

# GREENWICH

## ASTRONOMICAL OBSERVATIONS,

### 1858.

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#### INTRODUCTION.

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

THROUGHOUT the year 1858, the establishment of Assistants in the Astronomical department of the Observatory consisted of the following persons:—The Rev. Robert Main, M.A., First Assistant; Mr. Edwin Dunkin, Mr. Hugh Breen, Mr. William Ellis, Mr. George Stickland Criswick, and Mr. William Thynne Lynn.

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

Mr. Main, 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, Mr. Main superintends the calculations generally, and observes, occasionally, with any of the instruments; principally, however, with those which are not employed in the daily routine of meridional observations. The observations made by Mr. Main are distinguished by the signature M.

Mr. Dunkin has the superintendence of the Altazimuth, which is specially devoted to extrameridional observations of the Moon, and has also during the year 1858 taken general charge of the Transit-Circle; all special observations relating to its adjustments, and to determinations of micrometer values of the intervals of the wires in the eye-piece of its telescope, of the errors of division of its circle, and of the flexure of the telescope, being performed by him. The observations with both these instruments have been generally made by Mr. Dunkin, Mr. Ellis, Mr. Criswick, and Mr. Lynn. The initials of these observers are D., E., C., and L. Mr. Breen has used the Transit-Circle in one or two instances only. His initials are H.B. Other persons who have occasionally observed with these instruments are:—Mr. James Carpenter, Mr. William Piper Wakelin, and Mr. Wyvill James Christy, all employed as computers in the establishment; their signatures are J.C., W., and W.C.

The management of the Galvanic Apparatus for the Chronographic Registry of Transits, the movement of sympathetic clocks, and the 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. Ellis and Mr. Criswick.

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With regard to the reduction of the observations; Mr. Breen is placed in immediate direction of the staff of supernumerary computers usually employed, and exercises a general supervision of all computations performed, and of the passing of the results through the press. Mr. Ellis attends chiefly to the reduction of the Transit-observations made with the Transit-Circle, and Mr. Lynn to that of the Zenith-Distance-observations, while Mr. Dunkin attends exclusively to the reduction of the Altazimuth-observations, and to the reading of the proof-sheets of those observations when printed.

The observations with the Equatorials are not distinctly appropriated to any special observers.

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 by the First Assistant, but only at the command of the Astronomer Royal.

The course of observations and the succession of observers are arranged every Monday 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<sup>h</sup> mean time (3 o'clock in the morning) to the next 15<sup>h</sup>; and 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<sup>h</sup>, 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<sup>h</sup>, and early in the morning when the Moon passes first after 15<sup>h</sup>.

For many particulars relating to the internal constitution of the Observatory, reference may be made to the "Regulations of the Royal Observatory" forming Appendix II. to the Greenwich Observations, 1852.

## 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; 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 dismantled 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 dismantled, and its tube was divided (at its joints) into several parts, in May 1848; and the separate portions of the instrument are preserved in frames constructed to hold them, in the Octagon Room. 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 Great Transit-Circle, constructed by Messrs. Ransomes and May, as engineers, and by Mr. Simms, as optician, and erected in the year 1850.

A detailed description of this instrument, illustrated by Plates, is given in Appendix I. of the volume for 1852. The following particulars may be given here. The center of the instrument is about  $7\frac{1}{2}$  feet South and 19 feet East of the old transit-instrument. The length of the telescope of this instrument 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. 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 very small hole, behind which a light can be placed for illumination; and in the hollow of the western pivot there is fixed an object-glass at a distance from the perforated plate equal to its focal length. This combination forms a collimator 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. By a series of most careful observations in the autumn of 1850, and again in 1851 and 1852, and a third time at the latter end of 1856, no appreciable error could be discovered in the form of the pivots. The wire frame contained originally (besides the horizontal wire, to be noticed shortly) seven vertical wires, 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.

For determining the error of collimation, two horizontal telescopes of about 5 feet focal length and nearly 4 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. Each telescope is furnished with wires in its principal focus, to be used as collimating marks; and each telescope may be used as a collimator 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  $2\frac{3}{4}^{\circ}$ , 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 the portion of the 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 Collimators accurately on each other, the plates carrying the wires are moveable by micrometer-screws: that of the North Collimator in altitude only, and that of the South Collimator in azimuth only. Each micrometer head, when not in use, is locked up in a box attached to the eyepiece. In order to view either collimator by the transit-circle-telescope, it is only necessary to direct the transit-circle-telescope towards that collimator; but in order to view one collimator with 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 Collimators, and of using them for determining the line of collimation of the Transit-Circle-Telescope, is then as follows:—

On Monday of each week, the transit-circle is raised, and, a proper illumination being given to the North Collimator, the eye is applied to the eyepiece of the South Collimator, and the systems of wires in both are distinctly seen: the nearly vertical wires of one being inclined about  $5\frac{1}{2}^{\circ}$  to those of the other. By means of the micrometer screw, the middle of the nearly vertical side of the square of one is made to coincide with that of the other, 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, passing 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 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 two collimators, the images of the adopted points of their wires will in all respects represent two objects at infinite distance and exactly opposed to each other.

The 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 nearly vertical fine wire of the North Collimator, and several times upon the corresponding point of the South Collimator, and reading the micrometer for each coincidence. The mean of the readings for the North and South Collimators 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-wires in the process of observation.

Tables of the weekly micrometer-readings of the South Collimator-wire for coincidence with North Collimator-wire, and of the daily readings of the Transit-Micrometer for coincidence with Collimators, are given at the end of the 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  $45^\circ$  with the axis of the eyepiece, and which is placed between the last lens and the wires of the telescope. A beam of light being thrown horizontally upon the reflector, and a trough of quick-silver 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-screws 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 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 a dished or flat internal conical surface, 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 reading microscopes, six in number, are simply inclined perforations through the western pier; having their eyepieces at the back of the western pier arranged in a circle whose center is 5 feet 2 inches above the floor, and diameter about 21 inches; and their object-glasses on the other or eastern side of the pier, arranged in a circle of about 5 feet in diameter, pointing to the divisions of the circle. The pointer-microscope is between the two lowest reading-microscopes, and is a similar inclined perforation through the pier: it has a large field of view, and is

furnished with a single wire parallel to the divisions of the limb at which it is pointed. The divisions under the microscopes are illuminated by means of a central gas-light in the central opening at the external surface of the western pier, which throws light upon the proper divisions through six illuminating holes corresponding to the six microscopes; and this light is reflected from the divided limb accurately into the microscopes without any need of illuminating-reflectors.

The circle is completely shielded from the Sun by the steps which are used by the observers for ascending to the upper part of the pier.

The eyepiece of the telescope contains only one horizontal wire, moveable by a micrometer, with which all observations of zenith-distance are made. For 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 micrometer is on the north side and the micrometer readings increase as the wire is moved towards the head.

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.

The shutters of the Transit-Circle-Room leave an opening of 3 feet in width. The north and south wall-shutters are each in one piece; the opening in the roof, along the ridge, 36 feet in length, is covered by four shutters.

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 proper 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 its average reading of twenty revolutions, the clamping circle is fastened. The transit 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 of the fourth vertical wire, if practicable. The telescope-micrometer and the six microscope-micrometers are then 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 directed to the reflected image some minutes previously to the transit 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 or at the passage of the first vertical wire, and reads

the telescope-micrometer. He then descends rapidly into the pit, unclamps the instrument, turns the telescope to the direct image and fastens the clamping circle, bisects the star at its passage over one of the vertical wires by means of the micrometer-screw, and completes the direct observation in the usual way by reading the microscope-micrometers.

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 assisted by one or more of the 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 in its mean position; 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 of the vertical wires (the No. of which is registered). The telescope-micrometer is then read by the observer, and the microscope-micrometers by the assistants, who in fact commenced to read the micrometers as soon as the instrument was clamped. The instrument is then unclamped, and the other limb (lower or upper) is placed on the wire, 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. 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. To give additional time for the reading of the microscope-micrometers, it has been the practice since the end of November 1856 to employ two persons to read them.

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 to be observed in Zenith Distance (upper or lower) is brought near to the middle of the field, the instrument is clamped, and the horizontal micrometer-wire is brought repeatedly upon the limb (upper or lower) at its passage over the seven original vertical wires at wide intervals, the micrometer being read after each contact of the wire with the limb. 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, and the microscope-micrometers are read previously to the passage. The telescope-micrometer is then read for the contact of the wire with 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 being taken, 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 limb are very nearly full at the opposition of

the Moon, another person is employed to read the 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 the year 1854 an apparatus was connected with the Transit-Circle for the purpose of registering transits according to the American or 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 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 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; its ends are cemented together; when it is filled by the register about to be described, it 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 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 transit-clock. For this purpose, the wires of its galvanic magnet (after passing through a galvanic battery) are led to the transit-clock, and the circuit is there completed at every second of time. At first this was done by an attachment on the clock-pendulum, which at every swing united two slender springs. This method answered, for a time, very well, but the changes in the distance of the springs from the pendulum-support (in consequence of a peculiarity in the mounting of this clock) ultimately deranged the clock-rate. The following method was then adopted, and it appears to answer well. Upon the escape-wheel-arbor, a wheel of 60 teeth is mounted; and, at every second, the start of a tooth of this wheel presses together two springs, during a very small fraction of a second. Thus a series of punctures is made upon the revolving barrel, one at every

second of the transit-clock. 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. The opportunity was taken of the Transit-Clock being removed for repair in the month of November 1856, to have one of the teeth in the wheel before mentioned cut away, so that once in each minute no contact of the two springs takes place. The omission of the corresponding puncture on the revolving barrel thus marks with certainty the commencement of each minute.

The other 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, where there is a nearly similar apparatus for completing circuit.

The Altazimuth, constructed by Messrs. Ransomes and May (as engineers), and by Mr. 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 32 feet South of the old Transit-Instrument, and about 47 feet West and  $24\frac{1}{2}$  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, upon 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 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

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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.

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.

It was intended, in the original plan of observations with this instrument, to determine the zero of azimuth of the horizontal circle, for each day or group of days, solely by the observations of stars in azimuth. The individual results obtained by this method were discordant, and I thought it desirable therefore in the spring of 1850 to establish a fixed mark of reference. No distant terrestrial object can be seen with the Altazimuth, and I therefore mounted (what is very much more convenient and more generally useful, especially at night,) a collimator. The object-glass for the collimator 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 Computing-Room. The iron frame is in fact higher than the ceiling of the Computing-Room ; but is 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, sur-

rounded 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  $12^{\circ}. 18'$  below the horizon.

By means of the branches of the galvanic wires going to the Altazimuth, the observations of transits can be registered on the same sheet of paper as those made with the Transit-Circle, in transit-clock-time; and thus all comparisons of clocks become unnecessary, and all errors arising from the transmission of time are avoided.

The wire-plate originally carried six horizontal and six vertical wires; 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.

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 its mounting (similar to that of the Palermo Circle) was 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  $35^{\circ}$ , and through a considerable horizontal extent to the altitude of  $53^{\circ}$ , 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 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,

at the present time, are so indistinct as to interfere very considerably with the use of the Instrument.

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 of the Dorpat Telescope. A stone pier is erected, whose extreme breadth from East to West is 1 foot 4 inches, and from North to South is 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 agate. 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<sup>m</sup> of time, and is read off to 2<sup>s</sup> 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 four 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  $10^\circ$ ) 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 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.

The Reflex Zenith-Tube, constructed under my direction by Mr. 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, revolving with the object-glass when the object-glass is turned. The moving frame of the micrometer A carries the resting-point of the micrometer-screw of the micrometer B. 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 (looking 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 carrying the remaining lenses of the eyepiece is supported by the large tube, and does not project over any part of the object-glass. At a distance below the object-glass, 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, for accuracy of result, no firmness of construction is requisite in this instrument, except in the connection between the micrometer and the object-glass.

Yet, though the instrument is thus theoretically perfect, the use of it was at first attended with a good deal of trouble, on account of the difficulty of providing a support for the mercury, which should be free from the communication of tremor. Its original situation near the entrance-gate of the Observatory rendered it very liable to disturbance, especially for observations made in the daytime. The instrument was, therefore, transferred, in November 1855, to 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. The mercury was now supported on a box of dry sand, resting on the ground. On planting a collimator vertically above the instrument, and viewing the wire of the collimator with the instrument, the tremor was found to be incessant and insufferably great. A well was then dug to various depths, finally to the depth of ten feet below the surface, or seven feet below the deepest foundation of the walls of the Observatory, and stages were erected from time to time for the support of the mercury-trough, always resting on the bottom of the well without touching the sides. The tremor was not at all diminished, and the surface was sensibly affected by the shutting of a door in any part of the Observatory, and even by the walking of a person within many yards. The well was then filled with incoherent rubbish, and a stage was placed upon it, and by this arrangement the tremor 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 mercury 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 any hour of the day or night, according to its time of passage.

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. Thus, if the equation to the pendulum's motion be  $\frac{d^2 x}{dt^2} = m^2 (y - x)$ , where  $m$  is small; and if  $y = a \cdot \cosine n t$ , where  $n$  is large, the corresponding term in  $x$  will be  $\frac{-m^2}{n^2 - m^2} \times a \cdot \cosine n t$ , 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 Equatorial 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. It is proper to mention that the object-glass of the 62-inch telescope mentioned in former years is now appropriated for the North Collimator to the Transit-Circle; and that of the transit-instrument formerly used as a collimator to Troughton's transit, is now fixed in the South Collimator. The other achromatic telescope, mentioned in former years, has been given to the Quebec Observatory.

Finally, there are two Newtonian reflecting telescopes, the largest being one of 10 feet, by Sir W. Herschel.

The Transit Clock, constructed by Hardy, and originally furnished with Hardy's escapement. A dead-beat escapement was substituted for this by Dent in the year 1829. The jewelled holes were removed by Dent in 1836, and the pivots now turn in brass holes. This clock was transferred from the Old Transit-Room to the Transit-Circle-Room in December 1850.

A clock in the North Dome, marked "Arnold 1;" one in the East Dome, marked "Earnshaw;" one in the South Dome (the place of the Altazimuth), marked "Graham 1;" one in the new 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 "Graham 2," at present placed in the Upper Record Room; one marked "Arnold 2," generally preserved in the passage that was formerly part of the Quadrant Room; and one marked "Graham 3," formerly used for the daily dropping of the Time-Signal-Ball at 1<sup>h</sup>, but now employed for facilitating the regulation of the galvanic motor clock. There is also 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. Besides these, there are some journeyman or assistant clocks now rarely used, and a watchman's clock.

The galvanic "motor clock" is placed in the lobby at the foot of the Octagon Room

staircase, near to the trigger of the ball-apparatus. By means of galvanic wires, this clock gives action to six sympathetic clocks, used for various purposes. Of these, one has a large dial exposed to public view on the east boundary wall of the Observatory; one is in the Chronometer-Room, and is used in the daily comparisons of Chronometers; one is in the Computing Room; one is in the hall of the Astronomer Royal's dwelling house; one is at the Royal Hospital Schools; and one is at the South-Eastern Railway Station, London Bridge, for automatic alteration of the galvanic contacts which determine the directions of the hourly galvanic signal-currents sent from the Royal Observatory. The motor clock also closes a circuit precisely at 1 o'clock, and by the intervention of electro-magnets releases automatically the detent which supports the trigger of the ball-apparatus, and thus drops the Signal-Ball; by nearly similar mechanism, it drops the Signal-Ball at Deal, and that in the Strand (the property of the Electric Telegraph Company); it regulates several clocks at the General Post Office; and it gives hourly galvanic signals, which are distributed on the principal lines of railway.

The Transit Clock, and the other ordinary clocks in daily use, are wound up every Monday.

### III. *Subjects of Observation in the Year 1858.*

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 rule has 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<sup>h</sup>, excepting at times when the Moon passes the meridian later than 15<sup>h</sup>. The small Planets have been observed only when the time of meridian passage is earlier than 15<sup>h</sup>. The observations of all Planets, excepting the Moon, 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). For this purpose the number of observations of each star made in the two preceding years is ascertained, and the additional number necessary to make up this to twenty is considered to be the number due from the present year. In far the greater number of instances this number is exceeded: in a few (especially of stars so near the pole that their transits are considered valueless unless Polaris or  $\epsilon$  Ursæ Minoris is observed above and below on the same day), the just number is not completed.

The other stars observed are principally . A list of stars whose right ascensions have been well determined, used, in connection with the Nautical Almanac Stars, for determining clock-error; Stars remaining from former years, including stars to complete previous catalogues; Moon-culminating Stars; Stars which have been occulted by the Moon; Stars observed with Comets; variable Stars discovered by Mr. Hind

or by other persons; Stars which pass near the North and South Horizon; Stars suspected to have or known to have large Proper Motions; Stars near the Pole used by Mr. Carrington for the determination of Azimuthal Errors; and Stars compared with Sirius; finally, Stars whose transits were observed at Greenwich and Edinburgh for the determination of the longitude of the Observatory of Edinburgh; and Stars observed with Mars at the opposition of 1858.

The Altazimuth has been used for observations of the Moon on every day when she could be seen, without exception; for the observations of Stars necessary for instrumental adjustments, and of the collimator for the same purpose; and for observations of Donati's Comet.

The Reflex Zenith-Tube has been used without interruption (except on Sundays) throughout the year 1858 for observations of  $\gamma$  Draconis.

The North Equatoreal has been used for observations of Difference of N. P. D. of cusps in the Solar Eclipse of 1858, March 14–15, and for Occultations of Stars by the Moon, and Eclipses of Jupiter's Satellites.

The East Equatoreal has been used for observations of the physical peculiarities of Donati's Comet, and for Occultations of Stars by the Moon, and for the phenomena of Jupiter's Satellites; and a double-image micrometer occasionally mounted on it has been used for measures of the diameters of Mercury, Mars, and Jupiter, and of the distance of the components of  $\gamma$  Virginis.

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

§ 1. *Transits observed with the Transit-Circle, and Computations of Apparent Right Ascension*, page [2] to [116].

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: this, however, is generally stated unequivocally, except where omitted from inadvertence. 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, it is to be remarked, that 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. The Greek or Italic letter of Bayer, as adopted in Baily's Flamsteed, with the name of the constellation.
2. Flamsteed's number, with the name of the constellation.
3. The number in the Catalogue of the British Association.
4. Piazzini's hour and number.

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5. The number in Groombridge's Catalogue.
6. The number in Bessel's Bradley.
7. The number in Baily's edition of Flamsteed's Catalogue.
8. The number in Santini's Catalogue of 1677 Stars, published in the *Memoirs of the Royal Astronomical Society*, vol. xii.
9. The hour and number in Weisse's Catalogue of the Stars in Bessel's Zones.
10. The number in the Catalogues of Lalande and Lacaille, published by the British Association.
11. The number in Rümker's Catalogue of 12,000 Stars.
12. The number in Oeltzen's Catalogue of Argelander's Zone Observations between  $45^{\circ}$  and  $80^{\circ}$  North Declination, published in vols. i. and ii. of the *Annals of the Observatory of Vienna*, 3rd Series.
13. Carrington's Red Hill Catalogue of 3735 Circumpolar Stars.
14. The North Polar Distance; which is generally accurate within a minute of arc.

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) prefixed to them. In other cases when some part of the galvanic apparatus has been out of order, the limits of time during which the eye-and-ear method has been employed are marked in the foot-notes to the observations.

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

The next *nine* columns contain the clock-times (seconds and decimals of seconds 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 were, 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.

With regard to the general method of 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.

In observing by galvanic contact, the observer merely makes contact of the galvanic spring at the instant of the object passing the wire. At the beginning of decades of

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minutes he occasionally makes contacts by a simple rule, which marks intelligibly the sidereal hour and the numeration of minutes. 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.

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.

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 were 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.

For the determination of the intervals of the wires, the South Collimator was generally employed in the following manner:—The eyepiece of the Transit-Circle was turned round through an angle of  $90^\circ$ , so as to bring the transit-wires into a sensibly horizontal position, and with the head of the micrometer upwards when the telescope was directed towards the South. Each of the transit-wires in succession was then brought upon a determinate point of the image of one of the nearly horizontal wires of the South Collimator, partly by turning the instrument in the ordinary way round its horizontal axis, and partly by turning the screw of the Right-Ascension-Micrometer; and, the instrument being clamped, the six microscopes of the Zenith-Distance-Circle were read, as well as the Right-Ascension-Micrometer.

