this formula the coefficients depending on the time are always positive.

Secondly; the tabular quantities $x_2$, $x_3$, before further use is made of them, are increased by constants which will in all cases make the first difference and the second difference positive. Thus the numbers whose differences we actually take are:—

| For Moon's R. A. | For Moon's N. P. D. |
|---|---|
| $x_1$ | $x_1$ |
| $x_2 + 40^s$ | $x_2 + 20'$ |
| $x_3 + 90^s$ | $x_3 + 41'$ |

| For Moon's Parallax and Semidiameter. |
|---|
| $x$ |
| $x_2 + 40''$ |
| $x_3 + 90''$ |

Then every operation of forming differences is a numerical subtraction of an upper number from a lower, every number so formed is positive, every number to be substituted in the last formula of interpolation is positive, and every operation of connexion of results is a numerical addition.

But, in this process, we have introduced into our final sum a quantity which depends upon our additive numbers (40 and 90, or 20 and 41), which quantity must now be subtracted. Taking the differences of these,

| | | | | | | |
|---|---|---|---|---|---|---|
| 0 | | | | 0 | | |
| | 40 | | | | 20 | |
| 40 | | 10 | or | 20 | | 1 |
| | 50 | | | | 21 | |
| 90 | | | | 41 | | |

it will be seen that we have introduced the quantity,

$$0 + 35 \times t + 5 \times t^2 \quad \text{or} \quad 0 + \frac{39}{2} \times t + \frac{1}{2} \times t^2.$$

Tables of these quantities (called Table $T^*$ and Table $T^{**}$) are computed with the argument $t$; and from these tables $T^*$ or $T^{**}$ is taken (according to the series of additive constants which has been used), and is applied, in all cases subtractively, to the number produced by the interpolation-formula.

Great numbers of errors produced by changes of sign are avoided by this method of interpolation.

It will be remarked that, for computing the Moon's R.A., in which $\Delta'$ (1) and $\Delta''$ (1) are always positive, there is no theoretical necessity for making any addition to $x_2$. The same additions, however, are made for the Moon's R.A. as for other elements, because the trouble of doing so is inconsiderable, and it dispenses with the necessity of a special table for the Moon's R.A.

The *ninth* column contains the correction to the Moon's N.P.D., necessary for referring her place to the point of the Earth's axis at which the normal drawn from Greenwich meets the axis. It is thus investigated: Let $a$ and $b$ be the semi-major and semi-minor axes of the terrestrial ellipse, in the proportion of 300 to 299; $x$ and $y$ the co-ordinates parallel to them, their equation being $\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$; then the subnormal upon the minor axis $= -x\frac{dx}{dy}=\frac{a^2}{b^2}y$, and the part of this included between the origin of co-ordinates and the foot of the normal, is $\frac{a^2-b^2}{b^2}y$. To find $y$, we remark that the tangent of the astronomical latitude of Greenwich, or tan $l$, $=-\frac{dx}{dy}=\frac{a^2}{b^2}\cdot\frac{y}{x}=\frac{a}{b}\cdot\frac{y}{\sqrt{(b^2-y^2)}}$; whence $y=\frac{b^2}{\sqrt{\{b^2+a^2\cot^2 l\}}}$; and the distance from the center of the spheroid to the foot of the normal, measured along the Earth's axis, is $\frac{a^2-b^2}{\sqrt{\{b^2+a^2\cot^2 l\}}}$; or, in parts of the semi-major axis, it is $\frac{a^2-b^2}{a\sqrt{\{b^2+a^2\cot^2 l\}}}$. The logarithm of this quantity is 7·7174788. Now if, from the Earth's center, we draw a perpendicular to the Moon's radius vector reaching the line drawn from the Moon to the foot of the normal, the length of that perpendicular will sensibly be, $a \times [7{\cdot}7174788] \times$ sin Moon's N.P.D.; the angle which it subtends as seen from the Moon will be $\frac{a}{\text{Moon's distance}}$ $\times$ [7·7174788] $\times$ sin Moon's N.P.D. = [7·7174788] $\times$ sin Moon's hor. equat. parallax $\times$ sin Moon's N.P.D.; and the value of this in seconds of arc will be [3·0319039] $\times$ sin Moon's hor. eq. par. $\times$ sin Moon's N.P.D.; or [7·7174788] $\times$ seconds of Moon's hor. eq. par. $\times$ sin Moon's N.P.D. In this manner the number in the ninth column has been computed. It is always subtractive.

The assumed colatitude 38°. 31′. 21″·89 is deduced from observations with the Transit-Circle, corrected by the quantity + 0″·29 for the difference of latitude of the positions of the two instruments as found by measurement on the plan of the Observatory before mentioned.

With the Hour Angle unaltered, and the N.P.D. altered (for the Moon) by the correction just described, and with the Colatitude 38°. 31′. 21″·89; the Tabular Azimuth in the *tenth* column of the left-hand page, and the Tabular Normal-centric

Zenith Distance in the *fifth* column of the right-hand page, are computed by the following formulæ:—

Log tan $\alpha$=log cos hour-angle + log tan Normal-centric N.P.D.
$\beta=\alpha-$colatitude.
Log tan zenithal angle=log sin $\alpha$+log tan hour-angle−log sin $\beta$.
Log cotan zen. dist.=log cotan $\beta$+log cos zenithal angle.

As a check upon the accuracy of a large part of this computation, the terms of the following equation are computed numerically:—

Log sin zenithal angle + log sin zen. dist. = log sin hour-angle + log sin N.P.D; and, if the numbers are not strictly equal, the computation is again examined.

The correction to Azimuth for Moon's Semidiameter, in the *first* column of the right-hand page, is thus computed. The semidiameter is interpolated with second differences from the Nautical Almanac, and then increased by 0″·49. (See page cxvi and also Introduction to Greenwich Observations, 1863, pages lxxxvii and lxxxviii.) There is then applied the correction required for the difference between the distance of the Moon from the foot of the normal and her distance from the Earth's center. The former distance is greater than the latter by $a \times$ [7·71748] $\times$ cos Moon's N.P.D., and therefore her angular semidiameter is diminished in the proportion of Moon's distance to Moon's distance $-a \times$ [7·71748] $\times$ cos Moon's N.P.D., or 1: 1−sin hor. eq. par. $\times$ [7·71748] $\times$ cos Moon's N.P.D.: or, using the mean parallax 57′, the proportion is 1: 1−[5·93708] $\times$ cos Moon's N.P.D. The correction required is taken out from a small table. The Correction to Azimuth is computed by the formula $\frac{\text{Corrected semidiameter}}{\text{Sine Normal-centric Zenith Distance}}$; the term depending on the difference between the sine of semidiameter and the arc being insensible.

By application of this correction to the Tabular Azimuth in the last column of the left-hand page, the Tabular Azimuth of Limb in the *second* column of the right-hand page is formed. This Azimuth is necessarily the same at the place of observation as at the foot of the normal, for which the computation has been made.

The seconds of Observed Azimuth in the *third* column are transcribed from the section of Azimuths: and the apparent error of Tabular Azimuth in the *fourth* column is formed by subtracting the Observed Azimuth from the Tabular Azimuth in the last column of the left-hand page (for a star), or from that in the second column of the right-hand page (for the Moon).

The computation of the *fifth* column has already been mentioned.

The Normal-centric Semidiameter for the Zenith Distances in the *sixth* column is interpolated from the Nautical Almanac, increased by 1″·01 (see page cxvi and also Introduction, 1863, as above), and corrected for reduction to the foot of the Normal.

o 2

The last correction is $- 930'' \times [5{\cdot}93708] \times \cos$ Moon's N.P.D., and is readily tabulated.

For computation of the Parallax; in the first place, the horizontal equatoreal parallax is interpolated from the Nautical Almanac without alteration. It is then necessary to deduce from this the parallax referred to the foot of the Normal (the Moon's center having been referred to that point): and for this purpose, first, the Equatoreal Horizontal Parallax must be corrected so as to make the Horizontal Parallax depend on the Normal-centric radius, and must therefore be multiplied by $\frac{\text{Normal-centric Radius of Greenwich}}{\text{Earth's semi-major axis}}$. Using the same notation as before, the factor is found to be $= \frac{l}{a \sin l} \cdot \frac{a^2}{b^2} y = \frac{a}{\sqrt{\{b^2 \sin^2 l + a^2 \cos^2 l\}}}$; the logarithm of which is 0·0008851. Secondly, it must be made to depend on the Moon's distance from the foot of the normal, and for this must therefore be multiplied by $1 - [5{\cdot}93708] \times \cos$ Moon's N. P. D. These two corrections are embodied in one logarithmic table with argument N. P. D., the number for 60° being 0·0008664, that for 90° being 0·0008851, and that for 120° being 0·0009037. By the addition of this logarithm to the logarithm of the seconds of parallax (corrected as above) which is interpolated from the Nautical Almanac with second differences, the logarithm in the *seventh* column is formed.

The parallax in the *eighth* column is computed by the formula, Normal-centric horizontal parallax $\times$ sine of observed zenith distance of limb + small correction. The observed zenith distance of limb is taken from the section of Zenith Distances. The small correction is the sum of two terms, namely, $-\frac{P^3}{6}\sin^2 1''$. sin. zen. dist. $\cos^2$. zen. dist. (which gives the correction for the error produced by using the parallax instead of its sine, $P$ being $= 3420'' =$ number of seconds in Moon's mean parallax), and sin. zen. dist. $\times$ Airy's correction as given in the section of Occultations. The table of corrections used is given in page cxxii.

By application of this parallax, the Tabular Apparent Zenith Distance of Limb in the *ninth* column is formed; the numbers in the *tenth* column are transcribed from the section of Zenith Distance; and the numbers in the *eleventh* are formed by subtracting those in the tenth from those in the ninth column.

§ 10. *Computation of Clock Errors and Instrumental Errors for the Observations with the Altazimuth; and of Errors of the Moon's Tabular R. A. and N. P. D.,* page [cxxxvii] to [clx].