The intervals which have been used throughout the year are those which were determined on 1854, June 27, by the process explained above. The results are contained in the following Tables:—

For the seven wires of the original system, the distance in arc of each wire from center wire, is

|            |   |            |
|------------|---|------------|
| For wire N | + | 10. 22' 08 |
| O          | + | 6. 54' 03  |
| P          | + | 3. 26' 91  |
| T          |   | 0' 00      |
| X          | — | 3. 27' 78  |
| Y          | — | 6. 54' 65  |
| Z          | — | 10. 21' 24 |

and, for an Equatoreal star, the interval in time of star's passage from any wire to the center wire, is

|            |   |          |
|------------|---|----------|
| For wire N | + | 41' 47.2 |
| O          | + | 27' 60.2 |
| P          | + | 13' 79.4 |
| T          |   | 0' 00.0  |
| X          | — | 13' 85.2 |
| Y          | — | 27' 64.3 |
| Z          | — | 41' 41.6 |

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For the nine wires used for galvanic observations, the distance in arc of each wire from center wire, is

|            |   |           |
|------------|---|-----------|
| For wire P | + | 3. 26. 91 |
| Q          | + | 2. 44. 71 |
| R          | + | 2. 3. 20  |
| S          | + | 1. 22. 00 |
| T          |   | 0. 00     |
| U          | — | 1. 23. 88 |
| V          | — | 2. 5. 04  |
| W          | — | 2. 46. 26 |
| X          | — | 3. 27. 78 |

and, for an Equatoreal star, the interval in time of star's passage from any wire to the center wire, is

|            |   |         |
|------------|---|---------|
| For wire P | + | 13. 794 |
| Q          | + | 10. 981 |
| R          | + | 8. 213  |
| S          | + | 5. 467  |
| T          |   | 0. 000  |
| U          | — | 5. 592  |
| V          | — | 8. 336  |
| W          | — | 11. 084 |
| X          | — | 13. 852 |

Hence, for the usual circumpolar stars, the intervals in time from any wire to the center wire were calculated by means of the formula,

$$\text{Sine distance in time for star} = \frac{15 \sin 1'' \times \text{Equatoreal distance in seconds of time}}{\text{sine Star's N. P. D.}}$$

and the results are as follows :

For  $\lambda$  Ursæ Minoris, assuming its declination =  $88^\circ. 52' + n''$ .

|        |   |                                |
|--------|---|--------------------------------|
| Wire P | + | $11. 37. 70 + n \times 0. 171$ |
| Q      | + | $9. 15. 31 + n \times 0. 137$  |
| R      | + | $6. 55. 31 + n \times 0. 103$  |
| S      | + | $4. 36. 40 + n \times 0. 068$  |
| T      |   | 0. 00                          |
| U      | — | $4. 42. 74 - n \times 0. 068$  |
| V      | — | $7. 1. 52 - n \times 0. 103$   |
| W      | — | $9. 20. 54 - n \times 0. 137$  |
| X      | — | $11. 40. 64 - n \times 0. 171$ |

For Polaris, assuming its declination =  $88^\circ. 33' + n''$ .

|        |   |                               |
|--------|---|-------------------------------|
| Wire P | + | $9. 5. 26 + n \times 0. 106$  |
| Q      | + | $7. 14. 01 + n \times 0. 085$ |
| R      | + | $5. 24. 61 + n \times 0. 064$ |
| S      | + | $3. 36. 04 + n \times 0. 043$ |
| T      |   | 0. 00                         |
| U      | — | $3. 41. 00 - n \times 0. 043$ |
| V      | — | $5. 29. 46 - n \times 0. 064$ |
| W      | — | $7. 18. 10 - n \times 0. 085$ |
| X      | — | $9. 7. 56 - n \times 0. 106$  |

## CORRECTIONS TO IMPERFECT TRANSITS.

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For Cephei 51 (Hevelii), assuming its declination =  $87^{\circ}.14' + n''$ .

|        |   |                                                                   |
|--------|---|-------------------------------------------------------------------|
| Wire P | + | $\overset{m}{4}.45\overset{s}{.80} + n \times \overset{s}{0}.029$ |
| Q      | + | $3.47\overset{s}{.50} + n \times \overset{s}{0}.023$              |
| R      | + | $2.50\overset{s}{.18} + n \times \overset{s}{0}.017$              |
| S      | + | $1.53\overset{s}{.26} + n \times \overset{s}{0}.012$              |
| T      |   | $0.00$                                                            |
| U      | - | $1.55\overset{s}{.85} - n \times \overset{s}{0}.012$              |
| V      | - | $2.52\overset{s}{.70} - n \times \overset{s}{0}.017$              |
| W      | - | $3.49\overset{s}{.64} - n \times \overset{s}{0}.023$              |
| X      | - | $4.47\overset{s}{.00} - n \times \overset{s}{0}.029$              |

For  $\epsilon$  Ursæ Minoris, assuming its declination =  $86^{\circ}.35' + n''$ .

|        |   |                                                                   |
|--------|---|-------------------------------------------------------------------|
| Wire P | + | $\overset{m}{3}.51\overset{s}{.47} + n \times \overset{s}{0}.019$ |
| Q      | + | $3.4\overset{s}{.25} + n \times \overset{s}{0}.015$               |
| R      | + | $2.17\overset{s}{.82} + n \times \overset{s}{0}.011$              |
| S      | + | $1.31\overset{s}{.73} + n \times \overset{s}{0}.008$              |
| T      |   | $0.00$                                                            |
| U      | - | $1.33\overset{s}{.83} - n \times \overset{s}{0}.008$              |
| V      | - | $2.19\overset{s}{.88} - n \times \overset{s}{0}.011$              |
| W      | - | $3.5\overset{s}{.99} - n \times \overset{s}{0}.015$               |
| X      | - | $3.52\overset{s}{.44} - n \times \overset{s}{0}.019$              |

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 number so obtained is to be multiplied by

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

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

the computation being facilitated by a small table, of which the argument is the hourly increase of Right Ascension of the planet, taken from the Nautical Almanac; but it has generally been found easier to proceed as with stars, adding simply 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 whole factor is computed by the formula

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

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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  $\frac{3600 + I}{3600}$ , is used :—

| I = Var.<br>in R. A.<br>for $1^h$ of<br>Longitude. | $\frac{3600 + I}{3600}$ |         | I = Var.<br>in R. A.<br>for $1^h$ of<br>Longitude. | $\frac{3600 + I}{3600}$ |         |
|----------------------------------------------------|-------------------------|---------|----------------------------------------------------|-------------------------|---------|
|                                                    | Nat. Number.            | Log.    |                                                    | Nat. Number.            | Log.    |
| 100 <sup>s</sup>                                   | 1·02778                 | 0·01190 | 145 <sup>s</sup>                                   | 1·04028                 | 0·01715 |
| 101                                                | ·02806                  | ·01202  | 146                                                | ·04056                  | ·01727  |
| 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  |

## CORRECTION OF IMPERFECT TRANSITS OF THE MOON; AND ERROR OF COLLIMATION. xxiii

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 space. The sign of the error is considered positive when it implies an additive correction to the 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 collimators 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, once in every week, the reading of the micrometer of the south collimator, for coincidence of its nearly vertical wire with the image of that of the north collimator, is ascertained (the results of which will be found on page [118]), and that the micrometer-wire of the south collimator is then left in the position so ascertained. And that every day the reading of the transit-telescope-micrometer, for coincidence with the image of the wire of each collimator, is found (the results of which are given in pages [119] to [121]); that the mean of these gives the reading for the line of collimation for that day; and that the mean of these determinations, usually for a week, is adopted as the true reading for the geometrical line of collimation of the transit-telescope.

During the year 1851, the observations of the collimators 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, usually at the commencement of the evening's observations.

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 error of collimation, with the sign as explained above. This excess is converted into arc at the rate of  $14''.78$  for one revolution of the micrometer; this determination of the value of a revolution having been 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. A new investigation for verification of the value was made on June 27, 1854, the resulting value of a revolution being  $14''.76$ , which is essentially identical with the preceding. To the excess thus converted into arc is then applied  $-0''.19$  for diurnal aberration; and the result is the Error of Collimation which is given in the fifteenth column of the *Transits*, and which is adopted for correction of the observed transits.

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

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

*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, by taking the reading of the transit-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, and comparing this reading with the reading for the geometrical line of collimation, has been sufficiently explained in the description of the instrument above. 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 [122] to [125].

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

The observations for the error of level are usually made at the same time as those for the line of collimation. During the year 1851 they 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. Lately, however, there has appeared reason for believing that the variations of level have a very 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 at the end of long night watches, as well as at the commencement, so as to obtain as great a change of temperature as possible; and the following Table gives the results:—

| Approximate Mean<br>Solar Time,<br>1858. |     |    | Error of Level. | Temperature. | Approximate Mean<br>Solar Time,<br>1858. |     |    | Error of Level. | Temperature. |
|------------------------------------------|-----|----|-----------------|--------------|------------------------------------------|-----|----|-----------------|--------------|
| d                                        | h   | "  |                 |              | d                                        | h   | "  |                 |              |
| June                                     | 25. | 8  | + 1'63          | 62'8*        | August                                   | 27. | 14 | + 5'23          | 52'0*        |
|                                          |     | 14 | + 1'84          | 58'5*        |                                          |     |    |                 |              |
| July                                     | 1.  | 9  | + 2'47          | 55'7*        | September                                | 16. | 0  | + 3'58          | 68'0         |
|                                          |     | 12 | + 3'12          | 54'7*        |                                          |     | 6  | + 3'53          | 61'0         |
|                                          | 19. | 8  | + 1'55          | 61'4*        |                                          | 17. | 0  | + 3'99          | 66'0         |
|                                          |     | 12 | + 1'78          | 56'2*        |                                          |     | 7  | + 3'64          | 66'5         |
|                                          | 31. | 8  | + 2'40          | 59'6*        |                                          | 18. | 1  | + 3'76          | 65'0         |
|                                          |     | 11 | + 2'61          | 56'4*        |                                          |     | 6  | + 3'71          | 64'5         |
| August                                   |     |    |                 |              |                                          |     | 14 | + 4'61          | 54'0         |
|                                          | 9.  | 9  | + 3'02          | 62'5*        |                                          | 22. | 7  | + 3'92          | 65'0         |
|                                          |     | 15 | + 3'80          | 60'5*        |                                          |     | 14 | + 3'93          | 63'0         |
|                                          | 23. | 8  | + 4'00          | 59'2*        |                                          | 27. | 7  | + 5'15          | 61'5         |
|                                          |     | 14 | + 4'47          | 54'4*        |                                          |     | 18 | + 5'32          | 60'0         |
|                                          | 27. | 8  | + 4'74          | 54'6*        |                                          | 28. | 7  | + 5'20          | 60'0         |
|                                          |     |    |                 |              |                                          |     | 18 | + 5'14          | 59'0         |

## ERRORS OF LEVEL AND AZIMUTH.

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| Approximate Mean<br>Solar Time,<br>1858. |     |    | Error of Level. | Temperature. | Approximate Mean<br>Solar Time,<br>1858. |     |    | Error of Level. | Temperature. |
|------------------------------------------|-----|----|-----------------|--------------|------------------------------------------|-----|----|-----------------|--------------|
|                                          | d   | h  | "               | °            |                                          | d   | h  | "               | °            |
| September                                | 30. | 17 | + 5.64          | 52.5         | November                                 | 11. | 13 | + 6.29          | 41.0         |
|                                          |     | 19 | + 5.61          | 50.0         |                                          | 12. | 5  | + 6.16          | 43.7         |
| October                                  | 1.  | 7  | + 5.45          | 58.0         |                                          |     | 14 | + 6.38          | 37.7         |
|                                          |     | 12 | + 5.20          | 55.0         |                                          | 17. | 5  | + 6.38          | 38.0         |
|                                          |     | 20 | + 5.36          | 57.5         |                                          |     | 13 | + 6.65          | 36.5         |
|                                          | 5.  | 8  | + 5.46          | 53.0         |                                          | 18. | 5  | + 7.00          | 40.0         |
|                                          |     | 12 | + 6.32          | 49.0±        |                                          |     | 15 | + 6.78          | 34.5         |
|                                          |     | 18 | + 6.21          | 50.5         |                                          | 20. | 6  | + 6.59          | 39.0         |
|                                          | 6.  | 6  | + 6.45          | 53.3         |                                          |     | 13 | + 6.75          | 33.6         |
|                                          |     | 14 | + 6.69          | 53.0         |                                          | 22. | 5  | + 6.44          | 37.4         |
|                                          | 8.  | 7  | + 5.70          | 53.0         |                                          |     | 15 | + 6.88          | 28.7         |
|                                          |     | 15 | + 5.97          | 45.0         |                                          | 23. | 4  | + 6.57          | 32.0         |
|                                          | 11. | 6  | + 6.01          | 51.0         |                                          |     | 14 | + 6.75          | 30.0         |
|                                          |     | 15 | + 6.65          | 41.5         |                                          | 26. | 4  | + 3.33          | 51.5         |
|                                          | 15. | 7  | + 4.43          | 57.8         |                                          |     | 13 | + 3.29          | 48.4         |
|                                          |     | 14 | + 3.85          | 53.5         | December                                 | 2.  | 4  | + 4.88          | 49.0         |
|                                          | 25. | 6  | + 5.23          | 54.0         |                                          |     | 14 | + 5.35          | 41.0         |
|                                          |     | 15 | + 5.53          | 50.0±        |                                          | 3.  | 4  | + 5.26          | 48.0         |
|                                          | 27. | 6  | + 5.52          | 54.0         |                                          |     | 14 | + 5.14          | 49.0         |
|                                          |     | 12 | + 5.92          | 50.5         |                                          | 20. | 4  | + 5.12          | 44.0         |
|                                          | 28. | 7  | + 6.01          | 53.0         |                                          |     | 13 | + 5.23          | 44.0         |
|                                          |     | 15 | + 6.29          | 47.0         |                                          | 22. | 4  | + 4.17          | 48.0         |
| November                                 | 9.  | 6  | + 5.97          | 45.0         |                                          |     | 15 | + 4.47          | 48.0         |
|                                          |     | 14 | + 6.42          | 34.0         |                                          | 29. | 4  | + 5.45          | 44.0         |
|                                          | 11. | 5  | + 6.07          | 44.5         |                                          |     | 14 | + 5.71          | 40.0         |

The temperatures marked with an asterisk are those of the external air as determined at the Meteorological Observatory; the rest are determined by readings of the Interior Thermometer suspended in the Transit-Circle-Room.

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

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

*Error of Azimuth.*

This error is considered positive when the Eastern pivot is too far North. It is generally determined from observations of Polaris or of  $\delta$  Ursæ Minoris, at consecutive passages above and below the pole; or from one observation of Polaris combined with one observation of another star; or occasionally, from observations of  $\delta$  Ursæ Minoris combined with those of other stars. The stars Cephei 51 (Hev.) and  $\lambda$  Ursæ Minoris have also frequently been employed. 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 first 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 for 12<sup>h</sup>; and the difference, in seconds of time, between the altered first transit and the second transit (rejecting 12<sup>h</sup>) is divided by 3.286 to obtain the azimuthal error in seconds of space.

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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 the clock's rate, and is then divided by 3.286.

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 a single observation only can be obtained, the letter  $z$  being put for the azimuthal error, the clock-error is found by comparing the R.A. of the Nautical Almanac (with a small alteration hereafter mentioned) with the time of transit including a term multiplied by  $z$ . The clock-error, therefore, from Polaris or  $\delta$  Ursæ Minoris, or other star near the pole, contains a term depending on  $z$ . In like manner the clock-error from some other star not near the pole contains a term depending on  $z$ . Equating these (with proper allowance for rate of the clock),  $z$  is found.

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,

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

The azimuthal errors actually used during the year 1858 are for the most part based upon the actual determinations of the error by consecutive observations of Polaris above and below the pole, in combination with the observations of the wires of the North Collimator made in the process of determining the error of collimation, in the following manner:—

The azimuthal error, determined in the usual way by transits of circumpolar stars, has been applied to the measured angle of deviation between the wire of the North Collimator and the line of collimation, so as to give the azimuth of the North Collimator; and this, when well determined, has been used in connection with the ordinary observations of the North Collimator to determine the azimuth of the Instrument. For the determination of the azimuth of the Collimator throughout the year 1858, only consecutive observations of Polaris or  $\delta$  Ursæ Minoris have been employed; and the results deduced from other observations of circumpolar stars, though scrupulously computed, have been used only to serve as a check upon the constancy of the position of the North Collimator, at times when Polaris or  $\delta$  Ursæ Minoris could not be observed both above and below the pole at consecutive transits.

In the foot-notes to the *Transits*, those observations of circumpolar stars which have been actually employed in deducing the azimuth of the collimator are always mentioned, as well as the resulting azimuths of the Instrument. The whole of the details of the operations for deducing the azimuth of Collimator and the azimuth of Transit-Circle are given at page [126] and following pages.

## FACTORS OF TRANSIT INSTRUMENTAL ERRORS.

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The numerical values of the three factors for the errors of collimation, level, and azimuth, have been obtained throughout the year 1858 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.                            |
|---------|----------------------------|-------------------------------------|-------------------------------------|---------|----------------------------|-------------------------------------|-------------------------------------|
|         | $\frac{1}{15 \sin N.P.D.}$ | $\frac{\cos Z. D.}{15 \sin N.P.D.}$ | $\frac{\sin Z. D.}{15 \sin N.P.D.}$ |         | $\frac{1}{15 \sin N.P.D.}$ | $\frac{\cos Z. D.}{15 \sin N.P.D.}$ | $\frac{\sin Z. D.}{15 \sin N.P.D.}$ |
| —45. 0  | —0.094                     | —0.011                              | +0.094                              | —13. 30 | —0.286                     | —0.176                              | +0.225                              |
| —44. 0  | —0.096                     | —0.013                              | +0.095                              | —13. 0  | —0.296                     | —0.184                              | +0.232                              |
| —43. 0  | —0.098                     | —0.014                              | +0.096                              | —12. 30 | —0.308                     | —0.194                              | +0.240                              |
| —42. 0  | —0.100                     | —0.016                              | +0.098                              | —12. 0  | —0.321                     | —0.204                              | +0.248                              |
| —41. 0  | —0.102                     | —0.018                              | +0.100                              | —11. 30 | —0.334                     | —0.214                              | +0.256                              |
| —40. 0  | —0.104                     | —0.021                              | +0.102                              | —11. 0  | —0.349                     | —0.227                              | +0.266                              |
| —39. 0  | —0.106                     | —0.023                              | +0.104                              | —10. 30 | —0.366                     | —0.240                              | +0.276                              |
| —38. 0  | —0.108                     | —0.025                              | +0.105                              | —10. 0  | —0.384                     | —0.254                              | +0.288                              |
| —37. 0  | —0.111                     | —0.027                              | +0.107                              | —9. 30  | —0.404                     | —0.270                              | +0.300                              |
| —36. 0  | —0.113                     | —0.030                              | +0.109                              | —9. 0   | —0.426                     | —0.288                              | +0.314                              |
| —35. 0  | —0.116                     | —0.033                              | +0.111                              | —8. 30  | —0.451                     | —0.308                              | +0.330                              |
| —34. 0  | —0.119                     | —0.036                              | +0.114                              | —8. 0   | —0.479                     | —0.330                              | +0.348                              |
| —33. 0  | —0.122                     | —0.039                              | +0.116                              | —7. 30  | —0.511                     | —0.355                              | +0.368                              |
| —32. 0  | —0.126                     | —0.042                              | +0.119                              | —7. 0   | —0.547                     | —0.383                              | +0.390                              |
| —31. 0  | —0.129                     | —0.045                              | +0.121                              | —6. 30  | —0.589                     | —0.416                              | +0.417                              |
| —30. 0  | —0.133                     | —0.049                              | +0.124                              | —6. 0   | —0.638                     | —0.455                              | +0.447                              |
| —29. 0  | —0.138                     | —0.053                              | +0.127                              |         |                            |                                     |                                     |
| —28. 0  | —0.142                     | —0.057                              | +0.130                              | 6. 0    | +0.638                     | +0.538                              | —0.343                              |
| —27. 0  | —0.147                     | —0.061                              | +0.133                              | 6. 30   | +0.589                     | +0.499                              | —0.312                              |
| —26. 0  | —0.152                     | —0.065                              | +0.137                              | 7. 0    | +0.547                     | +0.466                              | —0.286                              |
| —25. 0  | —0.158                     | —0.070                              | +0.141                              | 7. 30   | +0.511                     | +0.438                              | —0.263                              |
| —24. 0  | —0.164                     | —0.076                              | +0.145                              | 8. 0    | +0.479                     | +0.413                              | —0.243                              |
| —23. 0  | —0.171                     | —0.082                              | +0.150                              | 8. 30   | +0.451                     | +0.391                              | —0.226                              |
| —22. 0  | —0.178                     | —0.088                              | +0.155                              | 9. 0    | +0.426                     | +0.371                              | —0.210                              |
| —21. 0  | —0.186                     | —0.094                              | +0.160                              | 9. 30   | +0.404                     | +0.353                              | —0.196                              |
| —20. 0  | —0.195                     | —0.102                              | +0.166                              | 10. 0   | +0.384                     | +0.337                              | —0.183                              |
| —19. 30 | —0.200                     | —0.106                              | +0.170                              | 10. 30  | +0.366                     | +0.323                              | —0.172                              |
| —19. 0  | —0.205                     | —0.110                              | +0.173                              | 11. 0   | +0.349                     | +0.310                              | —0.161                              |
| —18. 30 | —0.210                     | —0.114                              | +0.176                              | 11. 30  | +0.334                     | +0.298                              | —0.152                              |
| —18. 0  | —0.216                     | —0.119                              | +0.180                              | 12. 0   | +0.321                     | +0.287                              | —0.143                              |
| —17. 30 | —0.222                     | —0.124                              | +0.184                              | 12. 30  | +0.308                     | +0.277                              | —0.135                              |
| —17. 0  | —0.228                     | —0.129                              | +0.188                              | 13. 0   | +0.296                     | +0.267                              | —0.128                              |
| —16. 30 | —0.235                     | —0.134                              | +0.192                              | 13. 30  | +0.286                     | +0.259                              | —0.122                              |
| —16. 0  | —0.242                     | —0.140                              | +0.197                              | 14. 0   | +0.276                     | +0.251                              | —0.116                              |
| —15. 30 | —0.249                     | —0.146                              | +0.202                              | 14. 30  | +0.266                     | +0.244                              | —0.111                              |
| —15. 0  | —0.257                     | —0.153                              | +0.207                              | 15. 0   | +0.257                     | +0.236                              | —0.105                              |
| —14. 30 | —0.266                     | —0.160                              | +0.213                              | 15. 30  | +0.249                     | +0.230                              | —0.099                              |
| —14. 0  | —0.276                     | —0.168                              | +0.219                              | 16. 0   | +0.242                     | +0.224                              | —0.093                              |
| —13. 30 | —0.286                     | —0.176                              | +0.225                              | 16. 30  | +0.235                     | +0.218                              | —0.088                              |

## xxviii INTRODUCTION TO GREENWICH ASTRONOMICAL OBSERVATIONS, 1858.

| N.P.D. | Collimation.               | Level.                             | Azimuth.                           | N.P.D. | Collimation.               | Level.                             | Azimuth.                           |
|--------|----------------------------|------------------------------------|------------------------------------|--------|----------------------------|------------------------------------|------------------------------------|
|        | $\frac{1}{15 \sin N.P.D.}$ | $\frac{\cos Z.D.}{15 \sin N.P.D.}$ | $\frac{\sin Z.D.}{15 \sin N.P.D.}$ |        | $\frac{1}{15 \sin N.P.D.}$ | $\frac{\cos Z.D.}{15 \sin N.P.D.}$ | $\frac{\sin Z.D.}{15 \sin N.P.D.}$ |
| 16. 30 | +0.235                     | +0.218                             | -0.088                             | 70. 0  | +0.071                     | +0.060                             | +0.037                             |
| 17. 0  | +0.228                     | +0.212                             | -0.084                             | 71. 0  | +0.071                     | +0.059                             | +0.038                             |
| 17. 30 | +0.222                     | +0.207                             | -0.080                             | 72. 0  | +0.070                     | +0.058                             | +0.039                             |
| 18. 0  | +0.216                     | +0.202                             | -0.076                             | 73. 0  | +0.070                     | +0.057                             | +0.039                             |
| 18. 30 | +0.210                     | +0.197                             | -0.072                             | 74. 0  | +0.069                     | +0.056                             | +0.040                             |
| 19. 0  | +0.205                     | +0.193                             | -0.068                             | 75. 0  | +0.069                     | +0.055                             | +0.041                             |
| 19. 30 | +0.200                     | +0.189                             | -0.065                             | 76. 0  | +0.069                     | +0.054                             | +0.042                             |
| 20. 0  | +0.195                     | +0.185                             | -0.062                             | 77. 0  | +0.068                     | +0.053                             | +0.043                             |
| 21. 0  | +0.186                     | +0.177                             | -0.056                             | 78. 0  | +0.068                     | +0.053                             | +0.043                             |
| 22. 0  | +0.178                     | +0.171                             | -0.051                             | 79. 0  | +0.068                     | +0.052                             | +0.044                             |
| 23. 0  | +0.171                     | +0.164                             | -0.046                             | 80. 0  | +0.068                     | +0.051                             | +0.045                             |
| 24. 0  | +0.164                     | +0.159                             | -0.041                             | 81. 0  | +0.067                     | +0.050                             | +0.045                             |
| 25. 0  | +0.158                     | +0.153                             | -0.037                             | 82. 0  | +0.067                     | +0.049                             | +0.046                             |
| 26. 0  | +0.152                     | +0.148                             | -0.033                             | 83. 0  | +0.067                     | +0.048                             | +0.047                             |
| 27. 0  | +0.147                     | +0.144                             | -0.029                             | 84. 0  | +0.067                     | +0.047                             | +0.048                             |
| 28. 0  | +0.142                     | +0.140                             | -0.026                             | 85. 0  | +0.067                     | +0.046                             | +0.048                             |
| 29. 0  | +0.138                     | +0.136                             | -0.023                             | 86. 0  | +0.067                     | +0.045                             | +0.049                             |
| 30. 0  | +0.133                     | +0.131                             | -0.020                             | 87. 0  | +0.067                     | +0.044                             | +0.050                             |
| 31. 0  | +0.129                     | +0.128                             | -0.017                             | 88. 0  | +0.067                     | +0.043                             | +0.051                             |
| 32. 0  | +0.126                     | +0.125                             | -0.014                             | 89. 0  | +0.067                     | +0.042                             | +0.052                             |
| 33. 0  | +0.122                     | +0.122                             | -0.012                             | 90. 0  | +0.067                     | +0.041                             | +0.052                             |
| 34. 0  | +0.119                     | +0.119                             | -0.009                             | 91. 0  | +0.067                     | +0.040                             | +0.053                             |
| 35. 0  | +0.116                     | +0.116                             | -0.007                             | 92. 0  | +0.067                     | +0.040                             | +0.054                             |
| 36. 0  | +0.113                     | +0.113                             | -0.005                             | 93. 0  | +0.067                     | +0.039                             | +0.054                             |
| 37. 0  | +0.111                     | +0.111                             | -0.003                             | 94. 0  | +0.067                     | +0.038                             | +0.055                             |
| 38. 0  | +0.108                     | +0.108                             | -0.001                             | 95. 0  | +0.067                     | +0.037                             | +0.056                             |
| 39. 0  | +0.106                     | +0.106                             | +0.001                             | 96. 0  | +0.067                     | +0.036                             | +0.057                             |
| 40. 0  | +0.104                     | +0.104                             | +0.003                             | 97. 0  | +0.067                     | +0.035                             | +0.057                             |
| 41. 0  | +0.102                     | +0.101                             | +0.004                             | 98. 0  | +0.067                     | +0.034                             | +0.058                             |
| 42. 0  | +0.100                     | +0.099                             | +0.006                             | 99. 0  | +0.067                     | +0.033                             | +0.059                             |
| 43. 0  | +0.098                     | +0.097                             | +0.007                             | 100. 0 | +0.068                     | +0.032                             | +0.060                             |
| 44. 0  | +0.096                     | +0.096                             | +0.009                             | 101. 0 | +0.068                     | +0.031                             | +0.060                             |
| 45. 0  | +0.094                     | +0.094                             | +0.011                             | 102. 0 | +0.068                     | +0.030                             | +0.061                             |
| 46. 0  | +0.093                     | +0.092                             | +0.012                             | 103. 0 | +0.068                     | +0.029                             | +0.062                             |
| 47. 0  | +0.091                     | +0.090                             | +0.013                             | 104. 0 | +0.069                     | +0.028                             | +0.063                             |
| 48. 0  | +0.090                     | +0.088                             | +0.015                             | 105. 0 | +0.069                     | +0.027                             | +0.063                             |
| 49. 0  | +0.088                     | +0.087                             | +0.016                             | 106. 0 | +0.069                     | +0.027                             | +0.064                             |
| 50. 0  | +0.087                     | +0.085                             | +0.017                             | 107. 0 | +0.070                     | +0.026                             | +0.065                             |
| 51. 0  | +0.086                     | +0.084                             | +0.018                             | 108. 0 | +0.070                     | +0.025                             | +0.066                             |
| 52. 0  | +0.085                     | +0.082                             | +0.020                             | 109. 0 | +0.071                     | +0.024                             | +0.066                             |
| 53. 0  | +0.083                     | +0.081                             | +0.021                             | 110. 0 | +0.071                     | +0.023                             | +0.067                             |
| 54. 0  | +0.082                     | +0.080                             | +0.022                             | 111. 0 | +0.072                     | +0.022                             | +0.068                             |
| 55. 0  | +0.081                     | +0.078                             | +0.023                             | 112. 0 | +0.072                     | +0.021                             | +0.069                             |
| 56. 0  | +0.080                     | +0.077                             | +0.024                             | 113. 0 | +0.073                     | +0.020                             | +0.070                             |
| 57. 0  | +0.080                     | +0.075                             | +0.025                             | 114. 0 | +0.073                     | +0.018                             | +0.071                             |
| 58. 0  | +0.079                     | +0.074                             | +0.026                             | 115. 0 | +0.074                     | +0.017                             | +0.072                             |
| 59. 0  | +0.078                     | +0.073                             | +0.027                             | 116. 0 | +0.075                     | +0.016                             | +0.072                             |
| 60. 0  | +0.077                     | +0.072                             | +0.028                             | 117. 0 | +0.075                     | +0.015                             | +0.073                             |
| 61. 0  | +0.076                     | +0.070                             | +0.029                             | 118. 0 | +0.076                     | +0.014                             | +0.074                             |
| 62. 0  | +0.076                     | +0.069                             | +0.030                             | 119. 0 | +0.076                     | +0.013                             | +0.075                             |
| 63. 0  | +0.075                     | +0.068                             | +0.031                             | 120. 0 | +0.077                     | +0.012                             | +0.076                             |
| 64. 0  | +0.074                     | +0.067                             | +0.032                             | 121. 0 | +0.078                     | +0.011                             | +0.077                             |
| 65. 0  | +0.073                     | +0.066                             | +0.033                             | 122. 0 | +0.079                     | +0.009                             | +0.078                             |
| 66. 0  | +0.073                     | +0.065                             | +0.034                             | 123. 0 | +0.080                     | +0.008                             | +0.079                             |
| 67. 0  | +0.072                     | +0.064                             | +0.035                             | 124. 0 | +0.080                     | +0.007                             | +0.080                             |
| 68. 0  | +0.072                     | +0.063                             | +0.035                             | 125. 0 | +0.081                     | +0.005                             | +0.081                             |
| 69. 0  | +0.071                     | +0.061                             | +0.036                             | 126. 0 | +0.082                     | +0.004                             | +0.082                             |
| 70. 0  | +0.071                     | +0.060                             | +0.037                             |        |                            |                                    |                                    |

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  $50^{\circ}$ , there has been used in the year 1858, as in preceding years, another list of stars, previously selected, and observed for this purpose, and lying within the same limit of Polar Distance. The tabular R.A. of Polaris, Cephei 51 (H $\epsilon$ v.),  $\epsilon$  Ursæ Minoris, and  $\lambda$  Ursæ Minoris, are set down to enable the reader to judge of the general state of adjustment of the instrument.

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 Greenwich Catalogue of 1576 Stars for 1850. To bring up the Mean Right Ascensions from the epoch of the Catalogue, viz., 1850, to the year 1858, the precessions of the British Association Catalogue have been used, and the proper motions given by Mr. Main in his paper printed in Volume xix. of the Memoirs of the Royal Astronomical Society, excepting in a few instances in which the stars are not found in that paper ; for such cases the proper motions given in the British Association Catalogue are used. Precisely the same process is used in bringing up the Right Ascensions of the Stars used for clock-error which are not included in the Nautical-Almanac-list ; excepting that for the stars  $\alpha$  Tauri and  $\mu$  Eridani precessions and proper motions deduced from the same sources have been used to bring up to 1858 the Right Ascensions from the epochs of the annual Catalogues of 1854, 1855, 1856, and 1857, whose results are then combined (after increasing the Right Ascensions of 1854 and 1855 by  $0^{\circ}.01$ ) ; and for  $\beta$  Canis Majoris, the place in the Catalogue for 1855, increased by  $0^{\circ}.01$ , has been combined with that in the Catalogue of 1576 Stars for 1850, precessions and proper motions deduced from the same sources being used. Hence all the places of the clock-stars are manifestly referred to the same equinox, since their observed places are fundamentally based on the Greenwich Catalogue of 1576 Stars. The corrections necessary to bring up the stars' Right Ascensions to the day of observation are computed by the formula  $E e + F f + G g + H h + L + l - 300^{\circ}$ , 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 1858, January 1, of all the stars which have been used in 1858 for determining clock-errors, together with the constant alterations to the Right Ascensions of the Nautical-Almanac-stars ; it gives also, in addition, the Right Ascensions of Polaris and the other stars lying very near the pole, which have been observed throughout the year 1858.

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## INTRODUCTION TO GREENWICH ASTRONOMICAL OBSERVATIONS, 1858.

| Star's Name.                       | Assumed Mean R.A.<br>1858, Jan. 1.                | Correction to<br>N.A. | Star's Name.                   | Assumed Mean R. A.<br>1858, Jan. 1.   | Correction to<br>N.A. |
|------------------------------------|---------------------------------------------------|-----------------------|--------------------------------|---------------------------------------|-----------------------|
| $\alpha$ Andromedæ . . . . .       | <sup>h</sup> 0. <sup>m</sup> 1. <sup>s</sup> 3.27 | + 0.05                | 15 Argûs . . . . .             | <sup>h</sup> 8. <sup>m</sup> 1. 29.83 | + 0.01                |
| $\gamma$ Pegasi . . . . .          | 0. 5. 55.63                                       | + 0.05                | $\beta$ Cancri . . . . .       | 8. 8. 48.75                           |                       |
| 12 Ceti . . . . .                  | 0. 22. 47.54                                      | - 0.02                | $\eta$ Cancri . . . . .        | 8. 24. 29.49                          | 0.00                  |
| $\epsilon$ Andromedæ . . . . .     | 0. 31. 3.53                                       |                       | $\gamma$ Cancri . . . . .      | 8. 35. 3.74                           |                       |
| $\beta$ Ceti . . . . .             | 0. 36. 27.59                                      | + 0.09                | $\epsilon$ Hydræ . . . . .     | 8. 39. 15.21                          | - 0.01                |
| $\mu$ Andromedæ . . . . .          | 0. 48. 52.95                                      |                       | $\alpha$ Cancri . . . . .      | 8. 50. 43.02                          |                       |
| $\epsilon$ Piscium . . . . .       | 0. 55. 34.60                                      | + 0.01                | $\kappa$ Cancri . . . . .      | 9. 0. 3.17                            |                       |
| $\beta$ Andromedæ . . . . .        | 1. 1. 47.52                                       |                       | 83 Cancri . . . . .            | 9. 11. 3.04                           | + 0.08                |
| Polaris . . . . .                  | 1. 7. 25.08                                       | - 0.24                | $\alpha$ Hydræ . . . . .       | 9. 20. 36.54                          | + 0.03                |
| $\theta$ Ceti . . . . .            | 1. 16. 55.57                                      | + 0.06                | $\circ$ Leonis . . . . .       | 9. 33. 34.09                          |                       |
| $\eta$ Piscium . . . . .           | 1. 23. 53.34                                      | + 0.01                | $\epsilon$ Leonis . . . . .    | 9. 37. 47.06                          | + 0.02                |
| $\nu$ Piscium . . . . .            | 1. 34. 2.64                                       | 0.00                  | $\mu$ Leonis . . . . .         | 9. 44. 40.82                          |                       |
| $\beta$ Arietis . . . . .          | 1. 46. 48.14                                      | + 0.02                | $\pi$ Leonis . . . . .         | 9. 52. 42.38                          | - 0.01                |
| $\alpha$ Arietis . . . . .         | 1. 59. 10.57                                      | + 0.04                | Regulus . . . . .              | 10. 0. 48.36                          | + 0.02                |
| 67 Ceti . . . . .                  | 2. 9. 54.11                                       | + 0.02                | $\gamma^1$ Leonis . . . . .    | 10. 12. 8.32                          | + 0.01                |
| $\xi^2$ Ceti . . . . .             | 2. 20. 36.78                                      | + 0.01                | $\rho$ Leonis . . . . .        | 10. 25. 19.91                         | + 0.02                |
| $\gamma$ Ceti . . . . .            | 2. 35. 56.75                                      | + 0.05                | 34 Sextantis . . . . .         | 10. 35. 17.43                         |                       |
| $\sigma$ Arietis . . . . .         | 2. 43. 39.39                                      |                       | $l$ Leonis . . . . .           | 10. 41. 47.40                         | 0.00                  |
| $\alpha$ Ceti . . . . .            | 2. 54. 51.60                                      | + 0.08                | $d$ Leonis . . . . .           | 10. 53. 13.54                         |                       |
| $\delta$ Arietis . . . . .         | 3. 3. 30.90                                       | + 0.01                | $\chi$ Leonis . . . . .        | 10. 57. 41.42                         | 0.00                  |
| $\circ$ Tauri . . . . .            | 3. 17. 10.59                                      |                       | $\delta$ Leonis . . . . .      | 11. 6. 33.11                          | + 0.04                |
| $f$ Tauri . . . . .                | 3. 23. 2.28                                       |                       | $\delta$ Crateris . . . . .    | 11. 12. 14.65                         | + 0.08                |
| 11 Tauri . . . . .                 | 3. 32. 17.80                                      |                       | $\tau$ Leonis . . . . .        | 11. 20. 38.02                         |                       |
| $\eta$ Tauri . . . . .             | 3. 39. 2.95                                       | + 0.02                | $\nu$ Leonis . . . . .         | 11. 29. 40.70                         | - 0.03                |
| $\gamma$ Eridani . . . . .         | 3. 51. 24.33                                      | + 0.07                | $\beta$ Leonis . . . . .       | 11. 41. 48.86                         | + 0.06                |
| $\omega^1$ Tauri . . . . .         | 4. 0. 53.92                                       |                       | $\pi$ Virginis . . . . .       | 11. 53. 35.72                         |                       |
| $\omega^1$ Eridani . . . . .       | 4. 4. 56.18                                       | + 0.03                | $\epsilon$ Corvi . . . . .     | 12. 2. 49.65                          | + 0.05                |
| $\gamma$ Tauri . . . . .           | 4. 11. 42.98                                      |                       | $\eta$ Virginis . . . . .      | 12. 12. 38.45                         | - 0.02                |
| $\epsilon$ Tauri . . . . .         | 4. 20. 19.72                                      | 0.00                  | $\delta$ Corvi . . . . .       | 12. 22. 31.37                         |                       |
| Aldebaran . . . . .                | 4. 27. 46.58                                      | + 0.01                | $\beta$ Corvi . . . . .        | 12. 26. 56.05                         | + 0.11                |
| $\mu^1$ Eridani . . . . .          | 4. 38. 24.25                                      |                       | $\delta$ Virginis . . . . .    | 12. 48. 27.11                         |                       |
| $\epsilon$ Aurigæ . . . . .        | 4. 47. 45.07                                      | - 0.02                | $\theta$ Virginis . . . . .    | 13. 2. 36.02                          | + 0.01                |
| $\epsilon$ Leporis . . . . .       | 4. 59. 27.03                                      | + 0.05                | Spica . . . . .                | 13. 17. 42.99                         | + 0.05                |
| Rigel . . . . .                    | 5. 7. 42.90                                       | + 0.04                | $\zeta$ Virginis . . . . .     | 13. 27. 27.60                         | - 0.01                |
| $\beta$ Tauri . . . . .            | 5. 17. 19.11                                      | + 0.06                | $\tau$ Boötis . . . . .        | 13. 40. 30.87                         |                       |
| $\delta$ Orionis . . . . .         | 5. 24. 45.21                                      | 0.00                  | $\eta$ Boötis . . . . .        | 13. 47. 55.43                         | + 0.06                |
| $\alpha$ Leporis . . . . .         | 5. 26. 28.11                                      | 0.00                  | $\tau$ Virginis . . . . .      | 13. 54. 25.32                         | + 0.04                |
| $\epsilon$ Orionis . . . . .       | 5. 29. 0.55                                       | + 0.03                | $\kappa$ Virginis . . . . .    | 14. 5. 19.50                          |                       |
| $\alpha$ Columbæ . . . . .         | 5. 34. 30.53                                      | - 0.06                | Arcturus . . . . .             | 14. 9. 11.15                          | + 0.06                |
| $\alpha$ Orionis . . . . .         | 5. 47. 29.10                                      | + 0.03                | $\rho$ Boötis . . . . .        | 14. 25. 42.58                         | - 0.03                |
| 1 Geminorum . . . . .              | 5. 55. 29.29                                      |                       | $\epsilon$ Boötis . . . . .    | 14. 38. 47.14                         | + 0.07                |
| $\nu$ Orionis . . . . .            | 5. 59. 27.81                                      | - 0.07                | $\alpha$ Libræ . . . . .       | 14. 43. 1.74                          | + 0.06                |
| $\eta$ Geminorum . . . . .         | 6. 6. 18.33                                       |                       | $\psi$ Boötis . . . . .        | 14. 58. 21.76                         | + 0.03                |
| $\mu$ Geminorum . . . . .          | 6. 14. 22.20                                      | + 0.04                | $\beta$ Libræ . . . . .        | 15. 9. 22.17                          | + 0.03                |
| $\beta$ Canis Majoris . . . . .    | 6. 16. 26.92                                      |                       | $\omega^2$ Libræ . . . . .     | 15. 15. 6.86                          |                       |
| $\gamma$ Geminorum . . . . .       | 6. 29. 30.50                                      | - 0.01                | $\alpha$ Coronæ . . . . .      | 15. 28. 40.62                         | + 0.08                |
| Cephei 51 . . . . .                | 6. 32. 38.19                                      | + 1.89                | $\alpha$ Serpentis . . . . .   | 15. 37. 16.54                         | + 0.07                |
| Sirius . . . . .                   | 6. 38. 53.35                                      | - 0.19                | $\epsilon$ Serpentis . . . . . | 15. 43. 44.45                         |                       |
| $\theta$ Canis Majoris . . . . .   | 6. 47. 35.60                                      |                       | $\gamma$ Serpentis . . . . .   | 15. 49. 53.82                         |                       |
| $\epsilon$ Canis Majoris . . . . . | 6. 53. 2.77                                       | + 0.04                | $\beta^1$ Scorpii . . . . .    | 15. 57. 11.11                         | + 0.03                |
| $\gamma$ Canis Majoris . . . . .   | 6. 57. 20.09                                      | + 0.02                | $\delta$ Ophiuchi . . . . .    | 16. 6. 54.41                          | + 0.05                |
| $\delta$ Geminorum . . . . .       | 7. 11. 38.40                                      | + 0.02                | $\gamma$ Herculis . . . . .    | 16. 15. 39.49                         |                       |
| $\beta$ Canis Minoris . . . . .    | 7. 19. 26.94                                      |                       | Antares . . . . .              | 16. 20. 42.34                         | - 0.01                |
| Castor . . . . .                   | 7. 25. 32.05                                      | + 0.01                | $\zeta$ Ophiuchi . . . . .     | 16. 29. 20.58                         |                       |
| Procyon . . . . .                  | 7. 31. 52.07                                      | + 0.12                | $\zeta$ Herculis . . . . .     | 16. 35. 56.02                         | + 0.01                |
| Pollux . . . . .                   | 7. 36. 37.29                                      | + 0.01                | $\kappa$ Ophiuchi . . . . .    | 16. 50. 56.91                         | - 0.02                |
| $\xi$ Navis . . . . .              | 7. 43. 19.29                                      |                       | $\eta$ Ophiuchi . . . . .      | 17. 2. 14.23                          |                       |
| 6 Cancri . . . . .                 | 7. 54. 47.52                                      | - 0.03                | $\alpha$ Herculis . . . . .    | 17. 8. 10.42                          | + 0.07                |