In general, the times of the transits taken with the Altazimuth by means of the method of galvanic contact are those of the Sidereal Standard Clock, and no comparisons of clocks are necessary. The errors of the Sidereal Standard Clock are obtained for the time of each observation, and, after correction by $-0^{s}\cdot03$ for difference of longitude, and for personal equation, are applied to the registered times of transit, to form the sidereal time. When, however, through failure of the galvanic apparatus, it is necessary to observe by eye and ear, the comparisons of the Clock Hardy and the Clock (Graham 1) of the South Dome, used with the Altazimuth, are usually made by means of a solar chronometer, whose name is mentioned. The chronometer is brought close to each of the clocks; and the time of accurate coincidence of beats is noted; the chronometer-interval between the comparisons, which is expressed as an interval of Solar Time, is converted into an interval of Sidereal Time; and the sidereal time at the comparison with the transit-clock, being found by correcting the transit-clock-time for error and rate of the transit-clock, for personal equation, and also for difference of longitude, the sidereal time at the comparison with the South Dome Clock is found, and thus the Error of that Clock is ascertained. From the successive Errors, rates of the Clock are deduced; and the Errors applicable to the observations, and which are given in the sections of Azimuth and Zenith Distance, are computed.

The instrumental constants of correction in Azimuth are thus investigated:—Let $w$ be the correction to the computed tabular azimuth of a high star, depending upon the error in the star's assumed place: $w$ will be an exceedingly small quantity, and will not sensibly vary between the observations made in reversed positions of the instrument. Let $x$ be the constant of correction for error of collimation, taken with that sign which corresponds to the position of the instrument with Graduated Face Right; $y$ the level-indication corresponding to horizontal position of the Horizontal Axis; and $z$ the Zero of Azimuth. Also, let $O^r$ and $O^l$ be the Concluded Readings of Horizontal Circle from observations of a high star, with Face Right and Face Left; $C^r$ and $C^l$ the corresponding computed azimuths; $L^r$ and $L^l$ the level indications; $D^r$ and $D^l$ the zenith distances; and let $o^r$, $o^l$, $c^r$, $c^l$, $l^r$, $l^l$, $d^r$, $d^l$, be the similar quanities for a low star. Then the true azimuth of the high star deduced from observation, Face Right, is

$$O_r + x \,.\, \text{cosecant}\ D_r + (L_r - y) \,.\, \text{cotangent}\ D_r - z\,;$$

the computed azimuth corrected is

$$C^r + w\,;$$

hence this observation gives the equation

$$O_r + L_r \,.\, \text{cotan}\ D_r - C_r = -x \,.\, \text{cosec}\ D_r + y \,.\, \text{cotan}\ D_r + z + w.$$

The true azimuth determined from observation, Face Left, is

$$O_l - x \,.\, \text{cosecant}\ D_l - (L_l - y) \,.\, \text{cotangent}\ D_l - z\,;$$

and this observation therefore gives the equation,

$$O_l - L_l \,.\, \text{cotan}\ D_l - C_l = +x \,.\, \text{cosec}\ D_l - y \,.\, \text{cotan}\ D_l + z + w.$$

Subtracting the first equation from the second,

$$(O_l - L_l \,.\, \text{cotan}\, D_l - C_l) - (O_r + L_r \,.\, \text{cotan}\, D_r - C_r) = x \,.\, (\text{cosec}\, D_l + \text{cosec}\, D_r) - y \,.\, (\text{cotan}\, D_l + \text{cotan}\, D_r).$$

Or $$\frac{(O_l - L_l \,.\, \text{cotan}\, D_l - C_l) - (O_r + L_r \,.\, \text{cotan}\, D_r - C_r)}{\text{cotan}\, D_l + \text{cotan}\, D_r} = x \times \frac{\text{cosec}\, D_l + \text{cosec}\, D_r}{\text{cotan}\, D_l + \text{cotan}\, D_r} - y.$$

A similar treatment of the observations of the low star gives

$$\frac{(o_l - l_l \,.\, \text{cotan}\, d_l - c_l) - (o_r + l_r \,.\, \text{cotan}\, d_r - c_r)}{\text{cotan}\, d_l + \text{cotan}\, d_r} = x \times \frac{\text{cosec}\, d_l + \text{cosec}\, d_r}{\text{cotan}\, d_l + \text{cotan}\, d_r} - y.$$

Subtracting the former from the latter, $x$ is given by a simple equation.

It has been already stated that, in 1850, a Collimator or Reversed Telescope was mounted, admitting of accurate observation with the telescope of the Altazimuth, and requiring for its observation that the telescope be directed at an angle of 12°. 18′ below the horizon.

From 1875, May 20, the Collimator has been used in a horizontal position, and the determination of Collimation-error is thus made independently of the observation of a high star. In fact the Collimation-error is simply half the excess of the circle reading with Face Right over that with Face Left (with 180° added), and is unaffected by the level-indication.

The construction of the instrument gives us reason to believe that the error of collimation is probably less variable than any other instrumental constant; it is usual, however, to make a new determination of the value of this element at the end of every lunation, founded on the observations of that lunation.

Every set of four azimuths like those above will give a value of $y$; implying that, for that determination, the varying or slightly erroneous value of $x$, deduced from that individual combination, has been employed in the preliminary correction for collimation. But as, on account of the steadiness of collimation, it appears better to use a mean value of $x$ throughout, a fresh investigation of $y$ is afterwards made from every pair of observations. Thus, let $O_r'$, $O_l'$, be the concluded readings of horizontal circle corrected for the adopted error of collimation. Then the first equations are,

$$O_r' + L_r \,.\, \text{cotan}\, D_r - C_r = + y \,.\, \text{cotan}\, D_r + z + w \;,$$
$$O_l' - L \;.\, \text{cotan}\, D_l - C_l = - y \,.\, \text{cotan}\, D_l + z + w \;.$$

Whence $$\frac{(O_r' + L_r \,.\, \text{cotan}\, D_r - C_r) - (O_l' - L_l \,.\, \text{cotan}\, D_l - C_l)}{\text{cotan}\, D_r + \text{cotan}\, D_l} = y.$$

Any one star, or the collimator, suffices for this determination; a high star, however, is best; and high stars have been exclusively used throughout the year.

The number $y$, it is to be observed, corresponds strictly with the horizontal position of the Horizontal Axis of the Vertical Circle, and has no relation whatever to the Level-Zero corresponding to a vertical position of the Vertical Axis of Azimuthal

Rotation: except that, supposing the workmanship of the vertical pivots to be perfectly good, and the position of the horizontal axis in its Y's to be invariable, there ought to be a constant difference between them. The latter Level-Zero would be the mean of the level-indications in opposite positions of the instrument: and it would be found with sufficient accuracy for this purpose by taking the mean of the level-indications for positions used in successive observations of the same object (though the instrument was not exactly reversed). The following are the results of comparisons of these Level-Zeros since the erection of the Altazimuth. By inspection of these results, it will be seen that the relative difference between the two zeros had been steadily increasing, the pivot on the same side as the Graduated Face of the Vertical-Circle being too high. This difference may have arisen from a wear of one of the horizontal pivots, or in the bearing of a horizontal pivot, or in one of the vertical pivots. The inconvenience produced by large numerical corrections on account of this discordance became at length so great that an instrumental correction of the error was attempted in 1859, March, by filing away the surfaces of the Y of the pivot on the same side as the Graduated Face. In 1872, September, the instrument was dismounted for alteration of the Y bearings, and was again erected in 1873, January, but was not sufficiently adjusted for perpendicularity of the two axes of rotation. The discordance was reduced on 1873, April 23, by placing two pieces of paper under one of the Y's, and again on 1873, May 26, by adding another piece of paper.

EXCESS OF THE LEVEL INDICATION FOR HORIZONTAL POSITION OF THE AXIS OF THE VERTICAL CIRCLE ABOVE THE LEVEL INDICATION FOR VERTICAL POSITION OF THE AXIS OF REVOLUTION, SINCE THE ERECTION OF THE ALTAZIMUTH.

| Year. | Mean Excess. | Year. | Mean Excess. |
|---|---|---|---|
| | ″ | | ″ |
| 1848 | + 1·13 | 1863 | − 5·39 |
| 1849 | + 2·33 | 1864 | − 5·01 |
| 1850 | + 6·67 | 1865 | − 4·56 |
| 1851 | + 8·75 | 1866 | − 5·07 |
| 1852 | + 10·50 | 1867 | − 4·30 |
| 1853 | + 11·36 | 1868 | − 5·94 |
| 1854 | + 11·71 | 1869 | − 5·06 |
| 1855 | + 12·51 | 1870 | − 3·28 |
| 1856 | + 13·23 | 1871 | − 3·02 |
| 1857 | + 13·59 | 1872 | − 3·47 |
| 1858 | + 13·70 | 1873 Jan. 8 to Apr. 19 | + 38·52 |
| 1859 Jan. & Feb. | + 13·75 | 1873 Apr. 29 to May 19 | + 16·45 |
| 1859 Mar. to Dec. | − 4·23 | 1873 May 27 to Dec. 31 | − 2·26 |
| 1860 | − 4·91 | 1874 | − 1·96 |
| 1861 | − 5·48 | 1875 | − 0·94 |
| 1862 | − 6·24 | 1876 | + 0·25 |

The comparison of the Observed Circle-Reading for a star, corrected for Collimation and Level, with the computed Azimuth for the same star, gives the Zero of Azimuth. Since the time of the establishment of the instrument, this Zero has been subject to greater and more sudden variations than any other element of reduction; and great pains have been taken to discover the source of the instability. In the Introduction to the volume for 1850 will be found an investigation, based on the Theory of Probabilities, for determining the relative stability of the Azimuthal Circle and of the Collimator, and the Error due to the transmission of time from the Transit-Instrument, on the assumption that there is no movement of the ground which carries both the Circle and the Collimator. From this investigation it seemed to be established that the Azimuthal Circle was the most stable part of the instrument, that the fluctuations of the position of the Collimators were somewhat greater, but that the principal source of errors was in the comparison of the circle-reading with the azimuth computed from the time-observation; and, in consequence, it became the practice to rely solely on the stability of the Azimuthal Circle, and, for a limited period, to use the same Zero of Azimuth, determined from the mean of all the separate determinations from star-observations on every day during that period, without special reference to the star-observations of the day of observation. In later years, however, the propriety of this proceeding has become questionable from two considerations; the first of which is that, since the introduction of the galvanic registration of transits, in which one source of error arising from the comparison of clocks is completely removed, the stability of the Zero of Azimuth does not seem at all to have improved; and the second, that there is now great reason to doubt the immobility of the ground carrying the Collimator and the Circle. From an investigation of the changes of azimuth of the Transit-Circle, it seems certain that the ground carrying that instrument is subject to frequent and sudden shifts; and a somewhat similar investigation made for the Altazimuth seems to prove instability of the ground on which it stands. In both instances, the changes appear to be connected with sudden changes of atmospheric temperature. Under these circumstances it has been thought best to use, for each day's observations, the Zero of Azimuth determined by the star-observations of that day, whenever the changes appear greater than would warrant the combination with other days.