ASSUMED RIGHT ASCENSIONS OF CLOCK STARS; AND CLOCK ERROR. xxx

| Star's Name.               | Assumed Mean R.A.<br>1858, Jan. 1.                    | Correction to<br>N.A. | Star's Name.             | Assumed Mean R.A.<br>1858, Jan. 1.                    | Correction to<br>N.A. |
|----------------------------|-------------------------------------------------------|-----------------------|--------------------------|-------------------------------------------------------|-----------------------|
| $\theta$ Ophiuchi.....     | <sup>h</sup> 17. <sup>m</sup> 13. <sup>s</sup> 17 '47 | + 0 '02               | $\epsilon$ Delphini..... | <sup>h</sup> 20. <sup>m</sup> 26. <sup>s</sup> 25 '69 | <sup>s</sup>          |
| $\sigma$ Ophiuchi.....     | 17. 19. 28 '23                                        |                       | $\alpha$ Delphini.....   | 20. 33. 2 '55                                         |                       |
| $\alpha$ Ophiuchi.....     | 17. 28. 20 '62                                        | + 0 '04               | $\epsilon$ Aquarii.....  | 20. 39. 59 '13                                        |                       |
| $\beta$ Ophiuchi.....      | 17. 36. 27 '51                                        |                       | 32 Vulpeculæ.....        | 20. 48. 30 '52                                        | + 0 '01               |
| $\mu$ Herculis.....        | 17. 40. 54 '17                                        | + 0 '06               | $\theta$ Capricorni..... | 20. 57. 57 '57                                        |                       |
| 72 Ophiuchi.....           | 18. 0. 37 '07                                         |                       | $\zeta$ Cygni.....       | 21. 6. 53 '64                                         | + 0 '06               |
| $\mu$ Sagittarii.....      | 18. 5. 16 '25                                         | + 0 '04               | $\epsilon$ Equulei.....  | 21. 8. 43 '44                                         |                       |
| $\eta$ Serpentis.....      | 18. 13. 57 '73                                        |                       | $\iota$ Capricorni.....  | 21. 14. 20 '06                                        |                       |
| $\delta$ Ursæ Minoris....  | 18. 18. 9 '16                                         | + 0 '05               | $\beta$ Aquarii.....     | 21. 24. 4 '84                                         | + 0 '05               |
| $\lambda$ Sagittarii.....  | 18. 19. 12 '38                                        |                       | $\xi$ Aquarii.....       | 21. 30. 11 '36                                        |                       |
| $\alpha$ Lyræ.....         | 18. 32. 7 '85                                         | + 0 '06               | $\epsilon$ Pegasi.....   | 21. 37. 12 '68                                        | - 0 '01               |
| $\beta$ Lyræ.....          | 18. 44. 50 '25                                        | + 0 '08               | $\delta$ Capricorni..... | 21. 39. 11 '92                                        |                       |
| $\epsilon$ Aquilæ.....     | 18. 53. 10 '67                                        |                       | 16 Pegasi.....           | 21. 46. 36 '20                                        | + 0 '04               |
| $\zeta$ Aquilæ.....        | 18. 58. 52 '99                                        | + 0 '10               | $\alpha$ Aquarii.....    | 21. 58. 29 '33                                        | + 0 '05               |
| $\omega$ Aquilæ.....       | 19. 11. 9 '06                                         | + 0 '03               | $\iota$ Pegasi.....      | 22. 0. 24 '15                                         |                       |
| $\delta$ Aquilæ.....       | 19. 18. 20 '27                                        | + 0 '04               | $\theta$ Aquarii.....    | 22. 9. 20 '25                                         | - 0 '01               |
| $\alpha$ Vulpeculæ.....    | 19. 22. 47 '84                                        |                       | $\gamma$ Aquarii.....    | 22. 14. 19 '23                                        |                       |
| $\mu$ Aquilæ.....          | 19. 27. 9 '11                                         |                       | $\eta$ Aquarii.....      | 22. 28. 3 '48                                         | 0 '00                 |
| $h^2$ Sagittarii.....      | 19. 28. 3 '65                                         | + 0 '06               | $\zeta$ Pegasi.....      | 22. 34. 22 '81                                        | + 0 '06               |
| $\gamma$ Aquilæ.....       | 19. 39. 30 '49                                        | + 0 '05               | $\mu$ Pegasi.....        | 22. 43. 9 '13                                         |                       |
| $\alpha$ Aquilæ.....       | 19. 43. 51 '27                                        | + 0 '05               | $\lambda$ Aquarii.....   | 22. 45. 12 '16                                        |                       |
| $\beta$ Aquilæ.....        | 19. 48. 20 '27                                        | + 0 '08               | Fomalhaut.....           | 22. 49. 47 '72                                        | + 0 '04               |
| $c$ Sagittarii.....        | 19. 53. 55 '20                                        |                       | $\alpha$ Pegasi.....     | 22. 57. 41 '38                                        | + 0 '04               |
| $\theta$ Aquilæ.....       | 20. 3. 58 '59                                         |                       | $\gamma$ Piscium.....    | 23. 9. 48 '26                                         | + 0 '01               |
| $\lambda$ Ursæ Minoris.... | 20. 5. 46 '39                                         | + 0 '16               | $\kappa$ Piscium.....    | 23. 19. 39 '18                                        | - 0 '01               |
| $\alpha^2$ Capricorni..... | 20. 10. 10 '34                                        | + 0 '04               | $\iota$ Piscium.....     | 23. 32. 38 '88                                        | + 0 '03               |
| $\beta$ Capricorni.....    | 20. 13. 1 '76                                         |                       | $\delta$ Sculptoris..... | 23. 41. 31 '43                                        | + 0 '02               |
| $\rho$ Capricorni.....     | 20. 20. 45. 35                                        | + 0 '08               | $\omega$ Piscium.....    | 23. 52. 1 '27                                         | 0 '00                 |

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 *nineteenth* column contains the adopted losing rate, and the adopted error of the clock at 0<sup>h</sup> sidereal, as found by the following process. The observations are divided into groups, marked by bars across these columns (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 held to be the clock-error corresponding to the mean of all the times of transit of those stars. The next step is to make allowance for personal equation; and it will be sufficient to explain that existing between any two observers, but more especially between Mr. Dunkin and some other observer; for example, between Mr. Dunkin and Mr. Ellis; since it has been the practice 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. Dunkin as the standard. It will be seen by one of the following tables in this Introduction that the clock-error given by Mr. Ellis's observations is greater than that given by Mr. Dunkin's observations by 0<sup>s</sup>.14, as deduced from observations suitable for the determination of this quantity in the year 1858; the quantity 0<sup>s</sup>.14 is therefore subtracted from Mr. Ellis's clock errors, and it is then considered that we have a set of clock-errors justly comparable

amongst themselves. Each mean clock-error 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 seventeenth 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  $0^h$  are 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. Dunkin or Mr. Ellis), no further computation is necessary for obtaining the right ascensions of these 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. Ellis, and the other object by Mr. Dunkin, a further correction  $-0^s.14$  must be applied: if the clock-stars are observed by Mr. Dunkin, and the object by Mr. Ellis,  $+0^s.14$  must be applied. These quantities 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 1858 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 PERSONAL EQUATIONS OF THE VARIOUS TRANSIT-OBSERVERS USING THE GALVANIC METHOD OF OBSERVING TRANSITS.

| Day, 1858.       | Observers in order of Seniority. | Interval of nearest Stars. | Order of Observations. | Clock Slow at $0^h$ by Senior Observer.  | Clock Slow at $0^h$ by Junior Observer. | Excess of Clock Slow by Junior Observer.   |
|------------------|----------------------------------|----------------------------|------------------------|------------------------------------------|-----------------------------------------|--------------------------------------------|
| May 25           | M and E                          | $^h$<br>0                  | M      E               | 37 <sup>.</sup> 50                       | 37 <sup>.</sup> 62                      | + 0 <sup>.</sup> 12                        |
| June 18<br>,, 30 | M and C                          | 0<br>3                     | M      C<br>C      M   | 10 <sup>.</sup> 19<br>30 <sup>.</sup> 60 | 9 <sup>.</sup> 96<br>30 <sup>.</sup> 54 | — 0 <sup>.</sup> 23<br>— 0 <sup>.</sup> 06 |
| December 23      |                                  | 0                          | C      M               | 37 <sup>.</sup> 71                       | 37 <sup>.</sup> 40                      | — 0 <sup>.</sup> 31                        |

## PERSONAL EQUATIONS IN GALVANIC TRANSITS.

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OBSERVATIONS FOR PERSONAL EQUATION—*continued*.

| Day, 1858.  | Observers in<br>order of<br>Seniority. | Interval<br>of<br>nearest<br>Stars. | Order of<br>Observations. |     | Clock Slow<br>at 0 <sup>h</sup><br>by<br>Senior<br>Observer. | Clock Slow<br>at 0 <sup>h</sup><br>by<br>Junior<br>Observer. | Excess of<br>Clock Slow<br>by<br>Junior<br>Observer. |
|-------------|----------------------------------------|-------------------------------------|---------------------------|-----|--------------------------------------------------------------|--------------------------------------------------------------|------------------------------------------------------|
| December 23 | M and W C                              | <sup>h</sup><br>5                   | M                         | W C | <sup>s</sup><br>37.71                                        | <sup>s</sup><br>37.60                                        | — 0.11                                               |
| January 1   | D and E                                | 2                                   | D                         | E   | 14.51                                                        | 14.64                                                        | + 0.13                                               |
| „ 9         |                                        | 6                                   | E                         | D   | 20.59                                                        | 20.78                                                        | + 0.19                                               |
| February 4  |                                        | 4                                   | D                         | E   | 39.52                                                        | 39.69                                                        | + 0.17                                               |
| „ 7         |                                        | 0                                   | D                         | E   | 41.72                                                        | 41.93                                                        | + 0.26                                               |
| March 6     |                                        | 5                                   | E                         | D   | 2.17                                                         | 2.41                                                         | + 0.24                                               |
| „ 9         |                                        | 1                                   | D                         | E   | 3.27                                                         | 3.30                                                         | + 0.03                                               |
| „ 16        |                                        | 0                                   | E                         | D   | 7.67                                                         | 7.82                                                         | + 0.15                                               |
| „ 20        |                                        | 1                                   | E                         | D   | 10.47                                                        | 10.64                                                        | + 0.17                                               |
| „ 22        |                                        | 0                                   | E                         | D   | 12.12                                                        | 12.28                                                        | + 0.16                                               |
| „ 24        |                                        | 2                                   | D                         | E   | 13.65                                                        | 13.80                                                        | + 0.15                                               |
| „ 26        |                                        | 0                                   | E                         | D   | 14.68                                                        | 14.87                                                        | + 0.19                                               |
| April 1     |                                        | 1                                   | D                         | E   | 17.42                                                        | 17.53                                                        | + 0.11                                               |
| „ 3         |                                        | 0                                   | E                         | D   | 164.51                                                       | 164.70                                                       | + 0.19                                               |
| „ 15        |                                        | 1                                   | E                         | D   | 54.36                                                        | 54.52                                                        | + 0.16                                               |
| „ 17        |                                        | 1                                   | D                         | E   | 57.92                                                        | 58.07                                                        | + 0.15                                               |
| „ 19        |                                        | 1                                   | E                         | D   | 59.11                                                        | 59.22                                                        | + 0.11                                               |
| „ 21        |                                        | 1                                   | D                         | E   | 61.10                                                        | 61.22                                                        | + 0.12                                               |
| „ 23        |                                        | 1                                   | D                         | E   | 3.45                                                         | 3.61                                                         | + 0.16                                               |
| „ 25        |                                        | 2                                   | D                         | E   | 6.60                                                         | 6.79                                                         | + 0.19                                               |
| May 5       |                                        | 3                                   | D                         | E   | 16.30                                                        | 16.41                                                        | + 0.11                                               |
| „ 7         |                                        | 4                                   | E                         | D   | 18.68                                                        | 18.86                                                        | + 0.18                                               |
| June 1      |                                        | 5                                   | E                         | D   | 45.32                                                        | 45.50                                                        | + 0.18                                               |
| „ 12        |                                        | 0                                   | E                         | D   | 61.00                                                        | 61.15                                                        | + 0.15                                               |
| „ 19        |                                        | 0                                   | E                         | D   | 11.71                                                        | 11.77                                                        | + 0.06                                               |
| „ 21        |                                        | 1                                   | E                         | D   | 14.97                                                        | 14.98                                                        | + 0.01                                               |
| „ 23        |                                        | 0                                   | D                         | E   | 18.22                                                        | 18.32                                                        | + 0.10                                               |
| „ 25        |                                        | 0                                   | D                         | E   | 21.26                                                        | 21.42                                                        | + 0.16                                               |
| „ 27        |                                        | 1                                   | E                         | D   | 24.34                                                        | 24.45                                                        | + 0.11                                               |
| September 1 |                                        | 5                                   | D                         | E   | 31.97                                                        | 32.01                                                        | + 0.04                                               |
| „ 30        |                                        | 5                                   | D                         | E   | 53.14                                                        | 53.37                                                        | + 0.23                                               |
| December 18 |                                        | 0                                   | D                         | E   | 30.68                                                        | 30.74                                                        | + 0.06                                               |
| „ 20        |                                        | 1                                   | D                         | E   | 33.60                                                        | 33.94                                                        | + 0.34                                               |
| „ 22        |                                        | 1                                   | D                         | E   | 36.39                                                        | 36.73                                                        | + 0.14                                               |
| „ 24        |                                        | 6                                   | D                         | E   | 38.80                                                        | 38.87                                                        | + 0.07                                               |
| January 9   | D and C                                | 2                                   | C                         | D   | 21.26                                                        | 21.18                                                        | — 0.08                                               |
| „ 19        |                                        | 1                                   | C                         | D   | 28.48                                                        | 28.38                                                        | — 0.10                                               |
| „ 21        |                                        | 0                                   | D                         | C   | 30.08                                                        | 30.06                                                        | — 0.02                                               |
| „ 23        |                                        | 2                                   | C                         | D   | 31.69                                                        | 31.60                                                        | — 0.09                                               |
| „ 25        |                                        | 1                                   | D                         | C   | 33.33                                                        | 33.25                                                        | — 0.08                                               |
| „ 27        |                                        | 0                                   | C                         | D   | 34.39                                                        | 34.21                                                        | — 0.18                                               |

GREENWICH OBSERVATIONS, 1858.

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## xxxiv INTRODUCTION TO GREENWICH ASTRONOMICAL OBSERVATIONS, 1858.