In order to obtain a better determination of the Zero of Azimuth, the practice was commenced, in the latter part of 1871, of observing a low star as well as a high star, when practicable.

Since the alteration in the position of the Collimator on 1875, May 20, the observation of the low star has been used solely for determination of Zero of Azimuth, the collimator being observed regularly for Collimation Error.

In the Zenith Distances, the only instrumental constant deduced from observation is the Zenith Point (including so much of the level-indication as corresponds to a vertical position of the axis of azimuthal rotation). In two successive observations of the same star, Face Right and Face Left, let $O_r$ and $O_l$ be the observed circle-readings of the vertical circle corrected for level; $C_r$ and $C_l$ the computed Zenith Distances; $e$ the possible error, which will be sensibly the same for both; $Z$ the Zenith Point. Then we have

$$O_r - Z = \text{true Zenith Distance with Face Right} = C_r + e$$
$$Z - O_l = \text{true Zenith Distance with Face Left} = C_l + e$$

Subtracting the first from the second,

$$2\,Z - (O_r + O_l) = C_l - C_r\,,$$
$$Z = \frac{(O_r + O_l) - (C_r - C_l)}{2}$$

When, instead of a star, the Collimator is used, $C_r$ and $C_l$ are necessarily equal, and the formula is simply,

$$Z = \frac{Or + O_l}{2}.$$

The only point which it is now necessary to explain is the method of investigating the Errors of the Moon's Tabular Place in Right Ascension and North Polar Distance. The following method is based upon the assumption that, although the Moon's positions in respect of the meridian and horizon of Greenwich are very different at the different observations made in the same evening, and although the Errors of Tabular Azimuth and the Errors of Tabular Zenith Distance will vary much in the course of an evening, yet the Moon's North Polar Distance will not vary much, and the Errors of Tabular Right Ascension and Tabular North Polar Distance may be assumed to be invariable. It is also necessary to take into account, in arranging the form of calculation, that the Error of Tabular Azimuth and the Error of Tabular Zenith Distance are never observed at the same time.

Let $\delta\,.\,R.A.$, $\delta\,.\,N.P.D.$, $\delta\,.\,A.$, $\delta\,.\,Z$, be the Errors of Tabular Right Ascension (expressed in arc), North Polar Distance, Azimuth, and Zenith Distance, in any observation: and (supposing the Moon to be west of the meridian) let $S$ be the angle at the Moon made by the great circles drawn to the Pole and to the Zenith. Then we have,

$$\delta.Z = -\sin S\,.\,\sin N.P.D. \times \delta.\,R.A. + \cos S \times \delta.\,N.P.D.\;,$$
$$\delta.A = -\frac{\cos S}{\sin Z}.\sin N.P.D. \times \delta.\,R.A. - \frac{\sin S}{\sin Z} \times \delta.\,N.P.D.\;.$$

Let $\sin S = p$, $\cos S = q$, $\frac{\cos S}{\sin Z} = r$, $\frac{\sin S}{\sin Z} = s$; then

$$\delta.\,Z = -p\,.\,\sin N.P.D. \times \delta.\,R.A. + q \times \delta.\,N.P.D.\;,$$
$$\delta.\,A = -r\,.\,\sin N.P.D. \times \delta.\,R.A. - s \times \delta.\,N.P.D.\;.$$

and, taking the sum of a series of equations in each element, and observing that $p$, $q$, $r$, $s$, will vary considerably during the observations,

$$\Sigma(\delta.Z) = -\delta.\ R.A. \times \sin N.P.D. \times \Sigma(p) + \delta.\ N.P.D. \times \Sigma(q),$$
$$\Sigma(\delta.A) = -\delta.\ R.A. \times \sin N.P.D. \times \Sigma(r) - \delta.\ N.P.D. \times \Sigma(s).$$

By solution of these equations,

$$\delta.R.A. = \frac{\Sigma(s).\Sigma(\delta.Z) + \Sigma(q).\Sigma(\delta.A)}{-\sin N.P.D..\{\Sigma(p).\Sigma(s) + \Sigma(q).\Sigma(r)\}},$$
$$\delta.N.P.D. = \frac{\Sigma(r).\Sigma(\delta.Z) - \Sigma(p).\Sigma(\delta.A)}{\Sigma(p).\Sigma(s) + \Sigma(q).\Sigma(r)}.$$

The expression for $\delta.\ R.A.$ must be divided by 15 to give the error of Tabular Right Ascension in seconds of time.

A table of double entry, appended to the Introduction to the *Greenwich Observations* of 1854, is prepared, from which the values of $p$, $q$, $r$, $s$, are taken out at sight, with arguments Hour Angle and North Polar Distance of the Moon; and then the calculation is made by means of these formulæ.

§ 11. *Catalogue of the Mean Places of Stars observed in the Year* 1876; *and New Constants for Stars in the Catalogue, not observed in preceding years;* page 1 to 26.

The right ascensions in the catalogue are the means of all the separate determinations of the mean right ascension of each star, excluding only those which are contained in brackets. For the Nautical Almanac Stars, the annual variations in right ascension are taken from the Nautical Almanac. For all other stars, the geometrical precessions are computed independently, with the elements given by Professor C. A. F. Peters in the *Numerus Constans Nutationis:* the annual variations in right ascension set down are the precessions thus computed, affected with proper motions derived in the order of preference from Mr. Main's or Mr. Stone's papers in the *Mem. R. Ast. Soc.*, or from the *British Association Catalogue.*

The North Polar Distances in the catalogue are the means of the daily results, affected with the corrections for flexure and errors of division of the Transit-Circle, and for discordance of direct and reflexion results, as has been previously explained. The adopted seconds of N.P.D. are found by taking the means of the groups of direct and reflexion observations, giving to each a weight proportional to its number of observations. With regard to circumpolar stars, these rules have been followed:—For stars whose N.P.D. does not exceed 15°, the observations above and below the pole are considered equally good; from N.P.D. 15° to N.P.D. 36°, those below have the weight $\frac{2}{3}$ for each observation; from N.P.D. 36° to N.P.D. 41°, those below have the weight $\frac{1}{2}$: beyond 41° N.P.D., the observations are not combined. The annual variations in North Polar Distance are formed in the same manner as the annual variations in right ascension, above.

The nomenclature of the stars is identical with that described at page xxxiv.

The new star-constants require no further explanation than what is given at pages lxii and lxxviii. They are printed for the sake of enabling any person, using the *Greenwich Observations*, to employ the same method of reduction for all the stars found in those volumes.

§ 12. *Horizontal and Vertical Diameters, Right Ascensions, and North Polar Distances of the Sun, Moon, and Planets; deduced from the Observations, and compared with the Nautical Almanac and other Ephemerides: with the inferred Position of the Ecliptic, the Geocentric Errors of the Sun, Moon, and Planets, in Longitude and Ecliptic Polar Distance, and the Equations between the Geocentric Errors of the Planets and the Heliocentric Errors of the Earth and Planets,* page 27 to 63.

The duration of the passage of the Sun's diameter is found by subtracting the clock-time of transit of the first limb from that of the second limb in the *Transits observed*, &c., without any further correction. The tabular duration is found by doubling the time of the passage of the semidiameter given in the Nautical Almanac. The excess of the latter above the former is set down as the apparent error of the Nautical Almanac. The mean of 99 measures of the value of this error is $+0^{s}\cdot11$, agreeing nearly with the results of preceding years.

The Sun's vertical diameter is found by subtracting the zenith-distance of the north limb, corrected for refraction and parallax, from that of the south limb, similarly corrected. The tabular diameter is found by doubling the semidiameter of the Nautical Almanac. The excess of the latter above the former is set down as the error of the Nautical Almanac, and the mean of 96 measures of the value of this error is $+1''\cdot03$.

For the duration of the passage of the Moon's diameter, a correction is necessary (negative to the time of passage of the first limb, or positive to that of the second limb, accordingly as the Moon had passed or had not passed the opposition in right ascension), thus investigated:—The excess or defect of the difference of R.A. of the Sun and Moon from $12^{h}$, at the time of the Moon's transit, being found, and expressed in arc, this quantity is multiplied by the cosine of the Sun's declination, and thus an arc $\theta$ is obtained which represents the angle, upon the Moon's surface, of the

p 2

unenlightened part of the disk (with respect to right ascension); the correction required is, duration of passage of semidiameter × versed sine $\theta$. The mean of four determinations of the error of the Moon's tabular duration of passage in 1876 is $+0^s{\cdot}17$.

The Moon's vertical diameter is found in the same manner as that of the Sun (the correction for defective illumination having been already applied, see page lxxiv). The mean of three determinations of the error of the Moon's tabular vertical diameter made in 1876 is $-3''{\cdot}62$.

From a comparison of the observed vertical diameters with the tabular diameters of the Moon, made from the erection of the Transit-Circle, to the end of 1863 (see 1863, Introduction, page lxxxvii) it appears that Hansen's semidiameter requires to be increased by $+0''{\cdot}18$, in order to represent the observations of diameter made with the Transit-Circle.

From a similar comparison of the observations made with the Altazimuth, from 1848 to 1863, (Introduction, 1863, pages lxxxvii and lxxxviii), it appears that the required corrections to the Nautical Almanac semidiameters (Hansen's) are,—

$+\ 0''{\cdot}49$ for azimuthal observations.
$+\ 1''{\cdot}01$ for zenithal observations.

For the planets, the duration of passage of diameter is found by subtracting the clock-time of transit of the first limb from that of the second limb in the *Transits observed:* no correction for defect of illumination having been necessary, except for Mars, for which the amount of correction is stated in the notes.

The vertical diameters of Mercury, Venus and Mars are found by subtracting the N.P.D. of the north limb from that of the south limb, after the correction for defective illumination has been applied, as explained at page lxxiv. The vertical diameters of the other planets are obtained in a similar way, excepting that there is no correction for defective illumination.

The Mean Solar Time is found, in all cases, from the Right Ascension or Sidereal Time, by adding together the Mean Solar Time at the transit of the first point of Aries next preceding, and the equivalents in Mean Solar Time for the hours, minutes, and seconds of Sidereal Time: the whole of these numbers being taken from the Nautical Almanac. In practice, this operation is made a little easier by putting the addition in the following form:—

1. Sidereal Time.
2. Mean Solar Time of preceding Transit of first point of Aries diminished by $4^m$.
3. $3^m.\ 47^s{\cdot}00$ — hours of Sid. Time + solar equiv. for hours.
4. $10^s{\cdot}00$ — minutes of Sid. Time + solar equiv. for minutes.
5. $3^s{\cdot}00$ — seconds of Sid. Time + solar equiv. for seconds.

Small tables of the 3rd, 4th, and 5th quantities are prepared (see Appendix to Observations, 1837, Table No. IV.), and the operation is then very simple, consisting entirely of addition, with few figures, and no interpolation.

In the year 1876 there are very few instances in which only one element of the Sun or a planet has been observed. In any case where the North Polar Distance has been observed without the corresponding Right Ascension, the Right Ascension at Transit (for the calculation of the Mean Solar Time) is taken from the Nautical Almanac for the Sun and for Planets included in that work; and from other Ephemerides, for Planets not included in the Nautical Almanac; but in all cases as near an approximation as possible is made to the correct Right Ascension, by the application of corrections derived from neighbouring observations.

The Right Ascensions of the Sun's center are generally the means of those deduced from the observations of the two limbs; but, when one limb only has been observed, the R.A. of the center is deduced from that of the limb, by application of the duration of transit of semidiameter given in the Nautical Almanac, corrected by $-0^s{\cdot}04$. The Right Ascensions are transcribed from those in the *Transits observed* without alteration, except that, when necessary, the personal equation is applied, as mentioned in a former part of this Introduction (page lx).

The North Polar Distances of the Sun are taken from the Section of *North Polar Distances*, &c., the correction for discordance of direct and reflexion results being applied. The Tabular Right Ascensions and North Polar Distances are taken without correction from the Nautical Almanac.

The observed Right Ascensions of the Moon's Center are taken from the *Transits observed*, corrected, when necessary, for personal equation, and also for the Moon's motion in R.A. during the passage from the mean of wires to the true meridian. When both limbs of the Moon are observed, the correction for defective illumination (page cxv) is first applied to the proper limb, and the mean of the two is then taken without any farther alteration.

The Tabular Right Ascension of the Center of the Moon is found by applying to the Right Ascension of the limb (given in the section *Moon-culminating Stars* of the Nautical Almanac) the sidereal duration of passage of semidiameter, which is given in the same section of the Nautical Almanac.

The observed North Polar Distances of the Moon's Center are taken from the section of *Zenith Distances observed*, &c., corrected solely for the values of $\frac{1}{2}$ (R−D). The motion in N.P.D. during the passage from the mean of wires to the true meridian has been applied when it amounted to $0''{\cdot}05$.

The Tabular North Polar Distances of the Moon's Center are taken from the section *Moon-culminating Stars* of the Nautical Almanac.

For all the planets, the Right Ascensions are extracted from the twentieth column of *Transits observed*, &c., with no alteration, except for personal equation when necessary: the North Polar Distances are taken from the last column in the upper part of the page of the *Zenith Distances observed*, &c., corrected for the values of $\frac{1}{2}$ (R—D), as has been previously explained. The tabular places are taken from the Nautical Almanac, for such planets as are given in that work and its appendixes. For all others the tabular places are taken from the *Berliner Jahrbuch*, 1878, or its Circulars.

In this section will be found Observations of the Asteroids made at the Observatory of Paris. The results are distinguished by the letter P.

The investigation of the position of the Ecliptic is conducted in the same manner as in preceding Volumes from the year 1836. The mean of all the errors in each month, for R.A. and for N.P.D., is supposed to be the error for the day which is nearest to the mean of all the days of observation. When the same day is not found for R.A. and for N.P.D., an alteration of a unit or more has sometimes been made. From these, the error in the Ecliptic Polar Distance is obtained by means of the factors R and S in the tables forming the second part of the Appendix to the *Greenwich Observations*, 1836. Supposing these errors to arise from an erroneous position of the ecliptic assumed in the Nautical Almanac, they may be expressed by the formula $x \times \cos \odot$ longitude $+ y \times \sin \odot$ longitude $+ z$. For convenience, the weight attributed to each monthly equation is so altered that the sums of those in opposite quarters of the year are equal. The rest of the process needs no explanation.

For the *Mean Errors of the Tabular Geocentric Places of the Sun and Planets*, the observations have been collected into groups rarely exceeding a month in duration, and the mean of all the errors in each group, for R.A. and for N.P.D., is supposed to be the error for the day which is nearest to the mean of all the days of observation in the group, an alteration of a unit or more being sometimes made, in order to refer R.A. and N.P.D. to the same day. The Errors in longitude and E.P.D. are formed by the use of the numbers P, Q, R, S, in the Appendix to the *Greenwich Observations*, 1836. For any of the older small planets, whose latitude exceeds the limits of the Tables, the longitude and E.P.D. are computed, 1st, from the R.A. and N.P.D. of the Nautical Almanac; 2nd, from these quantities affected with the Errors in R.A. and N.P.D.; and the difference between these results gives the Errors in Longitude and E.P.D.

For the *Errors in the Tabular Heliocentric Places of the Planets*, the following formulæ are used.

For the small planets, Ceres, Pallas, Juno, and Vesta,

Let $R$ = radius vector of planet, $L$ = planet's heliocentric longitude,
$\Delta$ = planet's distance from Earth, $\lambda$ = planet's geocentric longitude,
$r$ = Earth's radius vector, $l$ = Earth's heliocentric longitude.

Then,

$$\text{Error of geoc. long.} = \frac{R \times \cos \text{hel. lat.} \times \cos(\lambda - L)}{\Delta \times \cos \text{geoc. lat.}} \times \text{error of hel. long.}$$

$$- \frac{\sin(\lambda - L)}{\Delta \times \cos \text{geoc. lat.} \times \sin 1''} \times \text{error of projection of planet's radius vector.}$$

$$\text{Error of Hel. E.P.D.} = \frac{\Delta \times \cos \text{hel. lat.}}{R \times \cos \text{geoc. lat.}} \times \text{error of geocent. E.P.D.}$$

$$- \sin \text{hel. lat.} \times \cos \text{hel. lat.} \times \tan(\lambda - L) \times \text{error of geocent. long.}$$

$$- \frac{r \times \tan \text{geoc. lat.} \times \cos(L - l)}{R^2 \cos(\lambda - L) \times \sin 1''} \times \text{error of projection of planet's radius vector.}$$

For the other planets, the following are used :—

$$\text{Error of geocent. long.} = \frac{R \times \cos(\lambda - L)}{\Delta} \times \text{error of planet's heliocentric longitude}$$

$$- \frac{\sin(\lambda - L)}{\Delta \times \sin 1''} \times \text{error of projection of planet's radius vector}$$

$$- \frac{r \times \cos(\lambda - l)}{\Delta} \times \text{error of Earth's heliocentric longitude}$$

$$+ \frac{\sin(\lambda - l)}{\Delta \times \sin 1''} \times \text{error of Earth's radius vector.}$$

$$\text{Error of Hel. E. P. D.} = \frac{\Delta}{R} \times \text{error of geocen. E. P. D.}$$

In the expressions above, different quantities are neglected for the small planets and for the other planets. For the small planets, the latitude cannot be neglected in any part of the expressions; while, at the same time, their errors in general are so large that, in comparison with them, the Earth may be supposed to move exactly in the orbit assigned by the tables. For the other planets, the latitude may be neglected in the formula; but it appears proper to retain the errors of the Earth's place, as probably comparable in magnitude to those of the planets.

It is to be remarked that, in the column of *Extent of Group*, the day is given which answers to that under which the observations may be found in the sections of *Transits observed*, and *Observations of Zenith Distance:* but in the column of *Mean Day*, the day is given whose noon is nearest to the time of observation, or to the mean of times of observation.

The errors of Tabular Longitude and Ecliptic Polar Distance of the Moon are deduced from the Errors of Tabular Right Ascension and North Polar Distance by the use of the numbers, P, Q, R, S, for all the meridian observations as well as for the observations made with the Altazimuth. For the Altazimuth, the Errors of Tabular R.A. and N.P.D. are extracted from the last section of computations of the observations made with that instrument.

§ 13. *Observations of γ Draconis, with the Reflex Zenith-Tube*, page 65 to 67.

The details of the general construction of this instrument are given in Appendix I. to the *Greenwich Observations* for 1854, and the means taken to prevent the communication of tremor to the mercury are described at page xxii of the present Introduction. For the understanding of the tabular arrangement containing the successive steps of the reduction of the observations, the following explanation will suffice.

The micrometer was originally furnished with thirty wires, and, by bringing each of these successively on the acute wire-cross of an adjustment-eyepiece which was rendered capable of being brought opposite to different wires in succession, the values of the intervals of the wires were very accurately determined, in terms of revolutions both of micrometer A and micrometer B. These intervals were afterwards measured by observing the time of transit of γ Draconis over each of the wires; and eight series of observations, nearly complete, were obtained between 1851, July 18 and August 15. By comparing then the number of revolutions of each micrometer corresponding to the interval between each pair of consecutive wires, with the time occupied by γ Draconis in passing from one wire to the other, the value of one revolution of each is obtained in terms of time; and this is readily reduced to arc by multiplying by 15 × the sine of star's N. P. D. To ensure, however, the utmost accuracy, the hour-angle of each of the extreme observed wires on the two sides of wire "15" was found by successive addition of observed intervals (in time) of all the intermediate wires, assuming wire "15" to represent the meridian with sufficient accuracy; and the angular distance of wire "15" from each of the extreme wires was computed from these hour-angles. The intervals, in terms of the micrometer, of all the intermediate wires, were also added together, so as to exhibit the micrometrical distance of wire "15" from each extreme wire. By this means it was found that, on one side of the wire, 156·017 revolutions of Micrometer B corresponded to an arc of 43′. 38″·48; and on the other side, 181·936 revolutions corresponded to an arc of 50′. 51″·71.

Hence, in the first case, the value of a revolution was

$$\frac{\sin 43'.\ 38''\cdot 48}{156\cdot 017 \times \sin 1''} = 16''\cdot 784$$

and in the other case the value was

$$\frac{\sin 50'.\ 51''\cdot 71}{181\cdot 936 \times \sin 1''} = 16''\cdot 775.$$

The mean of these, or 16″·78, has been used.