OBSERVATIONS FOR PERSONAL EQUATION—*continued.*

| Day, 1858.         | Observers in<br>order of<br>Seniority. | Interval<br>of<br>nearest<br>Stars. | Order of<br>Observations. |     | Clock Slow<br>at 0 <sup>h</sup><br>by<br>Senior<br>Observer. | Clock Slow<br>at 0 <sup>h</sup><br>by<br>Junior<br>Observer. | Excess of<br>Clock Slow<br>by<br>Junior<br>Observer. |
|--------------------|----------------------------------------|-------------------------------------|---------------------------|-----|--------------------------------------------------------------|--------------------------------------------------------------|------------------------------------------------------|
| February 4         | D and C                                | <sup>h</sup><br>4                   | D                         | C   | <sup>s</sup><br>39.52                                        | <sup>s</sup><br>39.45                                        | — 0.07                                               |
| “ 6                |                                        | 3                                   | C                         | D   | 41.07                                                        | 40.92                                                        | — 0.15                                               |
| “ 21               |                                        | 0                                   | C                         | D   | 53.58                                                        | 53.45                                                        | — 0.13                                               |
| “ 25               |                                        | 1                                   | C                         | D   | 57.00                                                        | 56.93                                                        | — 0.07                                               |
| “ 27               |                                        | 2                                   | D                         | C   | 58.46                                                        | 58.34                                                        | — 0.12                                               |
| March 3            |                                        | 3                                   | D                         | C   | 0.89                                                         | 0.81                                                         | — 0.08                                               |
| “ 6                |                                        | 0                                   | C                         | D   | 2.54                                                         | 2.57                                                         | + 0.03                                               |
| May 5              |                                        | 5                                   | D                         | C   | 16.30                                                        | 16.24                                                        | — 0.06                                               |
| “ 16               |                                        | 2                                   | D                         | C   | 28.46                                                        | 28.34                                                        | — 0.12                                               |
| “ 19               |                                        | 0                                   | D                         | C   | 31.42                                                        | 31.32                                                        | — 0.10                                               |
| “ 22               |                                        | 0                                   | D                         | C   | 34.17                                                        | 34.10                                                        | — 0.07                                               |
| August 23          |                                        | 0                                   | C                         | D   | 23.57                                                        | 23.44                                                        | — 0.13                                               |
| “ 25               |                                        | 0                                   | C                         | D   | 25.88                                                        | 25.81                                                        | — 0.07                                               |
| “ 27               |                                        | 0                                   | C                         | D   | 27.41                                                        | 27.26                                                        | — 0.15                                               |
| September 30       |                                        | 1                                   | D                         | C   | 53.14                                                        | 53.13                                                        | — 0.01                                               |
| November 11 and 12 |                                        | 0                                   | D                         | C   | 46.31                                                        | 46.11                                                        | — 0.20                                               |
| “ 18               |                                        | 1                                   | C                         | D   | 46.29                                                        | 46.36                                                        | + 0.07                                               |
| “ 21 and 22        |                                        | 1                                   | C                         | D   | 51.96                                                        | 51.95                                                        | — 0.01                                               |
| December 26        |                                        | 1                                   | D                         | C   | 43.17                                                        | 43.07                                                        | — 0.10                                               |
| February 6         | D and L                                | 0                                   | D                         | L   | 41.89                                                        | 41.63                                                        | — 0.26                                               |
| March 9            |                                        | 5                                   | L                         | D   | 3.27                                                         | 3.14                                                         | — 0.13                                               |
| April 3            |                                        | 4                                   | L                         | D   | 164.51                                                       | 164.30                                                       | — 0.21                                               |
| June 1             |                                        | 0                                   | L                         | D   | 45.32                                                        | 45.06                                                        | — 0.26                                               |
| “ 29               |                                        | 2                                   | L                         | D   | 28.24                                                        | 28.10                                                        | — 0.14                                               |
| July 1             |                                        | 4                                   | D                         | L   | 31.59                                                        | 31.32                                                        | — 0.27                                               |
| “ 14               |                                        | 0                                   | D                         | L   | 40.55                                                        | 40.29                                                        | — 0.26                                               |
| “ 16               |                                        | 0                                   | L                         | D   | 42.60                                                        | 42.34                                                        | — 0.26                                               |
| “ 18               |                                        | 1                                   | L                         | D   | 43.67                                                        | 43.42                                                        | — 0.25                                               |
| October 2          |                                        | 5                                   | D                         |     | 54.06                                                        | 53.87                                                        | — 0.19                                               |
| May 27             | D and J C                              | 4                                   | J C                       | D   | 39.74                                                        | 39.79                                                        | + 0.05                                               |
| July 1             |                                        | 7                                   | D                         | J C | 31.59                                                        | 31.54                                                        | — 0.05                                               |
| November 26        |                                        | 7                                   | D                         | J C | 56.37                                                        | 56.52                                                        | + 0.15                                               |
| May 29             | D and W                                | 0                                   | D                         | W   | 41.84                                                        | 41.72                                                        | — 0.12                                               |
| September 16       |                                        | 0                                   | D                         | W   | 43.77                                                        | 43.66                                                        | — 0.11                                               |
| “ 20               |                                        | 0                                   | D                         | W   | 46.94                                                        | 46.75                                                        | — 0.19                                               |

## PERSONAL EQUATIONS IN GALVANIC TRANSITS.

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## OBSERVATIONS FOR PERSONAL EQUATION—continued.

| Day, 1858.   | Observers in<br>order of<br>Seniority. | Interval<br>of<br>nearest<br>Stars. | Order of<br>Observations. | Clock Slow<br>at $\phi^h$<br>by<br>Senior<br>Observer. | Clock Slow<br>at $\phi^h$<br>by<br>Junior<br>Observer. | Excess of<br>Clock Slow<br>by<br>Junior<br>Observer. |
|--------------|----------------------------------------|-------------------------------------|---------------------------|--------------------------------------------------------|--------------------------------------------------------|------------------------------------------------------|
| September 1  | D and W C                              | <sup>h</sup><br>4                   | D W C                     | 31 <sup>s</sup> 97                                     | 31 <sup>s</sup> 95                                     | — 0 <sup>s</sup> 02                                  |
| „ 12         |                                        | 2                                   | W C D                     | 41 20                                                  | 41 26                                                  | + 0 06                                               |
| „ 18         |                                        | 0                                   | D W C                     | 45 65                                                  | 45 64                                                  | — 0 01                                               |
| „ 24         |                                        | 0                                   | D W C                     | 49 58                                                  | 49 66                                                  | + 0 08                                               |
| December 23  |                                        | 5                                   | W C D                     | 38 85                                                  | 38 80                                                  | — 0 05                                               |
| January 9    | E and C                                | 4                                   | E C                       | 20 78                                                  | 20 51                                                  | — 0 27                                               |
| „ 20         |                                        | 4                                   | E C                       | 29 37                                                  | 29 21                                                  | — 0 16                                               |
| February 1   |                                        | 4                                   | E C                       | 38 14                                                  | 37 93                                                  | — 0 21                                               |
| „ 4          |                                        | 0                                   | C E                       | 39 69                                                  | 39 45                                                  | — 0 24                                               |
| „ 9          |                                        | 2                                   | E C                       | 43 55                                                  | 43 25                                                  | — 0 30                                               |
| March 6      |                                        | 5                                   | E C                       | 2 41                                                   | 2 20                                                   | — 0 21                                               |
| „ 8          |                                        | 4                                   | C E                       | 3 46                                                   | 3 26                                                   | — 0 20                                               |
| May 5        |                                        | 2                                   | E C                       | 16 41                                                  | 16 24                                                  | — 0 17                                               |
| „ 6          |                                        | 4                                   | C E                       | 17 65                                                  | 17 43                                                  | — 0 22                                               |
| „ 18         |                                        | 1                                   | E C                       | 30 58                                                  | 30 30                                                  | — 0 28                                               |
| June 3       |                                        | 3                                   | E C                       | 48 42                                                  | 48 12                                                  | — 0 30                                               |
| July 17      |                                        | 0                                   | E C                       | 43 25                                                  | 43 09                                                  | — 0 16                                               |
| „ 21         |                                        | 1                                   | E C                       | 46 14                                                  | 45 99                                                  | — 0 15                                               |
| „ 25         |                                        | 2                                   | E C                       | 50 40                                                  | 50 17                                                  | — 0 23                                               |
| „ 29         |                                        | 0                                   | E C                       | 55 19                                                  | 54 97                                                  | — 0 22                                               |
| „ 31         |                                        | 0                                   | E C                       | 57 65                                                  | 57 43                                                  | — 0 22                                               |
| August 6     |                                        | 2                                   | C E                       | 4 53                                                   | 4 32                                                   | — 0 21                                               |
| September 30 |                                        | 3                                   | C E                       | 53 25                                                  | 53 13                                                  | — 0 12                                               |
| January 11   | E and L                                | 0                                   | E L                       | 23 03                                                  | 22 66                                                  | — 0 37                                               |
| „ 18         |                                        | 0                                   | E L                       | 27 82                                                  | 27 48                                                  | — 0 34                                               |
| „ 20         |                                        | 1                                   | L E                       | 29 37                                                  | 29 10                                                  | — 0 27                                               |
| „ 22         |                                        | 1                                   | L E                       | 31 03                                                  | 30 73                                                  | — 0 30                                               |
| „ 24         |                                        | 2                                   | L E                       | 32 63                                                  | 32 28                                                  | — 0 35                                               |
| „ 26         |                                        | 0                                   | E L                       | 33 99                                                  | 33 62                                                  | — 0 37                                               |
| „ 28         |                                        | 2                                   | L E                       | 35 29                                                  | 34 83                                                  | — 0 46                                               |
| February 1   |                                        | 0                                   | L E                       | 38 14                                                  | 37 77                                                  | — 0 37                                               |
| „ 16         |                                        | 1                                   | E L                       | 48 97                                                  | 48 56                                                  | — 0 41                                               |
| „ 18         |                                        | 1                                   | L E                       | 50 89                                                  | 50 56                                                  | — 0 33                                               |
| „ 20         |                                        | 0                                   | E L                       | 52 85                                                  | 52 41                                                  | — 0 44                                               |
| „ 22         |                                        | 1                                   | L E                       | 54 75                                                  | 54 34                                                  | — 0 41                                               |
| „ 24         |                                        | 0                                   | E L                       | 56 27                                                  | 55 97                                                  | — 0 30                                               |
| „ 25 and 26  |                                        | 7                                   | E L                       | 57 90                                                  | 57 54                                                  | — 0 36                                               |
| March 8      |                                        | 0                                   | L E                       | 3 46                                                   | 3 21                                                   | — 0 25                                               |
| April 3      |                                        | 3                                   | L E                       | 164 70                                                 | 164 30                                                 | — 0 40                                               |

## xxxvi INTRODUCTION TO GREENWICH ASTRONOMICAL OBSERVATIONS, 1858.

OBSERVATIONS FOR PERSONAL EQUATION—*continued*.

| Day, 1858.      | Observers in<br>order of<br>Seniority. | Interval<br>of<br>nearest<br>Stars. | Order of<br>Observations. |     | Clock Slow<br>at $0^h$<br>by<br>Senior<br>Observer. | Clock Slow<br>at $0^h$<br>by<br>Junior<br>Observer. | Excess of<br>Clock Slow<br>by<br>Junior<br>Observer. |
|-----------------|----------------------------------------|-------------------------------------|---------------------------|-----|-----------------------------------------------------|-----------------------------------------------------|------------------------------------------------------|
| May 6           | E and L                                | <sup>h</sup><br>2                   | L                         | E   | <sup>s</sup><br>17.65                               | <sup>s</sup><br>17.41                               | — 0.24                                               |
| „ 23            |                                        | 0                                   | L                         | E   | 35.30                                               | 34.86                                               | — 0.44                                               |
| „ 28            |                                        | 1                                   | E                         | L   | 40.96                                               | 40.60                                               | — 0.36                                               |
| „ 30            |                                        | 4                                   | L                         | E   | 43.05                                               | 42.68                                               | — 0.37                                               |
| June 1          | „                                      | 5                                   | E                         | L   | 45.50                                               | 45.06                                               | — 0.44                                               |
| „ 3             |                                        | 3                                   | L                         | E   | 48.42                                               | 47.99                                               | — 0.43                                               |
| „ 7             |                                        | 3                                   | L                         | E   | 54.11                                               | 53.72                                               | — 0.39                                               |
| July 30         | „                                      | 3                                   | L                         | E   | 56.27                                               | 55.91                                               | — 0.36                                               |
| August 3        | „                                      | 5                                   | L                         | E   | 60.72                                               | 60.36                                               | — 0.36                                               |
| „ 6             |                                        | 5                                   | E                         | L   | 4.53                                                | 4.26                                                | — 0.27                                               |
| „ 16            |                                        | 0                                   | E                         | L   | 16.57                                               | 16.23                                               | — 0.34                                               |
| „ 20            |                                        | 1                                   | E                         | L   | 21.25                                               | 20.94                                               | — 0.31                                               |
| „ 22            |                                        | 0                                   | L                         | E   | 22.65                                               | 22.33                                               | — 0.32                                               |
| „ 24            |                                        | 0                                   | L                         | E   | 24.79                                               | 24.50                                               | — 0.29                                               |
| „ 26            |                                        | 0                                   | L                         | E   | 26.65                                               | 26.30                                               | — 0.35                                               |
| September 27    | „                                      | 0                                   | E                         | L   | 51.33                                               | 50.84                                               | — 0.49                                               |
| November 11     | „                                      | 1                                   | E                         | L   | 45.95                                               | 45.56                                               | — 0.39                                               |
| „ 15            |                                        | 1                                   | L                         | E   | 46.10                                               | 45.77                                               | — 0.33                                               |
| „ 17            |                                        | 0                                   | L                         | E   | 45.87                                               | 45.41                                               | — 0.46                                               |
| „ 21            |                                        | 4                                   | L                         | E   | 50.72                                               | 50.38                                               | — 0.34                                               |
| „ 23            |                                        | 0                                   | E                         | L   | 53.20                                               | 52.95                                               | — 0.25                                               |
| July 19         | E and JC                               | 0                                   | J C                       | E   | 44.41                                               | 44.34                                               | — 0.07                                               |
| August 3        |                                        | 5                                   | J C                       | E   | 60.72                                               | 60.46                                               | — 0.26                                               |
| December 24     |                                        | 0                                   | E                         | J C | 40.27                                               | 40.14                                               | — 0.13                                               |
| „ 28            | „                                      | 0                                   | E                         | J C | 45.63                                               | 45.43                                               | — 0.20                                               |
| June 15         | E and W                                | 1                                   | E                         | W   | 5.45                                                | 5.15                                                | — 0.30                                               |
| July 31         |                                        | 5                                   | E                         | W   | 57.65                                               | 57.36                                               | — 0.29                                               |
| August 9        |                                        | 1                                   | E                         | W   | 8.45                                                | 8.35                                                | — 0.10                                               |
| „ 30            | „                                      | 2                                   | W                         | E   | 30.31                                               | 30.01                                               | — 0.30                                               |
| June 17         | E and WC                               | 0                                   | W C                       | E   | 8.73                                                | 8.63                                                | — 0.10                                               |
| July 30         |                                        | 4                                   | W C                       | E   | 56.27                                               | 56.21                                               | — 0.06                                               |
| August 28       |                                        | 1                                   | E                         | W C | 28.35                                               | 28.39                                               | + 0.04                                               |
| September 1     |                                        | 0                                   | E                         | W C | 32.01                                               | 31.95                                               | — 0.06                                               |
| January 3 and 4 | C and L                                | 0                                   | L                         | C   | 17.64                                               | 17.58                                               | — 0.06                                               |
| „ 6 and 7       |                                        | 0                                   | C                         | L   | 20.22                                               | 20.07                                               | — 0.15                                               |
| „ 11            |                                        | 6                                   | C                         | L   | 22.62                                               | 22.66                                               | + 0.04                                               |

## PERSONAL EQUATIONS IN GALVANIC TRANSITS.

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OBSERVATIONS FOR PERSONAL EQUATION—*continued.*

| Day, 1858.   | Observers in<br>order of<br>Seniority. | Interval<br>of<br>nearest<br>Stars. | Order of<br>Observations. |     | Clock Slow<br>at $0^h$<br>by<br>Senior<br>Observer. | Clock Slow<br>at $0^h$<br>by<br>Junior<br>Observer. | Excess of<br>Clock Slow<br>by<br>Junior<br>Observer. |
|--------------|----------------------------------------|-------------------------------------|---------------------------|-----|-----------------------------------------------------|-----------------------------------------------------|------------------------------------------------------|
| February 1   | C and L                                | <sup>h</sup> 6                      | L                         | C   | <sup>s</sup> 37.93                                  | <sup>s</sup> 37.77                                  | — 0.16                                               |
| " 6          |                                        | 4                                   | C                         | L   | 40.92                                               | 40.81                                               | — 0.11                                               |
| March 8      |                                        | 2                                   | C                         | L   | 2.86                                                | 2.74                                                | — 0.12                                               |
| " 21         |                                        | 1                                   | L                         | C   | 11.23                                               | 11.16                                               | — 0.07                                               |
| " 23         |                                        | 1                                   | L                         | C   | 12.84                                               | 12.77                                               | — 0.07                                               |
| " 29         |                                        | 0                                   | C                         | L   | 16.15                                               | 16.08                                               | — 0.07                                               |
| April 18     |                                        | 4                                   | L                         | C   | 57.74                                               | 57.74                                               | 0.00                                                 |
| " 20         |                                        | 0                                   | L                         | C   | 60.01                                               | 59.82                                               | — 0.19                                               |
| " 22         |                                        | 0                                   | C                         | L   | 62.15                                               | 62.05                                               | — 0.10                                               |
| " 24         |                                        | 1                                   | L                         | C   | 4.45                                                | 4.26                                                | — 0.19                                               |
| " 26         | =                                      | 1                                   | C                         | L   | 6.49                                                | 6.43                                                | — 0.06                                               |
| " 28         |                                        | 1                                   | C                         | L   | 9.67                                                | 9.53                                                | — 0.14                                               |
| " 30         |                                        | 0                                   | L                         | C   | 11.56                                               | 11.45                                               | — 0.11                                               |
| May 4        |                                        | 3                                   | L                         | C   | 15.11                                               | 14.94                                               | — 0.17                                               |
| " 6          |                                        | 2                                   | C                         | L   | 17.43                                               | 17.41                                               | — 0.02                                               |
| " 20         |                                        | 0                                   | C                         | L   | 32.26                                               | 32.05                                               | — 0.21                                               |
| June 3       |                                        | 6                                   | L                         | C   | 48.12                                               | 47.99                                               | — 0.13                                               |
| August 1     |                                        | 6                                   | L                         | C   | 58.13                                               | 57.93                                               | — 0.20                                               |
| September 13 |                                        | 0                                   | C                         | L   | 41.69                                               | 41.52                                               | — 0.17                                               |
| " 15         |                                        | 0                                   | L                         | C   | 42.99                                               | 42.78                                               | — 0.21                                               |
| " 17         | C and JC                               | 0                                   | C                         | L   | 44.52                                               | 44.38                                               | — 0.14                                               |
| " 25         |                                        | 1                                   | C                         | L   | 49.82                                               | 49.65                                               | — 0.17                                               |
| June 16      |                                        | 1                                   | J C                       | C   | 6.74                                                | 6.79                                                | + 0.05                                               |
| " 22         |                                        | 0                                   | C                         | J C | 16.43                                               | 16.55                                               | + 0.12                                               |
| August 13    |                                        | 1                                   | C                         | J C | 12.77                                               | 12.84                                               | + 0.07                                               |
| " 19         |                                        | 1                                   | J C                       | C   | 19.96                                               | 20.06                                               | + 0.10                                               |
| " 31         |                                        | 0                                   | C                         | J C | 30.84                                               | 30.95                                               | + 0.11                                               |
| February 19  | C and W                                | 0                                   | W                         | C   | 51.71                                               | 51.69                                               | — 0.02                                               |
| " 24         |                                        | 0                                   | C                         | W   | 19.83                                               | 19.68                                               | — 0.15                                               |
| July 31      |                                        | 5                                   | C                         | W   | 57.43                                               | 57.36                                               | — 0.07                                               |
| August 30    |                                        | 6                                   | C                         | W   | 30.10                                               | 30.01                                               | — 0.09                                               |
| December 2   |                                        | 0                                   | C                         | W   | 8.41                                                | 8.36                                                | — 0.05                                               |
| " 21         |                                        | 0                                   | C                         | W   | 35.31                                               | 35.25                                               | — 0.06                                               |
| June 14      | C and WC                               | 0                                   | WC                        | C   | 3.56                                                | 3.75                                                | + 0.19                                               |
| " 28         |                                        | 1                                   | WC                        | C   | 26.44                                               | 26.62                                               | + 0.18                                               |
| December 19  |                                        | 0                                   | WC                        | C   | 31.77                                               | 31.86                                               | + 0.09                                               |
| July 1       | L and JC                               | 2                                   | L                         | J C | 31.32                                               | 31.54                                               | + 0.22                                               |
| " 28         |                                        | 0                                   | L                         | J C | 53.66                                               | 53.89                                               | + 0.23                                               |
| August 3     |                                        | 1                                   | L                         | J C | 60.36                                               | 60.46                                               | + 0.10                                               |