By obtaining the values of the intervals of several of the wires in terms of revolutions of micrometer A in a manner analogous to that explained above, and comparing them with the intervals obtained in terms of revolutions of micrometer B, it was found that 142·957 revolutions of B were equal to 142·986 revolutions of A. Hence the screws of A and B are assumed to have equal values, and one revolution of each is equal to 16″·78, as stated in the foot-notes to the Observations.

All the wires were found broken on 1876, March 14, and only the wires numbered "15" and "16" were replaced, these being the wires generally used for the bisection of the star. The interval in arc between these wires, as determined in 1876, May 6 and 9, is 3'. 37''·47. This value has been used throughout the year.

The correction due to the readings of the level-scale is determined from the following considerations:—When micrometer A is to the left—that is, south of the zenith—the micrometer readings increase as the wire moves to the left—that is, as the north zenith distance of the star increases; and, in this position, the readings of the level-scale increase from left to right, and therefore the level-indications will increase when the right or northern edge of the object-glass is raised.

Supposing this northern edge to be raised, the central ray of light for a zenithal star, descending through the focal center and reflected up through the focal center, meets the wire-frame (which is above the focal center) not at its zenithal point, but at a point which is north or to the right of the zenithal point.

Therefore the wire, when in that position it is laid upon the star, is more to the north or right than it ought to be; and therefore its micrometer-reading is smaller than it ought to be, and a positive correction is required: that is, for increasing readings of the level-scale the correction is positive.

The linear amount of the correction (omitting a constant depending on the zero of the level-scale) is {dist. from focal center to wire-frame} × {$\frac{1}{2}$ sum of readings of level-scale} × {value of one division of level-scale}.

The angular amount of the correction is this quantity divided by the focal length of the object-glass.

From statements made by the late Mr. William Simms, it is assumed that the focal center coincides sensibly with the upper surface of the object-glass, and therefore that the distance of plane of wires from focal center = $0^{\text{in}}{\cdot}25$; and that the value of one division of the level-scale is 6'' nearly. Also, the focal length of the object-glass, which is that of Troughton's transit instrument dismounted in the year 1851, is 116 inches.

With these data, the correction to zenith distance due to the readings of the level-scale is found to be 0''·00646 × sum of readings of the level-scale.

From these numbers, the numerical value of the sums of equivalents for micrometer-readings and for level-readings is computed by the formula given in the foot-notes to the Observations; and thus is obtained the zenithal distance of the star, as measured towards micrometer B, increased by an instrumental constant, which it is necessary to determine from the observations. This constant is usually determined by forming for each day the half-sum of the two sums of equivalents in the two reversed positions of the instrument, and by taking the arithmetical mean of those half-sums determined on different days. By subtracting this constant from the sum of equivalents when B is north, or by subtracting the sum of equivalents from this constant when B is south, the star's apparent north zenith distance is obtained; and by applying to this with reversed sign the correction for the reduction of apparent N.P.D. to mean N.P.D., the mean zenith distances north given in the last column but one of the tabular arrangement are found.

When the observation (as is usually the case) is made in both positions of the instrument, the mean of the results is given in the last column.

§ 14. *Eclipses, Occultations, and Transits of Jupiter's Satellites, compared with the Nautical Almanac; and Occultations of Stars by the Moon, with the Equations deduced from the Occultations*, page 69 to 75.

The clocks used in these observations are in general compared with the Sidereal Standard or with the clock Hardy near the time of the observation, and the mean solar time is computed in the usual way. Sid. S. signifies "the Sidereal Standard Clock"; A. 1 "Arnold 1"; G. 1 "Graham 1"; and A. 82 "Arnold 82", the regulated chronometer fixed on the eye-piece of the Great Equatoreal.

For the computation of the Occultations, the star's place is taken from the "Elements for facilitating the Computation of Occultations" in the Nautical Almanac. The Moon's geocentric place, semidiameter, and horizontal equatoreal parallax, are interpolated with second differences from the Nautical Almanac, and are used without alteration. The correction to be applied to the parallax of the Moon's center in order to obtain that for the point of the limb at which the occultation takes place, is derived from the following Table, for the principles of the formation of which I refer to preceding volumes, from 1843 to 1849 :—

**Correction to the Moon's Horizontal Parallax, to be used when the Parallax is applied to the Limb.**

| Angle from the Vertical as seen in an inverting Telescope. | | ZENITH DISTANCE. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 80° | 90° |
| ° 0 | ° 360 | +0·04″ | +0·06″ | +0·08″ | +0·10″ | +0·12″ | +0·13″ | +0·15″ | +0·16″ | +0·16″ | +0·16″ |
| 10 | 350 | +0·04 | +0·06 | +0·08 | +0·10 | +0·12 | +0·13 | +0·15 | +0·15 | +0·16 | +0·16 |
| 20 | 340 | +0·04 | +0·06 | +0·08 | +0·10 | +0·11 | +0·13 | +0·14 | +0·15 | +0·15 | +0·16 |
| 30 | 330 | +0·04 | +0·05 | +0·07 | +0·09 | +0·11 | +0·12 | +0·13 | +0·14 | +0·15 | +0·15 |
| 40 | 320 | +0·04 | +0·05 | +0·07 | +0·08 | +0·10 | +0·11 | +0·12 | +0·13 | +0·13 | +0·13 |
| 50 | 310 | +0·04 | +0·05 | +0·06 | +0·08 | +0·09 | +0·10 | +0·11 | +0·11 | +0·12 | +0·12 |
| 60 | 300 | +0·04 | +0·05 | +0·06 | +0·07 | +0·08 | +0·08 | +0·09 | +0·10 | +0·10 | +0·10 |
| 70 | 290 | +0·04 | +0·04 | +0·05 | +0·06 | +0·06 | +0·07 | +0·07 | +0·08 | +0·08 | +0·08 |
| 80 | 280 | +0·04 | +0·04 | +0·04 | +0·05 | +0·05 | +0·05 | +0·05 | +0·06 | +0·06 | +0·06 |
| 90 | 270 | +0·04 | +0·04 | +0·04 | +0·04 | +0·04 | +0·04 | +0·04 | +0·04 | +0·04 | +0·04 |
| 100 | 260 | +0·04 | +0·03 | +0·03 | +0·02 | +0·02 | +0·02 | +0·02 | +0·01 | +0·01 | +0·01 |
| 110 | 250 | +0·04 | +0·03 | +0·02 | +0·01 | +0·01 | 0·00 | 0·00 | −0·01 | −0·01 | −0·01 |
| 120 | 240 | +0·04 | +0·02 | +0·01 | 0·00 | −0·01 | −0·01 | −0·02 | −0·03 | −0·03 | −0·03 |
| 130 | 230 | +0·04 | +0·02 | +0·01 | −0·01 | −0·02 | −0·03 | −0·04 | −0·04 | −0·05 | −0·05 |
| 140 | 220 | +0·04 | +0·02 | 0·00 | −0·01 | −0·03 | −0·04 | −0·05 | −0·06 | −0·06 | −0·06 |
| 150 | 210 | +0·04 | +0·02 | 0·00 | −0·02 | −0·04 | −0·05 | −0·06 | −0·07 | −0·08 | −0·08 |
| 160 | 200 | +0·04 | +0·01 | −0·01 | −0·03 | −0·04 | −0·06 | −0·07 | −0·08 | −0·08 | −0·09 |
| 170 | 190 | +0·04 | +0·01 | −0·01 | −0·03 | −0·05 | −0·06 | −0·08 | −0·08 | −0·09 | −0·09 |
| 180 | 180 | +0·04 | +0·01 | −0·01 | −0·03 | −0·05 | −0·06 | −0·08 | −0·09 | −0·09 | −0·09 |

Let now $\delta$ and $\theta$ be the N. P. D. and hour-angle of the star, which are the same as the apparent N. P. D. and hour-angle of the point of the Moon's limb; $\delta'$ and $\theta'$ those of the corresponding point of the limb as seen from the Earth's center; $l$ the geocentric latitude of the place; and $P'$ the corrected horizontal parallax; then, by an investigation similar to that given in the Introductions to preceding volumes, from 1843 to 1849, it may be shown that

$$\sin(\theta - \theta') = \frac{\text{Radius of parallel for Greenwich}}{\text{Moon's distance from the Earth's axis}} \times \sin\theta.$$

$$\sin(\delta - \delta') = \frac{\sin l \,.\, \sin\delta \,.\, \sin\theta \,.\, \sin P'}{\sin\frac{1}{2}(\theta+\theta') \,.\, \cos\frac{1}{2}(\theta-\theta')} - \cot\tfrac{1}{2}(\theta+\theta') \,.\, \tan\tfrac{1}{2}(\theta-\theta') \,.\, \sin(\delta+\delta').$$

For the first step of the computation the following quantities are formed:—

$F$ = log. sin star's hour-angle + log. seconds of corrected eq. hor. parallax + 9·4942224.

$G$ = log. sin star's N. P. D. + log. sin star's hour-angle + log. seconds of corrected eq. hor. parallax + 9·8913935.

(The former numerical constant is the logarithm of half the distance of Greenwich from the Earth's axis, and the latter is the logarithm of the distance of Greenwich from the plane of the equator; supposing the Earth's ellipticity $= \frac{1}{300}$).

The preceding formulæ are then adapted to logarithmic computation, and the equations are solved by successive trials, assuming a value for $\delta'$, in the following manner:—

$$\text{log. } \tfrac{1}{2}(\theta - \theta') \text{ in seconds} = F - \text{log. sin } \delta' + \text{log. } \frac{\text{sine}}{\text{arc}} \text{ for hor. parallax} + \text{log. } \frac{\text{arc}}{\text{sine}} \text{ for } (\theta - \theta').$$

$$\text{log. 1}^{\text{st}} \text{ number} = G + \text{log. secant } \tfrac{1}{2}(\theta - \theta') + \text{log. } \frac{\text{sine}}{\text{arc}} \text{ for hor. parallax} + \text{log. } \frac{\text{arc}}{\text{sine}} \text{ for } (\delta - \delta') - \text{log. sine } \tfrac{1}{2}(\theta + \theta').$$

$$\text{log. 2}^{\text{nd}} \text{ number} = \text{log. } \tfrac{1}{2}(\theta - \theta') \text{ in seconds} + \text{log. } \frac{\tan}{\text{arc}} \text{ for } \tfrac{1}{2}(\theta - \theta') + \text{log. sin } (\delta + \delta' - 180^\circ) + \text{log. cot } \tfrac{1}{2}(\theta + \theta') + \text{log. } \frac{\text{arc}}{\text{sine}} \text{ for } (\delta - \delta').$$

$$\delta - \delta' = 1^{\text{st}} \text{ number} + 2^{\text{nd}} \text{ number}.$$

In the first trials, the log $\frac{\text{arc}}{\text{sine}}$, &c., are omitted. The convergence of these approximations is extremely rapid.