## OBSERVATIONS FOR PERSONAL EQUATION—concluded.

| Day, 1858.        | Observers in<br>order of<br>Seniority. | Interval<br>of<br>nearest<br>Stars. | Order of<br>Observations. |        | Clock Slow<br>at 0 <sup>h</sup><br>by<br>Senior<br>Observer. | Clock Slow<br>at 0 <sup>h</sup><br>by<br>Junior<br>Observer. | Excess of<br>Clock Slow<br>by<br>Junior<br>Observer. |
|-------------------|----------------------------------------|-------------------------------------|---------------------------|--------|--------------------------------------------------------------|--------------------------------------------------------------|------------------------------------------------------|
| April 13          | L and W                                | <sup>h</sup><br>1                   | W                         | L      | 53.06                                                        | 53.19                                                        | + 0.13                                               |
| July 26           |                                        | 0                                   | L                         | W      | 51.06                                                        | 50.99                                                        | - 0.07                                               |
| August 7<br>,, 30 |                                        | 1<br>0                              | L<br>L                    | W<br>W | 5.44<br>29.84                                                | 5.44<br>30.01                                                | 0.00<br>+ 0.17                                       |
| May 26            | L and WC                               | 3                                   | L                         | W C    | 38.39                                                        | 38.74                                                        | + 0.35                                               |
| July 30           |                                        | 1                                   | L                         | W C    | 55.91                                                        | 56.21                                                        | + 0.30                                               |
| August 5          |                                        | 1                                   | W C                       | L      | 2.89                                                         | 3.24                                                         | + 0.35                                               |
| September 1       |                                        | 5                                   | W C                       | L      | 31.80                                                        | 31.95                                                        | + 0.15                                               |

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 M.                                                                                                                                                                   | For C.                                                                                                                                                                      |
| $M - E = - 0.12$<br>$3 (M - C) = + 0.60$<br>$M - W C = + 0.11$                                                                                                           | $3 (C - M) = - 0.60$<br>$25 (C - D) = - 2.09$<br>$18 (C - E) = - 3.87$<br>$25 (C - L) = + 2.98$<br>$5 (C - J C) = - 0.45$<br>$6 (C - W) = + 0.44$<br>$3 (C - W C) = - 0.46$ |
| For D.                                                                                                                                                                   | For L.                                                                                                                                                                      |
| $34 (D - E) = - 4.97$<br>$25 (D - C) = + 2.09$<br>$10 (D - L) = + 2.23$<br>$3 (D - J C) = - 0.15$<br>$3 (D - W) = + 0.42$<br>$5 (D - W C) = - 0.06$                      | $10 (L - D) = - 2.23$<br>$37 (L - E) = - 13.26$<br>$25 (L - C) = - 2.98$<br>$3 (L - J C) = - 0.55$<br>$4 (L - W) = - 0.23$<br>$4 (L - W C) = - 1.15$                        |
| For E.                                                                                                                                                                   | For J C.                                                                                                                                                                    |
| $E - M = + 0.12$<br>$34 (E - D) = + 4.97$<br>$18 (E - C) = + 3.87$<br>$37 (E - L) = + 13.26$<br>$4 (E - J C) = + 0.66$<br>$4 (E - W) = + 0.99$<br>$4 (E - W C) = + 0.18$ | $3 (J C - D) = + 0.15$<br>$4 (J C - E) = - 0.66$<br>$5 (J C - C) = + 0.45$<br>$3 (J C - L) = + 0.55$                                                                        |

| For W.    |              | For W C.    |              |
|-----------|--------------|-------------|--------------|
|           | <sup>s</sup> |             | <sup>s</sup> |
| 3 (W - D) | = - 0.42     | W C - M     | = - 0.11     |
| 4 (W - E) | = - 0.99     | 5 (W C - D) | = + 0.06     |
| 6 (W - C) | = - 0.44     | 4 (W C - E) | = - 0.18     |
| 4 (W - L) | = + 0.23     | 3 (W C - C) | = + 0.46     |
|           |              | 4 (W C - L) | = + 1.15     |

Now, since one of the quantities denoted by M, D, E, &c., must evidently remain indeterminate, we will refer all the rest to D as a standard; and, putting  $D = 0$ , the initials M, E, C, &c., will represent the values of "clock-slow," which would be given by the observations of Mr. Main, Mr. Ellis, Mr. Criswick, &c., when that given by the observations of Mr. Dunkin  $= 0$ .

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 coefficient :

|                                                |             |
|------------------------------------------------|-------------|
| 5 M - E - 3 C - W C                            | $= + 0.59$  |
| 102 E - M - 18 C - 37 L - 4 J C - 4 W - 4 W C  | $= + 24.05$ |
| 85 C - 3 M - 18 E - 25 L - 5 J C - 6 W - 3 W C | $= - 4.05$  |
| 83 L - 37 E - 25 C - 3 J C - 4 W - 4 W C       | $= - 20.40$ |
| 15 J C - 4 E - 5 C - 3 L                       | $= + 0.49$  |
| 17 W - 4 E - 6 C - 4 L                         | $= - 1.62$  |
| 17 W C - M - 4 E - 3 C - 4 L                   | $= + 1.38$  |

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 coefficient, 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 :—

$$M = + 0.11; E = + 0.14; C = - 0.08; L = - 0.21; J C = 0.00; W = - 0.14; \\ W C = + 0.06;$$

or, restoring D :—

|       |            |         |            |         |            |
|-------|------------|---------|------------|---------|------------|
| D - M | $= - 0.11$ | D - L   | $= + 0.21$ | D - W C | $= - 0.06$ |
| D - E | $= - 0.14$ | D - J C | $= 0.00$   |         |            |
| D - C | $= + 0.08$ | D - W   | $= + 0.14$ |         |            |

During a portion of the year 1858, it was necessary to resort to the method of observation by eye and ear, and the following Table gives the personal equations resulting from observations made by that method.

## OBSERVATIONS FOR THE PERSONAL EQUATIONS OF THE VARIOUS TRANSIT-OBSERVERS USING THE EYE-AND-EAR METHOD OF OBSERVING TRANSITS.

| Day, 1858.       | Observers in order of Seniority. | Interval of nearest Stars. | Order of Observations. | Clock Slow at 0 <sup>h</sup> by Senior Observer. | Clock Slow at 0 <sup>h</sup> by Junior Observer. | Excess of Clock Slow by Junior Observer. |
|------------------|----------------------------------|----------------------------|------------------------|--------------------------------------------------|--------------------------------------------------|------------------------------------------|
| October 16       | M and L                          | 0                          | L M                    | 60 <sup>s</sup> 40                               | 60 <sup>s</sup> 04                               | - 0 <sup>s</sup> 36                      |
| October 11       | D and E                          | 0                          | E D                    | 58 88                                            | 58 82                                            | - 0 06                                   |
| „ 15             |                                  | 0                          | E D                    | 61 12                                            | 61 15                                            | + 0 03                                   |
| „ 17             |                                  | 2                          | D E                    | 58 48                                            | 58 45                                            | - 0 03                                   |
| „ 25             |                                  | 0                          | D E                    | 47 37                                            | 47 36                                            | - 0 01                                   |
| October 30       | D and C                          | 7                          | C D                    | 46 42                                            | 46 52                                            | + 0 10                                   |
| October 4        | D and L                          | 2                          | D L                    | 48 20                                            | 47 80                                            | - 0 40                                   |
| October 29       | E and C                          | 5                          | E C                    | 46 20                                            | 46 38                                            | + 0 18                                   |
| November 2 and 3 |                                  | 6                          | E C                    | 43 72                                            | 43 78                                            | + 0 06                                   |
| October 27       | E and W                          | 1                          | W E                    | 46 75                                            | 46 81                                            | + 0 06                                   |
| November 2       | E and L                          | 4                          | L E                    | 43 72                                            | 43 38                                            | - 0 34                                   |
| October 22       | C and L                          | 0                          | L C                    | 47 54                                            | 47 20                                            | - 0 34                                   |
| „ 26             |                                  | 0                          | L C                    | 46 98                                            | 46 60                                            | - 0 38                                   |
| „ 28             |                                  | 7                          | C L                    | 46 22                                            | 45 92                                            | - 0 30                                   |
| October 28       | C and W C                        | 0                          | C W C                  | 46 22                                            | 46 29                                            | + 0 07                                   |
| October 20       | L and W C                        | 0                          | L W C                  | 50 33                                            | 50 62                                            | + 0 29                                   |

Treating these results for personal equation precisely as in the case of the transits made by the galvanic method, we arrive at the following results applicable to transits made by eye and ear:—

$$\begin{array}{ll}
 D - M = -0^s \cdot 01 & D - L = +0^s \cdot 35 \\
 D - E = +0^s \cdot 04 & D - W = -0^s \cdot 02 \\
 D - C = -0^s \cdot 01 & D - W C = +0^s \cdot 06
 \end{array}$$

The personal equations as applicable to both methods of observing have been applied to the results of transits in the ledger results of stars, and in the collected results for the Sun, Moon, and Planets, whenever they were needed throughout the year 1858.

## PERSONAL EQUATION; DURATION OF PASSAGE OF PLANETS' SEMIDIAMETERS. xli

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

For Venus, a correction is applied to the Nautical-Almanac-semidiameter, determined by means of observations made in 1851, 1852, and 1853, with the Transit-Circle. The investigation is given in detail in the volume for 1854, to which it is sufficient to refer. The correction derived from it and applied to the Nautical-Almanac-semidiameter during the year 1858, is

$$0^s \cdot 04 + 0 \cdot 004 \times \text{tabular duration of passage of semidiameter.}$$

For Mars a correction has been applied, derived from the transits of both limbs at and near the opposition of 1858. From twenty-six transits, extending from April 19 to June 11, the mean error of the time of transit of the diameter given in the Nautical Almanac was found to be  $-0^s \cdot 23$ , corresponding to a time of transit equal to  $1^s \cdot 14$ . Hence, the correction to be applied additively to the tabular time of transit of semidiameter is easily found to be

$$0 \cdot 206 \times \text{time of transit of semidiameter.}$$

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 from a few of the neighbouring observations.

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, excluding Polaris, have been observed; and no result is set down for Polaris or  $\delta$  Ursæ Minoris, or other close circumpolar stars, unless Polaris or  $\delta$  Ursæ Minoris has been observed at opposite passages.

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 1858. 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 (corrected, in

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the case of Polaris, Cephei 51 (Hev.),  $\delta$  Ursæ Minoris, and  $\lambda$  Ursæ Minoris, for the Moon's longitude): the sign of the quantity so found is changed.

For other stars, the corrections are computed by the formula

$$E e + F f + G g + H h + L + l - 300^{\circ},$$

which is derived from the well-known formula,

$$A a + B b + C c + D d,$$

or its equivalent,

$$\frac{A}{15} \cos R.A. \operatorname{cosec} N.P.D. + \frac{B}{15} \sin R.A. \operatorname{cosec} N.P.D. + C \sin R.A. \cotan N.P.D. \times \text{numb. log. } 0.1259 + \frac{D}{15} \cos R.A. \cot N.P.D. + C \times \text{numb. log. } 0.4869,$$

by a process which is explained with sufficient detail in the Introduction to the Twelve-Year-Catalogue appended to the volume for 1847, and in the Catalogue of 1576 Stars for 1850, appended to the volume for 1854. It will be sufficient here to state that  $E = A + 25$ ,  $F = B + 25$ ,  $G = C + 1.2$ ,  $H = D + 25$ ,  $e = a + 1.2$ ,  $f = b + 1.2$ ,  $g = c + 25$ ,  $h = d + 1.2$ ,  $L = 210 - 1.2 \times E - 1.2 \times F - 25 \times G - 1.2 \times H$ ,  $l = 210 - 25 \times e - 25 \times f - 1.2 \times g - 25 \times h$ . The values of the day-constants  $\log. E$ ,  $\log. F$ ,  $\log. G$ ,  $\log. H$ , and  $L$ , for the years from 1849 to 1860, both inclusive, and the values of the star-constants,  $\log. e$ ,  $\log. f$ ,  $\log. g$ ,  $\log. h$ , and  $l$ , are generally contained in the "Greenwich Twelve-Year-Catalogue." For stars not included in the Twelve-Year-Catalogue, the values of  $\log. e$ ,  $\log. f$ , &c., will be found either in the Catalogue of 1576 Stars for 1850, or in the annual Catalogues for 1854, 1855, 1856, and 1857, or in that included in the present volume. The values of  $\log. A$ ,  $\log. B$ ,  $\log. C$ ,  $\log. D$ , for the formation of the numbers above, were taken from the Nautical Almanac for all the published volumes, and, for the other years, they were obligingly supplied, at my request, by Lieut. Stratford, the late Superintendent of that work. The values of  $\log. a$ ,  $\log. b$ ,  $\log. c$ ,  $\log. d$ , have been taken from the Catalogue of the British Association, whenever the star was found in that Catalogue.

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, Level, and Azimuth, page [118] to [133].*

Very little information is needed, with regard to these tables, in addition to the explanation which has been given in the description of the instrument, and in the explanation of the methods of determining the errors of collimation and level.

A few remarks under the head of each separate Table will be sufficient.

## STAR-CORRECTIONS; OBSERVATIONS OF COLLIMATORS, AND OF WIRE BY REFLEXION. xliii

## OBSERVATIONS FOR COINCIDENCE OF COLLIMATORS.

These observations are made on the Monday of every week, the Transit-Circle being raised to admit a view of the North Collimator by the South Collimator.

By means of the micrometer of the South 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 South 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 v and xxiii). The mean of the readings for the separate collimators, and the resulting reading for the line of collimation, are set down in consecutive columns, and the last column gives the reading which has been adopted for the period of time limited by the bars above and below. 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  $-0''.19$  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 OF THE TRANSIT-CIRCLE.

The method of making these observations has been described (pages v and xxiv). 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.

## DETERMINATION OF THE AZIMUTH OF THE NORTH COLLIMATOR.

The reading of the Transit-Micrometer for coincidence of the transit-wire with the North Collimator, used in connexion with the reading for the line of collimation, and with the error of azimuth of the Transit-Circle deduced from observations of circumpolar

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stars, gives a determination of the azimuth of the wire of the collimator. The different columns of the Table give the mean readings for the collimator, the adopted reading for the line of collimation, the error of azimuth of the Transit-Circle, and the names of the circumpolar stars by means of which it has been deduced; and finally, the resulting and adopted values of the azimuth of the North Collimator, with the limits of time during which each value has been used.

The particulars of the determination of the separate values of the azimuth of the Transit-Circle are given in the foot-notes of the section *Transits observed*, &c.

DETERMINATION OF THE AZIMUTH OF THE TRANSIT-CIRCLE BY MEANS OF THE AZIMUTHS OF THE NORTH COLLIMATOR.

The values of the azimuth of the North Collimator, determined in the manner above described, are applied to determine the azimuth of the Transit-Circle for ordinary use. The advantage of the application of such a method depends on the degree of stability of the collimators and the transit-telescope. In the use of instruments of so massive a construction as the great Transit-Circle, and with collimators so firmly mounted as those under consideration, the mean errors of azimuth ultimately deduced by combining the micrometer-readings for coincidence of transit-wire with collimator, with the assumed azimuth of collimator, and the known reading for the line of collimation, will be, at least for a short period, more worthy of credit than the separate determinations deduced immediately from stars. The columns of the Table require no explanation.

§ 3. *Apparent Right Ascensions of  $\alpha^1$  Ursæ Minoris, Polaris, and  $\delta$  Ursæ Minoris; and Mean Right Ascensions of Stars observed in the Year 1858, page [136] to [154].*

The apparent right ascensions of  $\alpha^1$  Ursæ Minoris, Polaris, and  $\delta$  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 rigorously 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.

The rules for the nomenclature of stars are the same as those in the section of the *Transits observed*, detailed in page xvii, but they are more rigorously followed. The stars in Weisse's Catalogue 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 Stars in Carrington's Red Hill Catalogue are referred to under the initials R. H. Cat.

§ 4. *Observations of Zenith Distance with the Transit-Circle*, page (2) to (131).

The arrangement of the printed observations in the present volume is the same as in the late volumes, commencing with that for 1850, so as to include the whole of the reductions belonging to a single observation on one page. For this purpose, the elements for the reductions which are not frequently changed, and which do not require tabular arrangement, are given in the foot-notes: these are correction for runs; formulae for 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<sup>s</sup>. 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 vi. For other objects, the letter R. denotes that the object is observed by reflexion in the trough of mercury.

READINGS OF THE SIX MICROSCOPE-MICROMETERS.—The application of the letters 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. These readings in the observing books are placed in the order  $\begin{smallmatrix} A, C, E \\ B, D, F \end{smallmatrix}$ : 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, this will occasion no ambiguity. 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.

It is proper now to explain how the revolutions and parts of revolutions of the microscope-micrometers are converted into arc.

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 shewn 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 shewn 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 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.

From the ordinary observations of runs (those for the year 1858 being given at page (134) &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<sup>o</sup>3. Now, if the correction by 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  $\frac{50}{51} \times 30^{\circ}000$ , or 29<sup>o</sup>4118. 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<sup>o</sup>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  $\frac{r X}{100}$ : a quantity which can easily be taken from the ordinary sliding-rule.

The correction for runs on 100'', determined by the method just explained, is given in the foot-notes.

RUNS ; TELESCOPE-MICROMETER ; ERRORS OF DIVISION ; AND FLEXURE. xlvii

Whenever, on account of accidents, it has been practicable to read only four microscopes, the correction for the runs on  $100''$  is obtained in a manner analogous to that given above.

READING OF TELESCOPE-MICROMETER.—This column contains the reading of the micrometer in the eye-piece of the telescope. 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.

The value of one revolution of the zenith distance micrometer, as originally determined, was  $29''.626$ . This value is the result of the investigation made at the end of 1850, as is explained in the description of the Transit Circle, page {22} Appendix I. of the volume for 1852.

A new investigation for verification of the value was made on October 28, 1853, and the resulting value was  $29''.618$ .

On June 18, 1857, before the transit of the Sun, the screw of the Zenith-Distance Micrometer was accidentally broken. A new screw was substituted by Mr. Simms on June 22, and the value of a revolution, determined in the usual way, was found to be  $29''.602$ . This value has been used from that day to the present time.

VERTICAL WIRE AT WHICH OBSERVATION IS MADE.—Omitting, in this Section, all reference to the wires Q, R, S, U, V, W, (page xviii) 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  $14^s$  (Table, page xix), 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.