When $\delta'$ and $\theta'$ are found accurately, the distance of the corresponding point from the Moon's center is thus found, by means of a subsidiary angle $\psi$:—

If log. tan $\psi$ = log. diff. R.A. of Moon's center and corresponding point + $\frac{1}{2}$ log. sin N. P. D. of Moon's center + $\frac{1}{2}$ log. sin $\delta'$ — log. diff. N. P. D. of Moon's center and corresponding point;

Then log. dist. = log. diff. N. P. D. — log. cos $\psi$,

or = log. diff. R.A. + $\frac{1}{2}$ log. sin. N.P.D. of center + $\frac{1}{2}$ log. sin $\delta'$ — log. sin $\psi$.

q 2

The coefficients of small variations of the North Polar Distance and of the Difference of Right Ascension (in the expression for distance), are computed by the formulæ:—
log. 1st number = 2 log. diff. R.A. + log. sine (sum of N.P.D.) — log. dist. + 4·0835.
log. 2nd number = log. diff. N.P.D. — log. distance.
Coefficient of variation of greater N.P.D. = 1st number + 2nd number.
Coefficient of variation of smaller N.P.D. = 1st number — 2nd number.
Log. coefficient of variation of diff. R.A. =

log. diff. R.A. + log. sin $\delta'$ + log. sin Moon's N.P.D. — log. distance.

The variation of the R.A. of the corresponding point contains the following terms:—

1st. The alteration of the R.A. of the star by the quantity $e''$ will alter the R.A. of the corresponding point by very nearly the same quantity $e''$.

2nd. The alteration of the horizontal equatoreal parallax in the proportion of $1:1+\frac{m}{1000}$ will alter all the deduced parallaxes (in R.A. and in N.P.D.) in nearly the same proportion: and therefore the R.A. of the corresponding point will be altered by $\frac{m}{1000}\times$ correction for parallax in R.A.

3rd. The alteration in the position of the Moon with regard to the meridian, depending on the alteration of time $t^s$, will introduce an alteration in the correction for parallax. It is computed by the following formula:—

Alteration in correction of R.A. of corresponding point for parallax, depending on the alteration of time =

$$15''\times t\times\left\{\begin{array}{l}\sin P\,.\cos l\,.\ \text{cosec N.P.D.}\cos\text{hour-angle}\\ +\sin^2 P\,.\cos^2 l\,.\ \text{cosec}^2\ \text{N.P.D.}\cos 2\ \text{hour-angle}\end{array}\right\}.$$

The variation of the R.A. of the Moon's center is $x''+t\times$ change of R.A. in $1^s$.

The variation of the N.P.D. of the corresponding point contains three terms analogous to those for R.A.: namely—

1st. The alteration of the star's N.P.D. by the quantity $f''$ will alter the N.P.D. of the corresponding point by $f''$ nearly.

2nd. The correction for parallax in N.P.D. will be altered by $\frac{m}{1000}\times$ correction for parallax in N.P.D.

3rd. The increase of hour-angle (considered positive when the Moon is west of the meridian), depending on the alteration of time $t^s$, will alter the correction for parallax in N.P.D. by the following quantity:—

$$15''\times t\times\left\{\begin{array}{l}(-\sin P\,.\cos l\,.\cos\text{N.P.D.}-\sin^2 P\,.\sin l\,.\cos l\,.\cos 2\ \text{N.P.D.})\times\sin\\ \qquad\text{hour-angle.}\\ (-\tfrac{3}{2}\sin^2 P\,.\cos^2 l\,.\cot\text{N.P.D.}+\sin^2 P\,.\cos^2 l\,.\cot\text{N.P.D.}\cos^2\text{N.P.D.})\\ \qquad\times\sin 2\ \text{hour-angle.}\end{array}\right.$$

The variation of the N.P.D. of the Moon's center is $y''+t\times$ change of N.P.D. in $1^s$.

The computed distance, with addition of the sum of the products of the preceding variations by their proper coefficients, is made equal to the semidiameter increased by the term, semidiameter $\times\frac{n}{1000}$; and thus the final equation is formed.

The following table contains the values of log. $\left(\frac{\text{arc}}{\text{sin}}\right)$, log. $\left(\frac{\text{sin}}{\text{arc}}\right)$, and log. $\left(\frac{\text{tan}}{\text{arc}}\right)$ to the extent to which they are needed for these computations.

| ′ | Log. $\left(\frac{\text{Arc.}}{\text{Sin.}}\right)$ | Log. $\left(\frac{\text{Sin.}}{\text{Arc.}}\right)$ | ′ | Log. $\left(\frac{\text{Arc.}}{\text{Sin.}}\right)$ | Log. $\left(\frac{\text{Sin.}}{\text{Arc.}}\right)$ |
|---|---|---|---|---|---|
| 1 | 0·0000000 | 0·0000000 | 31 | 0·0000058 | 9·9999942 |
| 2 | 0·0000000 | 0·0000000 | 32 | 0·0000062 | 9·9999938 |
| 3 | 0·0000000 | 0·0000000 | 33 | 0·0000066 | 9·9999934 |
| 4 | 0·0000000 | 9·9999999 | 34 | 0·0000070 | 9·9999930 |
| 5 | 0·0000001 | 9·9999999 | 35 | 0·0000074 | 9·9999926 |
| 6 | 0·0000002 | 9·9999998 | 36 | 0·0000078 | 9·9999922 |
| 7 | 0·0000003 | 9·9999997 | 37 | 0·0000083 | 9·9999917 |
| 8 | 0·0000004 | 9·9999996 | 38 | 0·0000088 | 9·9999912 |
| 9 | 0·0000005 | 9·9999995 | 39 | 0·0000093 | 9·9999907 |
| 10 | 0·0000006 | 9·9999994 | 40 | 0·0000098 | 9·9999902 |
| 11 | 0·0000007 | 9·9999993 | 41 | 0·0000103 | 9·9999897 |
| 12 | 0·0000008 | 9·9999992 | 42 | 0·0000108 | 9·9999892 |
| 13 | 0·0000010 | 9·9999990 | 43 | 0·0000113 | 9·9999887 |
| 14 | 0·0000012 | 9·9999988 | 44 | 0·0000118 | 9·9999882 |
| 15 | 0·0000014 | 9·9999986 | 45 | 0·0000124 | 9·9999876 |
| 16 | 0·0000016 | 9·9999984 | 46 | 0·0000129 | 9·9999871 |
| 17 | 0·0000018 | 9·9999982 | 47 | 0·0000135 | 9·9999865 |
| 18 | 0·0000020 | 9·9999980 | 48 | 0·0000141 | 9·9999859 |
| 19 | 0·0000022 | 9·9999978 | 49 | 0·0000147 | 9·9999853 |
| 20 | 0·0000024 | 9·9999976 | 50 | 0·0000153 | 9·9999847 |
| 21 | 0·0000026 | 9 9999974 | 51 | 0·0000159 | 9·9999841 |
| 22 | 0·0000029 | 9·9999971 | 52 | 0·0000165 | 9·9999835 |
| 23 | 0·0000032 | 9·9999968 | 53 | 0·0000171 | 9·9999829 |
| 24 | 0·0000035 | 9·9999965 | 54 | 0·0000178 | 9·9999822 |
| 25 | 0·0000038 | 9·9999962 | 55 | 0·0000185 | 9·9999815 |
| 26 | 0·0000041 | 9·9999959 | 56 | 0·0000192 | 9·9999808 |
| 27 | 0·0000044 | 9·9999956 | 57 | 0·0000199 | 9·9999801 |
| 28 | 0·0000047 | 9·9999953 | 58 | 0·0000206 | 9·9999794 |
| 29 | 0·0000051 | 9·9999949 | 59 | 0·0000213 | 9·9999787 |
| 30 | 0·0000055 | 9·9999945 | 60 | 0·0000221 | 9·9999779 |

| ′ | Log. $\left(\frac{\text{Tan.}}{\text{Arc.}}\right)$ | ′ | Log. $\left(\frac{\text{Tan.}}{\text{Arc.}}\right)$ |
|---|---|---|---|
| 2 | 0·0000000 | 14 | 0·0000024 |
| 3 | 0·0000001 | 15 | 0·0000027 |
| 4 | 0·0000002 | 16 | 0·0000031 |
| 5 | 0·0000003 | 17 | 0·0000035 |
| 6 | 0·0000004 | 18 | 0·0000039 |
| 7 | 0·0000006 | 19 | 0·0000044 |
| 8 | 0·0000008 | 20 | 0·0000049 |
| 9 | 0·0000010 | 21 | 0·0000054 |
| 10 | 0·0000012 | 22 | 0·0000059 |
| 11 | 0·0000015 | 23 | 0·0000065 |
| 12 | 0·0000018 | 24 | 0·0000071 |
| 13 | 0·0000021 | 25 | 0·0000077 |

§ 15. *Spectroscopic Observations in the Year* 1876, page 77 to 122.

This section contains:—Position-Angles and Heights of Solar Prominences; Rotation of the Sun and of Jupiter deduced from the Relative Displacement of lines in the Spectrum at the east and west limbs respectively; Measures of Displacement of lines in the Spectra of Stars and Concluded Motions in the Line of Sight; Positions of dark lines and bands in the Spectra of $\alpha$ Orionis, Saturn, Neptune, Venus, $\beta$ Pegasi at minimum and maximum, and $\rho$ Persei at maximum; Measures of the position and breadth of the $H_\beta$ line in the Spectrum of Hydrogen at various pressures, in connexion with the Displacement of the F line in the Spectra of Stars.

The observations of Solar Prominences were usually made between 11 a.m. and 1 p.m. of the civil day given under the head Date. The Sun's image was always placed centrally with respect to the position-circle; an excentricity, either radial or tangential, being given to the Spectroscope, so that the slit swept round the Sun's limb.