CORRECTIONS FOR ERROR OF DIVISION AND 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 account of the instrument, printed as an Appendix to the volume for 1852. At the end of the year 1856 a new investigation was made both of the division-corrections, and of the astronomical flexure of the telescope. The principal reason for repeating these observations was that, in the former investigation, the focal adjustment of the object-glasses of the microscope used in determining the errors of the single degrees

was slightly defective. This defect does not exist sensibly in the present determination. 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. It will suffice, therefore, to give the table containing the final result for errors of division for every degree: ( $1^{\circ} = 61'' \cdot 4$  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. |
|---------|--------------------|---------|--------------------|---------|--------------------|---------|--------------------|---------|--------------------|---------|--------------------|---------|--------------------|---------|--------------------|---------|--------------------|---------|--------------------|
| 0       | 0                  | 36      | 0                  | 72      | 0                  | 108     | 0                  | 144     | 0                  | 180     | 0                  | 216     | 0                  | 252     | 0                  | 288     | 0                  | 324     | 0                  |
| 1       | 0.050              | 37      | 0.058              | 73      | 0.054              | 109     | 0.058              | 145     | 0.081              | 181     | 0.056              | 217     | 0.043              | 253     | 0.047              | 289     | 0.068              | 325     | 0.082              |
| 2       | 0.046              | 38      | 0.046              | 74      | 0.053              | 110     | 0.054              | 146     | 0.065              | 182     | 0.063              | 218     | 0.048              | 254     | 0.060              | 290     | 0.068              | 326     | 0.082              |
| 3       | 0.049              | 39      | 0.045              | 75      | 0.053              | 111     | 0.046              | 147     | 0.073              | 183     | 0.061              | 219     | 0.052              | 255     | 0.064              | 291     | 0.070              | 327     | 0.079              |
| 4       | 0.051              | 40      | 0.049              | 76      | 0.060              | 112     | 0.048              | 148     | 0.082              | 184     | 0.059              | 220     | 0.042              | 256     | 0.067              | 292     | 0.074              | 328     | 0.086              |
| 5       | 0.046              | 41      | 0.049              | 77      | 0.054              | 113     | 0.049              | 149     | 0.082              | 185     | 0.046              | 221     | 0.041              | 257     | 0.063              | 293     | 0.076              | 329     | 0.085              |
| 6       | 0.048              | 42      | 0.052              | 78      | 0.052              | 114     | 0.060              | 150     | 0.078              | 186     | 0.038              | 222     | 0.044              | 258     | 0.067              | 294     | 0.084              | 330     | 0.072              |
| 7       | 0.042              | 43      | 0.053              | 79      | 0.051              | 115     | 0.065              | 151     | 0.077              | 187     | 0.045              | 223     | 0.044              | 259     | 0.070              | 295     | 0.081              | 331     | 0.067              |
| 8       | 0.049              | 44      | 0.050              | 80      | 0.059              | 116     | 0.063              | 152     | 0.083              | 188     | 0.048              | 224     | 0.046              | 260     | 0.081              | 296     | 0.073              | 332     | 0.064              |
| 9       | 0.051              | 45      | 0.044              | 81      | 0.057              | 117     | 0.069              | 153     | 0.085              | 189     | 0.052              | 225     | 0.045              | 261     | 0.085              | 297     | 0.067              | 333     | 0.070              |
| 10      | 0.049              | 46      | 0.047              | 82      | 0.068              | 118     | 0.071              | 154     | 0.091              | 190     | 0.041              | 226     | 0.050              | 262     | 0.080              | 298     | 0.067              | 334     | 0.087              |
| 11      | 0.048              | 47      | 0.033              | 83      | 0.071              | 119     | 0.070              | 155     | 0.090              | 191     | 0.043              | 227     | 0.059              | 263     | 0.099              | 299     | 0.073              | 335     | 0.075              |
| 12      | 0.052              | 48      | 0.065              | 84      | 0.072              | 120     | 0.077              | 156     | 0.082              | 192     | 0.043              | 228     | 0.058              | 264     | 0.094              | 300     | 0.088              | 336     | 0.072              |
| 13      | 0.050              | 49      | 0.064              | 85      | 0.065              | 121     | 0.082              | 157     | 0.070              | 193     | 0.043              | 229     | 0.061              | 265     | 0.089              | 301     | 0.096              | 337     | 0.067              |
| 14      | 0.058              | 50      | 0.051              | 86      | 0.067              | 122     | 0.084              | 158     | 0.059              | 194     | 0.041              | 230     | 0.051              | 266     | 0.090              | 302     | 0.089              | 338     | 0.062              |
| 15      | 0.041              | 51      | 0.048              | 87      | 0.067              | 123     | 0.084              | 159     | 0.068              | 195     | 0.036              | 231     | 0.057              | 267     | 0.085              | 303     | 0.094              | 339     | 0.062              |
| 16      | 0.045              | 52      | 0.051              | 88      | 0.076              | 124     | 0.091              | 160     | 0.071              | 196     | 0.039              | 232     | 0.065              | 268     | 0.087              | 304     | 0.099              | 340     | 0.070              |
| 17      | 0.042              | 53      | 0.063              | 89      | 0.068              | 125     | 0.088              | 161     | 0.067              | 197     | 0.033              | 233     | 0.068              | 269     | 0.086              | 305     | 0.093              | 341     | 0.063              |
| 18      | 0.049              | 54      | 0.064              | 90      | 0.069              | 126     | 0.092              | 162     | 0.068              | 198     | 0.033              | 234     | 0.062              | 270     | 0.082              | 306     | 0.098              | 342     | 0.074              |
| 19      | 0.047              | 55      | 0.069              | 91      | 0.066              | 127     | 0.086              | 163     | 0.065              | 199     | 0.041              | 235     | 0.065              | 271     | 0.073              | 307     | 0.098              | 343     | 0.065              |
| 20      | 0.048              | 56      | 0.064              | 92      | 0.074              | 128     | 0.084              | 164     | 0.073              | 200     | 0.040              | 236     | 0.058              | 272     | 0.065              | 308     | 0.091              | 344     | 0.057              |
| 21      | 0.038              | 57      | 0.057              | 93      | 0.068              | 129     | 0.081              | 165     | 0.079              | 201     | 0.042              | 237     | 0.065              | 273     | 0.064              | 309     | 0.083              | 345     | 0.070              |
| 22      | 0.047              | 58      | 0.062              | 94      | 0.071              | 130     | 0.072              | 166     | 0.081              | 202     | 0.049              | 238     | 0.071              | 274     | 0.061              | 310     | 0.084              | 346     | 0.066              |
| 23      | 0.055              | 59      | 0.067              | 95      | 0.067              | 131     | 0.076              | 167     | 0.071              | 203     | 0.053              | 239     | 0.078              | 275     | 0.073              | 311     | 0.094              | 347     | 0.059              |
| 24      | 0.043              | 60      | 0.065              | 96      | 0.065              | 132     | 0.074              | 168     | 0.057              | 204     | 0.048              | 240     | 0.074              | 276     | 0.074              | 312     | 0.097              | 348     | 0.067              |
| 25      | 0.047              | 61      | 0.063              | 97      | 0.064              | 133     | 0.064              | 169     | 0.051              | 205     | 0.046              | 241     | 0.068              | 277     | 0.079              | 313     | 0.094              | 349     | 0.065              |
| 26      | 0.053              | 62      | 0.068              | 98      | 0.075              | 134     | 0.072              | 170     | 0.044              | 206     | 0.050              | 242     | 0.056              | 278     | 0.091              | 314     | 0.094              | 350     | 0.049              |
| 27      | 0.048              | 63      | 0.063              | 99      | 0.079              | 135     | 0.074              | 171     | 0.047              | 207     | 0.049              | 243     | 0.065              | 279     | 0.084              | 315     | 0.084              | 351     | 0.056              |
| 28      | 0.047              | 64      | 0.067              | 100     | 0.074              | 136     | 0.080              | 172     | 0.038              | 208     | 0.041              | 244     | 0.075              | 280     | 0.082              | 316     | 0.091              | 352     | 0.057              |
| 29      | 0.044              | 65      | 0.057              | 101     | 0.072              | 137     | 0.078              | 173     | 0.036              | 209     | 0.045              | 245     | 0.069              | 281     | 0.077              | 317     | 0.093              | 353     | 0.059              |
| 30      | 0.054              | 66      | 0.057              | 102     | 0.073              | 138     | 0.072              | 174     | 0.034              | 210     | 0.056              | 246     | 0.065              | 282     | 0.082              | 318     | 0.090              | 354     | 0.046              |
| 31      | 0.063              | 67      | 0.056              | 103     | 0.069              | 139     | 0.075              | 175     | 0.043              | 211     | 0.060              | 247     | 0.062              | 283     | 0.083              | 319     | 0.078              | 355     | 0.044              |
| 32      | 0.069              | 68      | 0.056              | 104     | 0.066              | 140     | 0.075              | 176     | 0.062              | 212     | 0.051              | 248     | 0.046              | 284     | 0.078              | 320     | 0.083              | 356     | 0.041              |
| 33      | 0.070              | 69      | 0.057              | 105     | 0.055              | 141     | 0.075              | 177     | 0.062              | 213     | 0.044              | 249     | 0.045              | 285     | 0.071              | 321     | 0.073              | 357     | 0.050              |
| 34      | 0.063              | 70      | 0.061              | 106     | 0.037              | 142     | 0.082              | 178     | 0.062              | 214     | 0.045              | 250     | 0.062              | 286     | 0.064              | 322     | 0.077              | 358     | 0.055              |
| 35      | 0.051              | 71      | 0.061              | 107     | 0.052              | 143     | 0.086              | 179     | 0.054              | 215     | 0.042              | 251     | 0.054              | 287     | 0.052              | 323     | 0.089              | 359     | 0.040              |

On 1857, January 5 and 21, two series of observations were made for the determination of the astronomical flexure of the telescope. The result obtained on January 5 showed that the Horizontal South Readings ought to be increased by  $0''.46$ , while that obtained on January 21 gave  $0''.66$ . The mean of these results, or  $0''.56$ , has been adopted, and the product of this quantity by the sine of the zenith distance has been incorporated with the mean of the numbers in the preceding table, which apply

## CORRECTIONS FOR FLEXURE OF TELESCOPE AND ERRORS OF DIVISION OF CIRCLE. xlix

to the mean of the divisions that are viewed simultaneously under the six microscopes. These resulting corrections, which are contained in the following Table, have been applied additively to all circle-readings throughout the year 1858.

## 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. |
|------------------|-------|------------------|-------|------------------|-------|------------------|-------|------------------|-------|------------------|-------|------------------|-------|------------------|-------|------------------|-------|
| 0                | 0.76  | 36               | 1.23  | 72               | 1.55  | 108              | 1.76  | 144              | 1.65  | 180              | 0.76  | 216              | 0.57  | 252              | 0.49  | 288              | 0.70  |
| 1                | 0.80  | 37               | 1.31  | 73               | 1.60  | 109              | 1.71  | 145              | 1.58  | 181              | 0.78  | 217              | 0.65  | 253              | 0.52  | 289              | 0.65  |
| 2                | 0.83  | 38               | 1.43  | 74               | 1.69  | 110              | 1.62  | 146              | 1.49  | 182              | 0.79  | 218              | 0.75  | 254              | 0.61  | 290              | 0.58  |
| 3                | 0.82  | 39               | 1.51  | 75               | 1.74  | 111              | 1.56  | 147              | 1.38  | 183              | 0.76  | 219              | 0.81  | 255              | 0.66  | 291              | 0.52  |
| 4                | 0.81  | 40               | 1.51  | 76               | 1.80  | 112              | 1.31  | 148              | 1.29  | 184              | 0.73  | 220              | 0.79  | 256              | 0.72  | 292              | 0.27  |
| 5                | 0.89  | 41               | 1.51  | 77               | 1.87  | 113              | 1.04  | 149              | 1.20  | 185              | 0.79  | 221              | 0.77  | 257              | 0.79  | 293              | 0.00  |
| 6                | 1.01  | 42               | 1.57  | 78               | 1.84  | 114              | 1.10  | 150              | 1.07  | 186              | 0.89  | 222              | 0.83  | 258              | 0.74  | 294              | 0.08  |
| 7                | 1.11  | 43               | 1.60  | 79               | 1.88  | 115              | 1.28  | 151              | 0.99  | 187              | 0.97  | 223              | 0.84  | 259              | 0.78  | 295              | 0.26  |
| 8                | 1.12  | 44               | 1.59  | 80               | 2.09  | 116              | 1.32  | 152              | 0.99  | 188              | 0.96  | 224              | 0.81  | 260              | 0.99  | 296              | 0.32  |
| 9                | 1.08  | 45               | 1.59  | 81               | 2.16  | 117              | 1.29  | 153              | 0.90  | 189              | 0.90  | 225              | 0.81  | 261              | 1.06  | 297              | 0.29  |
| 10               | 1.12  | 46               | 1.56  | 82               | 2.06  | 118              | 1.23  | 154              | 0.85  | 190              | 0.92  | 226              | 0.76  | 262              | 0.96  | 298              | 0.25  |
| 11               | 1.17  | 47               | 1.59  | 83               | 1.95  | 119              | 1.22  | 155              | 1.00  | 191              | 0.95  | 227              | 0.77  | 263              | 0.85  | 299              | 0.24  |
| 12               | 1.14  | 48               | 1.65  | 84               | 1.88  | 120              | 1.24  | 156              | 1.13  | 192              | 0.90  | 228              | 0.81  | 264              | 0.76  | 300              | 0.28  |
| 13               | 1.19  | 49               | 1.60  | 85               | 1.82  | 121              | 1.27  | 157              | 1.20  | 193              | 0.93  | 229              | 0.76  | 265              | 0.70  | 301              | 0.31  |
| 14               | 1.28  | 50               | 1.53  | 86               | 1.74  | 122              | 1.28  | 158              | 1.30  | 194              | 1.02  | 230              | 0.67  | 266              | 0.62  | 302              | 0.34  |
| 15               | 1.34  | 51               | 1.47  | 87               | 1.64  | 123              | 1.26  | 159              | 1.36  | 195              | 1.06  | 231              | 0.61  | 267              | 0.52  | 303              | 0.32  |
| 16               | 1.41  | 52               | 1.23  | 88               | 1.55  | 124              | 1.23  | 160              | 1.34  | 196              | 1.11  | 232              | 0.55  | 268              | 0.43  | 304              | 0.31  |
| 17               | 1.49  | 53               | 0.97  | 89               | 1.47  | 125              | 1.30  | 161              | 1.32  | 197              | 1.17  | 233              | 0.07  | 269              | 0.35  | 305              | 0.38  |
| 18               | 1.46  | 54               | 1.04  | 90               | 1.35  | 126              | 1.40  | 162              | 1.37  | 198              | 1.12  | 234              | 0.14  | 270              | 0.23  | 306              | 0.50  |
| 19               | 1.51  | 55               | 1.23  | 91               | 1.28  | 127              | 1.49  | 163              | 1.38  | 199              | 1.15  | 235              | 0.31  | 271              | 0.16  | 307              | 0.59  |
| 20               | 1.73  | 56               | 1.28  | 92               | 1.29  | 128              | 1.48  | 164              | 1.35  | 200              | 1.35  | 236              | 0.36  | 272              | 0.17  | 308              | 0.60  |
| 21               | 1.81  | 57               | 1.26  | 93               | 1.21  | 129              | 1.42  | 165              | 1.34  | 201              | 1.41  | 237              | 0.32  | 273              | 0.09  | 309              | 0.56  |
| 22               | 1.72  | 58               | 1.21  | 94               | 1.17  | 130              | 1.45  | 166              | 1.29  | 202              | 1.30  | 238              | 0.27  | 274              | 0.05  | 310              | 0.59  |
| 23               | 1.62  | 59               | 1.21  | 95               | 1.32  | 131              | 1.48  | 167              | 1.31  | 203              | 1.18  | 239              | 0.25  | 275              | 0.20  | 311              | 0.64  |
| 24               | 1.55  | 60               | 1.24  | 96               | 1.46  | 132              | 1.44  | 168              | 1.35  | 204              | 1.09  | 240              | 0.28  | 276              | 0.34  | 312              | 0.60  |
| 25               | 1.50  | 61               | 1.28  | 97               | 1.53  | 133              | 1.47  | 169              | 1.29  | 205              | 1.02  | 241              | 0.30  | 277              | 0.43  | 313              | 0.65  |
| 26               | 1.42  | 62               | 1.30  | 98               | 1.64  | 134              | 1.55  | 170              | 1.20  | 206              | 0.94  | 242              | 0.32  | 278              | 0.54  | 314              | 0.75  |
| 27               | 1.33  | 63               | 1.29  | 99               | 1.71  | 135              | 1.59  | 171              | 1.13  | 207              | 0.83  | 243              | 0.29  | 279              | 0.61  | 315              | 0.81  |
| 28               | 1.25  | 64               | 1.27  | 100              | 1.70  | 136              | 1.65  | 172              | 0.87  | 208              | 0.73  | 244              | 0.23  | 280              | 0.60  | 316              | 0.87  |
| 29               | 1.18  | 65               | 1.35  | 101              | 1.69  | 137              | 1.71  | 173              | 0.59  | 209              | 0.64  | 245              | 0.33  | 281              | 0.59  | 317              | 0.95  |
| 30               | 1.07  | 66               | 1.46  | 102              | 1.75  | 138              | 1.66  | 174              | 0.65  | 210              | 0.51  | 246              | 0.44  | 282              | 0.65  | 318              | 0.92  |
| 31               | 1.01  | 67               | 1.56  | 103              | 1.76  | 139              | 1.70  | 175              | 0.82  | 211              | 0.43  | 247              | 0.52  | 283              | 0.68  | 319              | 0.96  |
| 32               | 1.03  | 68               | 1.56  | 104              | 1.74  | 140              | 1.90  | 176              | 0.86  | 212              | 0.43  | 248              | 0.52  | 284              | 0.66  | 320              | 1.18  |
| 33               | 0.95  | 69               | 1.51  | 105              | 1.74  | 141              | 1.96  | 177              | 0.82  | 213              | 0.35  | 249              | 0.47  | 285              | 0.66  | 321              | 1.26  |
| 34               | 0.92  | 70               | 1.54  | 106              | 1.70  | 142              | 1.85  | 178              | 0.76  | 214              | 0.30  | 250              | 0.50  | 286              | 0.62  | 322              | 1.17  |
| 35               | 1.08  | 71               | 1.59  | 107              | 1.72  | 143              | 1.73  | 179              | 0.74  | 215              | 0.44  | 251              | 0.53  | 287              | 0.64  | 323              | 1.07  |

In page {22} of the detailed account of the Transit-Circle before cited (Appendix I. of the volume for 1852) 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° would be brought under

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the microscope, and the errors of the intermediate divisions could be ascertained by the formulæ mentioned below. 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 observation 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 at the Nadir Point, for Polaris, and for Polaris S.P., are as follows:—

|                                                        |      |     | ° | ' | ''                     |
|--------------------------------------------------------|------|-----|---|---|------------------------|
| For Nadir Point, the division under Microscope A being | 90.  | 10, |   |   | the correction is 1'02 |
| For Polaris,                                           | 233. | 5,  |   |   | 1'09                   |
| For Polaris S.P.                                       | 230. | 10, |   |   | 1'40                   |

These corrections have been applied additively to the circle-readings whenever they were needed throughout the year 1858.

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 has been found by observations of stars made chiefly in 1857 at the first and seventh wires, which are given in the foot-notes to the observations; and the assumed value of the correction for one interval of the wires, 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)  $\times \sin 2 \text{ N.P.D.} \times t^2$ ,  $t$  being the interval between the time of meridian passage and the time of transit expressed in seconds of time. Lastly, for motion: 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  $\times \frac{\sin. \text{Geoc. Z.D.}}{\sin. \text{App. Z.D.}} \times \frac{14}{3600}$  (the logarithm of the last factor being 7.58983); this formula supposes the equatoreal interval of the wires to be 14<sup>s</sup>: 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.

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 telescope-micrometer-reading, and the corrections above mentioned. 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 method of formation of the Zenith-Point will be understood from the following explanation. 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. 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 at least one star to the north and one to the south of the zenith on every evening, and, in combining them for zenith point, to allow to each star-observation three times the weight of a nadir-point observation, lest too great weight should be given to the readings of those divisions of the circle which correspond to the nadir-point observations.

If  $D$  denote the circle-reading for a direct observation of a star, and  $R$  that for a reflexion observation, then the reading of the circle corresponding to the zenith, or the zenith-point, will be  $\frac{R+D}{2} \pm 90^\circ$ .

On account of the very small changes to which the zenith-point is found to be subject, its sensible invariability may be assumed for considerable periods of time; it has, however, been the practice to collect in one group observations occupying an interval of time rarely exceeding two weeks.

The adopted Correction for Zenith Point, determined by the rules explained above, is given in the foot notes.

APPARENT ZENITH DISTANCE.—The numbers in this column are found by adding the Zenith-Point-Correction to the Concluded Meridional Circle-Reading; the negative sign denotes that the object is North of the zenith. When the Moon 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 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

$$\tan \theta = \operatorname{Cosec} P \cdot \cos \delta_m \cdot \tan \delta_s - \cot P \cdot \sin \delta_m$$

and the correction required will be

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

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 semidiameter 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.

$$\begin{aligned} \text{Then} \quad & \tan \delta_1 = \tan \delta_m \cdot \cos MP S_1 \\ \text{And} \quad & \theta_1 = \delta_s - \delta_1 \\ \text{Also} \quad & \sin \theta = \sin \theta_1 \cdot \sin MS_1 P \\ & = \sin \theta_1 \frac{\sin MP}{\sin S_1 P} \\ & = \sin \theta_1 \frac{\cos \delta_m}{\cos \delta_1} \end{aligned}$$

Whence  $\theta$  is found; and the correction required is

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

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 (or of 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

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

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 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

## CORRECTION FOR DEFECTIVE ILLUMINATION; BAROMETER, THERMOMETERS, &amp;c. liii

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. The reading of this barometer appears to be less than that of the Standard Barometer by about 0.01 inch.