The position-angles have been first corrected for index error of the position-circle, which is determined, as opportunity offers, with the slit in the radial position, being that which has been exclusively used in the measurement of position-angles. The method employed for this purpose has been to bring the edge of the spectrum corresponding to the Sun's limb on to the cross-wires, by means of the slow motion in N.P.D., the position-circle being set approximately to its zero, and then to displace the Spectroscope laterally, *i.e.*, in a direction perpendicular to the slit, and, having again brought the Sun's limb on the slit by the slow motion in R.A., to place the cross-wires on the edge of the spectrum by turning the Spectroscope. The reading of the position-circle will be the zero for position-angles. In this operation the observer, by watching the movement of the edge of the spectrum (in the direction of its breadth) as a slight motion in R.A. is given to the Equatoreal, can determine when the true N. or S. point of the Sun's limb is on the slit. The following determinations of the correction for zero of position-circle have been made:—

| | | | | | |
|---|---|---|---|---|---|
| | | ° ′ | | | ° ′ |
| 1875, July | 26 | − 0. 31 | 1876, June | 27 | − 4. 33 |
| July | 29 | 0. 24 | June | 28 | 4. 51·5 |
| July | 31 | 0. 0 | July | 14 | 3. 58·5 |
| August | 10 | 0. 34 | July | 14 | 5. 12·5 |
| September | 6 | 0. 8 | July | 14 | 5. 24 |
| 1876, April | 7 | 0. 19 | July | 14 | 5. 21 |
| May | 3 | 0. 28 | October | 9 | 6. 0 |
| May | 8 | − 0. 12 | October | 9 | 5. 38 |
| | | | 1877, April | 23 | 5. 42 |
| | | | April | 23 | 5. 34 |
| | | | April | 23 | 5. 40 |
| | | | April | 23 | 5. 27 |
| | | | April | 23 | 5. 30 |
| | | | April | 23 | 5. 7 |
| | | | June | 4 | 5. 43 |
| | | | June | 4 | 6. 15 |
| | | | June | 4 | 6. 13 |
| | | | June | 4 | 6. 15 |
| | | | June | 4 | 6. 16 |
| | | | June | 4 | 6. 27 |
| | | | July | 4 | 5. 32 |
| | | | July | 4 | 5. 55 |
| | | | July | 4 | 5. 44 |
| | | | July | 4 | 5. 45 |
| | | | July | 4 | − 5. 49 |
| Mean correction ..... | | − 0. 20 | Mean correction ..... | | − 5. 36 |

From the beginning of 1876, to May 16, a correction of −0°. 20′ has been applied to the readings of the position-circle, and from May 30 to the end of the year, a correction of −5°. 36′. Between 1876, May 16 and May 30, a change was made in the attachment of the position-circle to the Equatoreal.

The corrected Position-Angles have then been converted into Heliographic N.P.D. by applying as a correction the position-angle of the Sun's North Pole, taken from "Auxiliary Tables for determining the Angle of Position of the Sun's Axis, and the Latitude and Longitude of the Earth referred to the Sun's Equator," by Warren De La Rue, Esq.

The heights of the prominences were read off on a pearl scale, divided to 0·005 inch (corresponding to 5″), and carried by the micrometer of the Spectroscope. Some of the more remarkable prominences are represented on Plates I. and II. at the beginning of the Volume.

The measures of displacement of lines in the spectra of stars were made with a micrometer in the collimator-telescope (for dispersive powers of 2, 4, or 6 prisms), or in the separate viewing telescope (for dispersive powers of $\frac{1}{2}$, $1\frac{1}{2}$, or $2\frac{1}{2}$ prisms). Estimations of the displacement, in terms of the apparent breadth of the bright comparison-line, were also made; the breadth corresponding to any given width of slit being determined by a careful observation under similar conditions. $1^{\text{div.}}$ in the width of the slit corresponds to 0·0013 inch, or 1″·3. It has not been thought necessary to give in detail all these particulars of the reductions. The values used in each case may be inferred from the observed motion, which is the algebraic sum of the concluded motion and of the earth's motion. One tenth-metre corresponds at D to a motion of 31·4 miles per second, at *b* to a motion of 35·7 miles, and at F to a motion of 38·1 miles. The methods of comparison employed at various times are explained at p. xxiv of this Introduction.

Whenever the star-line was sufficiently distinct to allow of its being seen at the same time as the bright comparison-line, a direct comparison of the two was made; in other cases the bright line was compared with the pointer which had just previously been placed on the star-line, giving an indirect comparison.

The reading of the position-circle is given, as it is conceivable that the results might be affected by the position of the Spectroscope. The slit lies north and south, and the deviation is towards the east when the reading is 0°.

With regard to the other observations contained in this section, it is sufficient to remark that curves have been laid down in the usual manner, connecting scale or micrometer readings and wave-lengths, and that for each series of observations a correction for index-error has been deduced from observations of comparison-lines and applied to the observed readings, to reduce them to the standard curve, from which the corresponding wave-lengths have been read off. The tabular wave-lengths of comparison-lines have been taken from Watts's Index of Spectra, and are inclosed in brackets, to distinguish them from the results of observation. In the experiments on the spectrum of Hydrogen, a vacuum tube was used in connexion with a Sprengel pump of the form devised by W. Crookes, Esq.

§ 16. *Measures of Positions and Areas of Spots and Faculæ upon the Sun's Disk on Photographs taken with the Photoheliograph in the year* 1876, page 123 to 133.

The photographs from which these measures were made, were taken with the Photoheliograph returned from the Transit of Venus Expedition to New Zealand. In the process adopted regularly in 1876 iodized Cadmium collodion has been used in connexion with the pyrogallic acid development.

The *first* column on each page contains the Mean Solar Time at which each photograph was taken, expressed in days of the year and decimals of a day, and also by the day of the month (civil reckoning), which latter is placed opposite the total area of Spots and Faculæ for the day.

The *second* column gives the No. of the group, and the letter for the individual spot in the case of extensive groups, where several spots have been measured separately. The groups are numbered in the order of their appearance at the east limb.

The *next two* columns give the distance from center in terms of the Sun's Radius, and the Position-Angle from the Sun's Axis, reckoned from the Sun's North Pole in the direction *n, f, s, p*, both results being corrected for the effects of instrumental distortion and astronomical refraction.

The measures were made with a large Position-micrometer, specially constructed by Mr. Simms. The photograph is held with the collodion-side uppermost, on two cross-slides, which give the means of accurately centering it on the large position-circle, which rotates with it. A positive eye-piece, having at its focus a glass diaphragm, ruled into squares, with sides of one-hundredth of an inch, is carried by a micrometer-screw diametrically across the photograph, the diaphragm being nearly in contact with the photographic film, so that parallax is avoided.

The following is the process of measurement of a photograph:—

By means of the cross-slides mounted on the position-circle, the image of the Sun is centered as accurately as possible by rotation. The position-circle is then set to the readings 0°, 90°, 180°, and 270° in succession, and the micrometer-readings taken for the two limbs. The mean difference of the two sets is taken as the Sun's mean diameter on the photograph and the mean of the half-sum as the reading for the Sun's center. At the principal focus of the photoheliograph are two cross-wires

It has been considered advisable to defer the Measures of Photographs in the year 1876, referred to in Section 16 of the Introduction, to the volume for 1877, where they will appear in due sequence with the Photographic Results for the years 1874 to 1877.

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(spider-lines) which in connexion with a position-circle on the photoheliograph serve to determine the zero of position-angles on the photograph.

The following determinations of the reading for zero have been made in the year 1876 by running a spot or the Sun's limb along the two wires respectively, by use of the R.A. slow motion alternately backwards and forwards. Each determination is the mean of six readings.

| Date, 1876. | | Reading of Position Circle. | |
|---|---|---|---|
| | | Wire *a*. | Wire *b*. |
| | | ° ′ | ° ′ |
| January | 5 | 353. 8 | 82. 41 |
| January | 18 | 353. 7 | 82. 38 |
| January | 31 | 353. 3 | 82. 41 |
| February | 22 | 359. 49 | 89. 43 |
| June | 26 | 179. 42 | .. |
| July | 12 | 359. 43 | 269. 32 |
| August | 2 | 359. 12 | 269. 10 |
| August | 17 | 358. 1 | 268. 1 |
| September | 1 | 358. 5 | 268. 6 |
| September | 5 | 358. 3 | 87. 56·5 |
| September | 22 | 358. 39 | 88. 28 |
| October | 19 | 358. 42 | .. |
| October | 19 | 355. 40 | 85. 8 |
| November | 14 | 355. 21 | 85. 18 |
| December | 6 | 355. 48 | 85. 43 |

February 10. Wires broken.

July 27. Inclination of wires altered.

August 17. Inclination of wires altered.

September 22. The camera was moved in its collar during the operation of taking the zero.

October 19. Inclination of wires altered between the two determinations of the zero.

December 6. The camera was moved in its collar during the operation of taking the zero.

The position-circle of the photoheliograph has usually been set to some convenient reading near that for zero, and a correction for zero of position of the photoheliograph for the mean of the two wires has been applied to the zero of the position-circle of the micrometer. This latter has been determined from the readings of the position-circle for the four extremities of the two wires. The resulting combined correction is applied to all position-circle readings for Spots and Faculæ, giving Position-Angles, and the difference between the micrometer-readings for Spots and Faculæ and the centre-reading gives uncorrected distance from Sun's centre. Two sets of measures of the Sun's limb and of Spots and Faculæ on each photograph, were taken respectively by Mr. Baker and Mr. Bell, computers in the Physical Department, and the mean of the two sets was adopted. In case of discordance the photograph was measured again by Mr. Maunder. Corrections are then applied for optical distortion of the photoheliograph and for refraction.

The distortion has been determined from measures of photographs of a scale of equal parts, 16 feet long, constructed by Mr. De La Rue, and lent by him for this purpose. The scale has eight plates of iron with edges carefully planed, the plates being each exactly one foot in breadth, and attached to a braced iron framework so as to leave equidistant spaces of exactly one foot between the plates. The scale was photographed at a distance of about 1200 feet, and extended completely across the field of view.

The following table gives the distortion thus determined for every tenth of an inch distance from the centre of the field:—

| Distance from Centre. | Distortion. | Distance from Centre. | Distortion. | Distance from Centre. | Distortion. |
|---|---|---|---|---|---|
| r | r | r | r | r | r |
| 0 | 0·000 | 9 | + 0·035 | 18 | + 0·010 |
| 1 | + ·006 | 10 | + ·036 | 19 | + ·004 |
| 2 | + ·012 | 11 | + ·035 | 20 | − ·004 |
| 3 | + ·017 | 12 | + ·034 | 21 | − ·012 |
| 4 | + ·022 | 13 | + ·032 | 22 | − ·020 |
| 5 | + ·026 | 14 | + ·028 | 23 | − ·029 |
| 6 | + ·029 | 15 | + ·024 | 24 | − ·038 |
| 7 | + ·032 | 16 | + ·020 | 25 | − ·047 |
| 8 | + ·034 | 17 | + ·016 | 26 | − ·057 |

$1^{r} = 0^{in}{\cdot}10.$

The distances as measured have been corrected for the corresponding distortion, and in cases where the centre of the Sun's image did not fall very close to the centre of the plate, a correction has been applied to the position-angles for the resolved part of the distortion. No correction has been applied to the measure of Sun's radius on account of distortion, the scale adopted in forming the table having been so chosen that the distortion shall be 0 at $19^{r}{\cdot}5$ the average place of the Sun's limb on the photographic plate.

The correction for the effect of refraction has been thus found, the Sun's image being assumed to be sensibly an ellipse. The refraction being sensibly $c \tan z$ where $c = \sin 57''\cdot 5 = \frac{1}{3600}$ nearly, and $z$ is the apparent zenith distance, we shall have :—

$$\frac{\text{Vertical Diameter}}{\text{Horizontal Diameter}} = \frac{1 - c \sec^2 z}{1 - c} = 1 - c \tan^2 z ;$$

and thus the effect of refraction will be to diminish any vertical ordinate $y$ by the quantity $c \tan^2 z$. Resolving this along and perpendicular to the radius vector $r$, and putting $v$ for the position-angle of the vertex, we have for $\delta r$ and $\delta \theta$, the corrections to radius vector and position-angle for the effect of refraction :—

$$\delta r = + c \tan^2 z \times r \cos^2 (\theta - v) = + c \tan^2 z \times r \times \frac{1 + \cos 2 (\theta - v)}{2},$$

$$\delta \theta = - c \tan^2 z \sin (\theta - v) \cos (\theta - v) = - c \tan^2 z \frac{\sin 2 (\theta - v)}{2}.$$

The quantity $\delta r$ thus found is the correction, on the supposition that a horizontal diameter of the Sun is taken as the scale. But, as the mean of two diameters at right angles has been used, the scale itself requires the correction $\delta \mathrm{R} = + c \tan^2 z \times \mathrm{R} \times \frac{1}{2} \left\{ \frac{1 + \cos 2 (\theta_0 - v)}{2} + \frac{1 + \cos 2 (\theta_0 + 90^\circ - v)}{2} \right\} = + \frac{1}{2} c \mathrm{R} \tan^2 z$, where R is the Sun's mean radius and $\theta_0$, $\theta_0 + 90^\circ$ the position-angles of the two diameters measured. Thus the final correction to $r$ becomes

$$\delta r = + c \tan^2 z \times r \times \frac{\cos 2 (\theta - v)}{2}.$$

The quantities $c \tan^2 z - \frac{\sin 2 (\theta - v)}{2}$ and $\frac{\cos 2 (\theta - v)}{2}$ have been tabulated for use as follows, $c \tan^2 z$ being expressed in circular measure and in arc for application to distances and position-angles respectively :—

$c \tan^2 z$.

| $z$. | In Circular Measure. | In Arc. | $z$. | In Circular Measure. | In Arc. | $z$. | In Circular Measure. | In Arc. |
|---|---|---|---|---|---|---|---|---|
| ° | | ′ | ° | | ′ | ° | | ′ |
| 80 | ·0089 | 31 | 70 | ·0021 | 7 | 60 | ·0008 | 3 |
| 79 | ·0073 | 25 | 69 | ·0019 | 6½ | 58 | ·0007 | 2 |
| 78 | ·0061 | 21 | 68 | ·0017 | 6 | 56 | ·0006 | 2 |
| 77 | ·0052 | 18 | 67 | ·0015 | 5½ | 54 | ·0005 | 2 |
| 76 | ·0045 | 15 | 66 | ·0014 | 5 | 52 | ·0005 | 2 |
| 75 | ·0039 | 13 | 65 | ·0013 | 4½ | 50 | ·0004 | 1 |
| 74 | ·0034 | 11½ | 64 | ·0012 | 4 | 45 | ·0003 | 1 |
| 73 | ·0030 | 10 | 63 | ·0011 | 4 | 40 | ·0002 | 1 |
| 72 | ·0026 | 9 | 62 | ·0010 | 3 | 30 | ·0001 | 0 |
| 71 | ·0023 | 8 | 61 | ·0009 | 3 | | | |

### Factors for Refraction.

| $\theta-v$ | $\theta-v$ | $-\frac{\text{Sin } 2(\theta-v)}{2}$ | $\frac{\text{Cos } 2(\theta-v)}{2}$ | $\theta-v$ | $\theta-v$ | $-\frac{\text{Sin } 2(\theta-v)}{2}$ | $\frac{\text{Cos } 2(\theta-v)}{2}$ |
|---|---|---|---|---|---|---|---|
| ° | ° | | | ° | ° | | |
| 0 | 180 | ·00 | + ·50 | 95 | 275 | + ·09 | − ·49 |
| 5 | 185 | − ·09 | + ·49 | 100 | 280 | + ·17 | − ·47 |
| 10 | 190 | − ·17 | + ·47 | 105 | 285 | + ·25 | − ·43 |
| 15 | 195 | − ·25 | + ·43 | 110 | 290 | + ·32 | − ·38 |
| 20 | 200 | − ·32 | + ·38 | 115 | 295 | + ·38 | − ·32 |
| 25 | 205 | − ·38 | + ·32 | 120 | 300 | + ·43 | − ·25 |
| 30 | 210 | − ·43 | + ·25 | 125 | 305 | + ·47 | − ·17 |
| 35 | 215 | − ·47 | + ·17 | 130 | 310 | + ·49 | − ·09 |
| 40 | 220 | − ·49 | + ·09 | 135 | 315 | + ·50 | ·00 |
| 45 | 225 | − ·50 | ·00 | 140 | 320 | + ·49 | + ·09 |
| 50 | 230 | − ·49 | − ·09 | 145 | 325 | + ·47 | + ·17 |
| 55 | 235 | − ·47 | − ·17 | 150 | 330 | + ·43 | + ·25 |
| 60 | 240 | − ·43 | − ·25 | 155 | 335 | + ·38 | + ·32 |
| 65 | 245 | − ·38 | − ·32 | 160 | 340 | + ·32 | + ·38 |
| 70 | 250 | − ·32 | − ·38 | 165 | 345 | + ·25 | + ·43 |
| 75 | 255 | − ·25 | − ·43 | 170 | 350 | + ·17 | + ·47 |
| 80 | 260 | − ·17 | − ·47 | 175 | 355 | + ·09 | + ·49 |
| 85 | 265 | − ·09 | − ·49 | 180 | 360 | ·00 | + ·50 |
| 90 | 270 | ·00 | − ·50 | | | | |

The position-angle of the Vertex $v$ was readily taken from a globe.

The distance from centre in terms of the Sun's radius given in the *third* column, is then readily found by dividing the measured distance $r_0$, as corrected for distortion and refraction, by the measured mean radius of the Sun R; and the Position-Angle from the Sun's Axis given in the *fourth* column is obtained by applying to the Corrected Position-Angle (from the N. point) the Position-Angle of the Sun's Axis derived from Warren De La Rue's Auxiliary Tables referred to in the preceding section.

The *fifth* and *sixth* columns give the Heliographic Longitude and Latitude computed by the formulæ $\sin(L - l) = \sin\chi \sin\rho \sec\lambda$; $\sin\lambda = \cos\rho \sin D + \sin\rho \cos D \cos\chi$, where L, $l$ are the Heliographic Longitudes from the ascending node, and D, $\lambda$ the Heliographic Latitudes of the Earth and the Spot or Facula respectively, referred to the Sun's Equator, $\rho$ the True Angular Distance from centre, and $\chi$ the Position-Angle from the Sun's Axis. The quantities L and D are derived from Warren De La Rue's Auxiliary Tables previously referred to, and log sin $\rho$ and log cos $\rho$ are taken from "Tables for the Reduction of Solar Observations, No. 2" by Warren De La Rue, Esq.

The Heliographic Longitude of the Spot or Facula is found from $l$, the Heliographic Longitude from Node by subtracting the Reduction to Prime Meridian, which is the longitude of the Node at the epoch of the photograph, referred to the assumed Prime Meridian, the latter being the meridian which passed through the ascending node at the epoch 1854·0. The period of rotation assumed is 25·38 days.

The measures of areas given in the *last three* columns were made with a glass diaphragm ruled into squares, with sides of one hundredth of an inch, and placed nearly in contact with the photographic film. The integral number of squares and parts of a square contained in the area of a spot or facula was estimated by the observer, one set of measures being taken by Mr. Maunder, and a second by his assistant Mr. Baker. The mean of the two sets of measures has been taken for each photograph, and then the means for all the photographs (usually two) taken on each day. The distance from the Sun's center for each spot and facula, and the radius of the Sun, were measured by means of concentric circles ruled on glass to each tenth of an inch, the position-micrometer not having been then brought into use; and from these quantities the factor for converting the areas, as measured in ten-thousandths of a square inch, into millionths of the Sun's visible hemisphere, allowing for the effect of foreshortening, has been inferred by means of a table of double entry, giving the equivalent of one square for different values of the Sun's radius, and for different distances of the spot or facula from the Sun's center.

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As a general remark, applying to every class of observation above mentioned, it is proper to state that the original entries of observations are in all cases preserved. The greater part of the regular observations with the Transit-Circle are entered in small memorandum books, in which the entries are made with a metallic pencil whose marks are not easily effaced; those with the Altazimuth are entered in printed skeleton forms arranged for the purpose: and some observations are written down at once with ink in the skeleton forms in which the calculations are to be made, or in the copy which is sent to the press. All, however, are preserved. The sheets punctured by the prickers of the galvanic magnets in registration of transits by the Chronographic method are also preserved. The proof sheets are read with the first skeleton forms in which the observations are entered; and in which, in fact, the examination for accidental errors, &c., is made.

G. B. AIRY.

1878, *July*