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  $4\frac{1}{2}$  feet, at a height of nearly seven feet from the ground. The following are the results of comparisons of its readings with a Standard Thermometer, made on 1858, May 26, the bulbs of both being plunged in water:—

| Temperatures.    | Excess of Reading of<br>Circle Thermometer. |
|------------------|---------------------------------------------|
| 32° to 40° ..... | 0.5                                         |
| 41 to 50 .....   | 0.6                                         |
| 51 to 55 .....   | 0.7                                         |
| 56 to 58 .....   | 0.8                                         |
| 59 to 63 .....   | 0.9                                         |
| 64 to 70 .....   | 1.0                                         |
| 71 to 75 .....   | 1.2                                         |
| 76 to 80 .....   | 1.3                                         |
| 81 to 85 .....   | 1.5                                         |
| 86 to 90 .....   | 1.6                                         |
| 90 to 93 .....   | 1.7                                         |
| 94 to 97 .....   | 1.8                                         |
| Above 98 .....   | 1.9                                         |

The readings, especially at high temperatures, being thus found to be too high, the circle thermometer was taken to Mr. Simms, and the tube was lowered relatively to the scale, so as to reduce the error for moderate temperatures to a very small quantity. The following are the results of comparisons with the standard made in October 1858:—

| Temperatures.   | Excess of Reading of<br>Circle Thermometer. |
|-----------------|---------------------------------------------|
| 21 to 29 .....  | -0.3                                        |
| 32 to 37 .....  | -0.2                                        |
| 42 to 50 .....  | -0.1                                        |
| 51 to 68 .....  | 0.0                                         |
| 72 to 82 .....  | 0.2                                         |
| 85 to 89 .....  | 0.6                                         |
| 95 to 100 ..... | 0.9                                         |

INTERIOR THERMOMETER.—This is a small thermometer suspended in a free current of air in the Transit-Circle Room.

**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  $85^\circ$ , 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  $85^\circ$ , in which cases the computation is made generally by means of the Supplementary Table in the *Tabulæ*. In the year 1858, however, it has been found necessary, on the authority of an investigation by Mr. Main of the corrections required to Bessel's Mean Refractions, which is printed in vol. xxvi. of the *Memoirs of the Royal Astronomical Society*, to make an alteration in Bessel's values of the mean refraction for stars near the horizon. The results of Mr. Main's paper showed that for Zenith Distances not greater than  $82^\circ$  no correction is needed to the results given in the *Tabulæ Regiomontanæ*; that, from  $82^\circ$  to  $85^\circ$  Zenith Distance, the Logarithms of the Mean Refractions of the *Tabulæ* require to be diminished by 0.00100; and finally, that, from  $85^\circ$  to the horizon, it is better to relinquish the use of the Mean Refractions given in the Supplementary Table of the *Tabulæ*, and to use the numbers of the *Fundamenta* diminished in the proportion of 1: 0.99848. This has accordingly been done throughout the year 1858, as is explained in the foot-notes to the observations.

**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,  $\log. \text{parallax} = \log. \sin. (\text{zen. dist.} - 11'. 12'') + \text{ar. co. log. distance} + 0.9325$ .

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—

$$\text{Parallax} = \text{Hor. Equat. Par. from N.A.} \times \text{Sin Dist. from Geoc. Zenith} \times \text{Geocentric Radius} \\ (\text{Log} = 9.9991136) + \text{Corr. derived from the following table :—}$$

| Z. D.      | Correction<br>for<br>South Limb. | Z. D.      | Correction<br>for<br>South Limb. | Z. D.      | Correction<br>for<br>North Limb. | Z. D.      | Correction<br>for<br>North Limb. |
|------------|----------------------------------|------------|----------------------------------|------------|----------------------------------|------------|----------------------------------|
| $30^\circ$ | — 0.01                           | $60^\circ$ | + 0.10                           | $30^\circ$ | — 0.08                           | $60^\circ$ | — 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 Cor-

## REFRACTION ; PARALLAX ; SEMIDIAMETER ; CORRECTION TO MEAN N.P.D. OF STARS. lv

rections given in a subsequent part of this Introduction for the Moon's parallax in Occultations, by supposing  $V$  (the angle for the Moon's limb from the vertical)  $= 0^\circ$  or  $180^\circ$ ; and of another due to the employment of the arc of equatoreal parallax instead of its sine, for which the formula is,

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

For the computation of the parallaxes of the newly discovered small planets, the distances are taken in general either from the Supplement to the *Nautical Almanac*, or from the *Berliner Jahrbuch*, for planets given in those works. For planets very recently discovered, the distances are in general taken from Ephemerides given in the *Astronomische Nachrichten*.

SEMIDIAMETER.—The semidiameters of the Sun, Moon, and Planets are given in the lower part of the page. For the Sun, Moon, Mercury, and Uranus, they are taken unchanged from the *Nautical Almanac*. For Venus and Jupiter, the semidiameters are also taken unchanged from the *Nautical Almanac*, except in cases where only one limb has been observed; when, for Venus, the correction  $+ 0''.59 + 0.004 \times \text{tabular semidiameter}$ , derived from an investigation mentioned at page xl, has been applied to the semidiameter given in that work; and, for Jupiter, a correction generally specified in the notes is applied to the tabular semidiameters. For Saturn, the North limb of the planet being generally hidden by the ring, the North and South limbs of the ring have been observed, and the difference between the N.P.D. of the North or the South limb of the ring, and that of the center, is computed from the formula

$$(\text{difference of N.P.D.})^2 = a^2 \sin^2 \theta + b^2 \cos^2 \theta,$$

where  $a$  and  $b$  are the semi-axes major and minor of the ring, and  $\theta$  the inclination of the axis-major to the horizon at the time of transit over the meridian, taken from the *Nautical Almanac*, page 513. In a few cases at the end of 1858, in which the limbs of the ball were observed, the diameter is taken unchanged from the *Nautical Almanac*.

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  $38^\circ. 31'. 22''. 00$ .

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 1858, 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 corrections from Mean N.P.D. to Apparent N.P.D. are computed by the formula,

$$E e' + F f' + G g' + H h' + L + l' - 300''$$

which is derived from the well-known formula

$$A a' + B b' + C c' + D d'$$

or its equivalent

$$A \cdot \sin N.P.D. \times (\text{numb. log} = 9.6376) - A \cdot \sin R.A. \cos N.P.D. + B \cdot \cos R.A. \cos N.P.D. + C \cdot \cos R.A. \times \text{numb. (log} = 1.3020) - D \cdot \sin R.A.$$

The formulæ for E, F, G, H, L, have been already given (page xlii):  $e' = a' + 1.2$ ,  $f' = b' + 1.2$ ,  $g' = c' + 25$ ,  $h' = d' + 1.2$ ,  $l' = 210 - 25 \times e' - 25 \times f' - 1.2 \times g' - 25 \times h'$ . The values of the day-constants log. E, log. F, log. G, log. H, and L, for the years from 1849 to 1860, inclusive, and the values of the star-constants log.  $e'$ , log.  $f'$ , log.  $g'$ , log.  $h'$ , and  $l'$ , for all the stars in the "Greenwich Twelve-Year-Catalogue" are given in that Catalogue. For other stars the star-constants will be found either in the Greenwich Catalogue of 1576 Stars for 1850, previously mentioned (page xlii), or in tables following the annual Catalogues of Stars for the years 1854 to 1857, or in a table following the Catalogue in the present volume.

The sign of the computed quantity is changed before application.

§ 5. *Runs of each Microscope-Micrometer of the Transit-Circle; and Zenith Points of the Transit-Circle, in the Year 1858; page (134) to (143).*

These Tables require but little explanation.

With regard to the *Runs of the Microscopes*, the columns under A, B, C, D, E, F, contain respectively the number of revolutions of each micrometer which measures an arc of 5' on the circle; and the last column gives the sum of these numbers, and exhibits the number of revolutions which, for the mean of the microscopes, measures an arc of 30', 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  $\frac{50}{51} \times 30^{\circ}.000$ , or to  $29^{\circ}.4118$ ; 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 column of the table in question and  $29^{\circ}.4118$ , is computed in the way that has been previously explained (page xlii).

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 observations are always divided into three groups, viz.: those resulting from north stars, from south stars, and from wire-observations respectively; and, to prevent too much weight being given to those divisions of the circle which are always under the microscopes for the wire-observations, to one observation of a star there is attributed three times the weight of a wire-observation.

## STAR-CORRECTIONS ; MICROMETER-RUNS ; ZENITH-POINTS ; STARS' MEAN N.P.D. lvii

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. This explanation is in a great measure a recapitulation of that given in page li, and is added for the sake of clearness.

§ 6. *Mean North Polar Distances of Stars deduced from each Day's Observations,*  
page (146) to (166).

The Mean North Polar Distances are found by applying to the North Polar Distances in Section 4, the corrections given for each star in the lower part of the page.

The results of the direct and reflexion observations are 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 are 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 have been 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 weight is a number proportional to the fraction, whose numerator is the product of the numbers of direct and of reflexion observations, and whose denominator is their sum.

EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS, FOR OBSERVATIONS  
OF ZENITH DISTANCE WITH THE TRANSIT-CIRCLE, 1858.

| Name of Star.                   | Approximate<br>N. P. D. | Seconds of R. | Seconds of D. | R.—D.  | Number of Obs. |    | Weight. |
|---------------------------------|-------------------------|---------------|---------------|--------|----------------|----|---------|
|                                 |                         |               |               |        | R.             | D. |         |
| $\lambda$ Ursæ Minoris S.P. ... | — 1. 7                  | 55.63         | 56.34         | + 0.71 | 1              | 13 | 4       |
| B. A. C. 1879.....              | + 3. 14                 | 25.92         | 24.57         | + 1.35 | 1              | 1  | 2       |
| B. A. C. 2326.....              | 7. 20                   | 45.00         | 45.07         | — 0.07 | 1              | 1  | 2       |
| $\epsilon$ Ursæ Minoris .....   | 7. 44                   | 9.76          | 8.94          | + 0.82 | 1              | 4  | 3       |
| B. A. C. 3577.....              | 8. 47                   | 35.86         | 35.79         | + 0.07 | 1              | 1  | 2       |
| B. A. C. 3629.....              | 8. 50                   | 5.78          | 4.29          | + 1.49 | 1              | 1  | 2       |
| B. A. C. 2930.....              | 9. 27                   | 52.78         | 53.06         | — 0.28 | 1              | 1  | 2       |
| B. A. C. 7299.....              | 9. 59                   | 57.73         | 57.70         | + 0.03 | 3              | 4  | 7       |
| B. A. C. 4112.....              | 11. 36                  | 40.86         | 39.70         | + 1.16 | 1              | 1  | 2       |
| $\zeta$ Ursæ Minoris.....       | 11. 46                  | 14.46         | 14.79         | — 0.33 | 4              | 7  | 10      |
| $\theta$ Ursæ Minoris .....     | 12. 11                  | 45.83         | 46.22         | — 0.39 | 6              | 6  | 12      |
| $\kappa$ Cephei .....           | 12. 43                  | 7.72          | 5.72          | + 2.00 | 2              | 3  | 5       |
| B. A. C. 1280 .....             | 14. 15                  | 7.66          | 7.03          | + 0.63 | 3              | 3  | 6       |
| $\beta$ Ursæ Minoris .....      | 15. 16                  | 52.51         | 50.95         | + 1.56 | 1              | 7  | 4       |
| B. A. C. 2596.....              | 15. 43                  | 37.41         | 36.97         | + 0.44 | 1              | 1  | 2       |
| B. A. C. 8314.....              | 16. 23                  | 47.86         | 46.68         | + 1.18 | 1              | 1  | 2       |

GREENWICH OBSERVATIONS, 1858.

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EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS, FOR OBSERVATIONS  
OF ZENITH DISTANCE WITH THE TRANSIT-CIRCLE, 1858—continued.

| Name of Star.                | Approximate<br>N. P. D. | Seconds of R. | Seconds of D. | R.—D.  | Number of Obs. |    | Weight. |
|------------------------------|-------------------------|---------------|---------------|--------|----------------|----|---------|
|                              |                         |               |               |        | R.             | D. |         |
| B. A. C. 1067.....           | 17. 8                   | 25.78         | 25.09         | + 0.69 | 1              | 1  | 2       |
| 6 Ursæ Minoris .....         | 17.26                   | 30.08         | 28.88         | + 1.20 | 1              | 1  | 2       |
| B. A. C. 6752 .....          | 18.43                   | 40.50         | 38.92         | + 1.58 | 1              | 1  | 2       |
| $\nu$ Draconis .....         | 18.54                   | 37.32         | 36.38         | + 0.94 | 2              | 4  | 5       |
| $\kappa$ Draconis .....      | 19.26                   | 42.94         | 43.38         | — 0.44 | 3              | 3  | 6       |
| $\beta^2$ Cephei .....       | 20. 4                   | 44.62         | 43.87         | + 0.75 | 3              | 7  | 8       |
| $\beta^1$ Cephei .....       | 20. 4                   | 48.54         | 48.51         | + 0.03 | 1              | 2  | 3       |
| $\epsilon$ Draconis .....    | 20. 6                   | 38.54         | 38.18         | + 0.36 | 7              | 17 | 20      |
| B. A. C. 4689.....           | 20.38                   | 13.78         | 13.01         | + 0.77 | 1              | 1  | 2       |
| B. A. C. 1980.....           | 20.38                   | 16.05         | 16.88         | — 0.83 | 1              | 1  | 2       |
| 55 Camelopardali .....       | 21. 7                   | 50.87         | 49.70         | + 1.17 | 2              | 2  | 4       |
| $\omega$ Draconis .....      | 21.11                   | 36.79         | 36.82         | — 0.03 | 5              | 5  | 10      |
| B. A. C. 2439 .....          | 21.15                   | 4.94          | 3.69          | + 1.25 | 1              | 1  | 2       |
| B. A. C. 5406.....           | 21.49                   | 56.56         | 55.68         | + 0.88 | 6              | 6  | 12      |
| 46 Cassiopeiæ .....          | 22. 1                   | 53.69         | 53.54         | + 0.15 | 3              | 3  | 6       |
| $\sigma^2$ Ursæ Majoris..... | 22.18                   | 37.33         | 36.37         | + 0.96 | 2              | 2  | 4       |
| 3 Draconis.....              | 22.28                   | 10.71         | 10.31         | + 0.40 | 7              | 7  | 14      |
| $\rho$ Draconis.....         | 22.32                   | 52.22         | 53.10         | — 0.88 | 7              | 11 | 17      |
| $\delta$ Draconis .....      | 22.35                   | 17.93         | 17.60         | + 0.33 | 2              | 2  | 4       |
| B. A. C. 744.....            | 23.14                   | 23.37         | 21.78         | + 1.59 | 1              | 1  | 2       |
| B. A. C. 8039.....           | 23.33                   | 20.38         | 20.93         | — 0.55 | 3              | 3  | 6       |
| B. A. C. 3531.....           | 23.43                   | 4.85          | 3.76          | + 1.09 | 4              | 4  | 8       |
| 9 Camelopardali .....        | 23.54                   | 19.07         | 18.79         | + 0.28 | 2              | 3  | 5       |
| B. A. C. 4834 .....          | 23.59                   | 1.08          | 0.83          | + 0.25 | 6              | 7  | 13      |
| 16 Cassiopeiæ.....           | 24. 2                   | 0.30          | 0.35          | — 0.05 | 3              | 3  | 6       |
| 55 Draconis .....            | 24.16                   | 31.71         | 33.00         | — 1.29 | 1              | 1  | 2       |
| B. A. C. 1751.....           | 24.23                   | 11.96         | 10.68         | + 1.28 | 2              | 2  | 4       |
| $\pi$ Draconis .....         | 24.34                   | 32.55         | 31.22         | + 1.33 | 1              | 2  | 3       |
| $i$ Draconis.....            | 24.34                   | 27.55         | 27.84         | — 0.29 | 1              | 2  | 3       |
| B. A. C. 1001.....           | 24.52                   | 20.08         | 19.85         | + 0.23 | 6              | 6  | 12      |
| 26 Cephei .....              | 25.35                   | 28.47         | 28.29         | + 0.18 | 7              | 8  | 15      |
| 36 Draconis .....            | 25.39                   | 2.08          | 1.13          | + 0.95 | 3              | 3  | 6       |
| 28 Ursæ Majoris .....        | 25.42                   | 47.11         | 47.26         | — 0.15 | 3              | 3  | 6       |
| 4 Ursæ Majoris .....         | 26.19                   | 14.47         | 13.81         | + 0.66 | 1              | 1  | 2       |
| B. A. C. 1203 .....          | 27.21                   | 58.26         | 58.80         | — 0.54 | 1              | 1  | 2       |
| $\alpha$ Cephei .....        | 28. 1                   | 55.28         | 55.34         | — 0.06 | 2              | 7  | 6       |
| $\eta$ Cephei .....          | 28.43                   | 42.41         | 43.04         | — 0.63 | 3              | 8  | 9       |
| 12 Cassiopeiæ .....          | 28.57                   | 23.50         | 22.06         | + 1.44 | 4              | 4  | 8       |
| 17 Lyncis .....              | 28.59                   | 25.42         | 27.50         | — 2.08 | 2              | 2  | 4       |
| $\nu$ Cephei .....           | 29.32                   | 1.26          | 1.10          | + 0.16 | 4              | 6  | 10      |
| B. A. C. 5917 .....          | 29.50                   | 53.66         | 55.60         | — 1.94 | 1              | 1  | 2       |
| 11 Lacertæ .....             | 46.28                   | 50.48         | 51.53         | — 1.05 | 3              | 8  | 9       |
| $\xi$ Cygni .....            | 46.38                   | 13.67         | 13.18         | + 0.49 | 1              | 2  | 3       |
| $\beta$ Canum Venaticum ...  | 47.52                   | 12.83         | 12.97         | — 0.14 | 2              | 3  | 5       |
| $\eta$ Aurigæ .....          | 48.58                   | 43.17         | 44.65         | — 1.48 | 1              | 5  | 3       |
| B. A. C. 4783 .....          | 50.58                   | 48.37         | 50.46         | — 2.09 | 1              | 1  | 2       |
| B. A. C. 7008 .....          | 51. 3                   | 34.84         | 36.49         | — 1.65 | 1              | 1  | 2       |
| $\alpha$ Lyre .....          | 51.21                   | 47.48         | 47.07         | + 0.41 | 1              | 8  | 4       |
| $\mu$ Andromedæ.....         | 52.16                   | 19.55         | 19.02         | + 0.53 | 4              | 7  | 10      |
| $\delta$ Boötis .....        | 56. 9                   | 11.42         | 12.88         | — 1.46 | 1              | 1  | 2       |
| $\beta$ Lyre .....           | 56.48                   | 59.87         | 59.53         | + 0.34 | 5              | 15 | 15      |
| $\iota$ Aurigæ .....         | 57. 4                   | 48.06         | 47.79         | + 0.27 | 1              | 4  | 3       |
| Castor .....                 | 57.48                   | 15.82         | 15.84         | — 0.02 | 1              | 6  | 3       |
| $\zeta$ Herculis .....       | 58. 8                   | 16.45         | 16.09         | + 0.36 | 2              | 7  | 6       |

## DISCORDANCE OF DIRECT AND REFLEXION RESULTS.

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EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS, FOR OBSERVATIONS  
OF ZENITH DISTANCE WITH THE TRANSIT-CIRCLE, 1858—concluded.

| Name of Star.              | Approximate<br>N. P. D. | Seconds of R. | Seconds of D. | R.—D.  | Number of Obs. |    | Weight. |
|----------------------------|-------------------------|---------------|---------------|--------|----------------|----|---------|
|                            |                         |               |               |        | R.             | D. |         |
| $\alpha$ Herculis .....    | 58. 38                  | 39.68         | 40.35         | — 0.67 | 1              | 1  | 2       |
| $\epsilon$ Herculis .....  | 58. 52                  | 43.95         | 43.83         | + 0.12 | 1              | 1  | 2       |
| $\rho$ Boötis .....        | 59. 0                   | 12.96         | 12.87         | + 0.09 | 4              | 14 | 12      |
| $\zeta$ Cygni .....        | 60. 21                  | 14.07         | 14.10         | — 0.03 | 4              | 9  | 11      |
| $\kappa$ Aurigæ .....      | 60. 27                  | 15.32         | 15.72         | — 0.40 | 1              | 6  | 3       |
| B. A. C. 3937 .....        | 61. 26                  | 2.78          | 4.22          | — 1.44 | 1              | 1  | 2       |
| $\epsilon$ Andromedæ ..... | 61. 28                  | 36.77         | 36.27         | + 0.50 | 3              | 4  | 7       |
| $\beta$ Tauri .....        | 61. 31                  | 0.44          | 1.34          | — 0.90 | 1              | 11 | 4       |
| $\rho^3$ Cancri .....      | 61. 32                  | 0.82          | 0.43          | + 0.39 | 1              | 1  | 2       |
| $30$ Comæ .....            | 61. 40                  | 25.99         | 25.38         | + 0.61 | 1              | 1  | 2       |
| $\alpha$ Andromedæ .....   | 61. 42                  | 38.07         | 37.32         | + 0.75 | 1              | 3  | 3       |
| $6$ Cancri .....           | 61. 49                  | 40.01         | 40.83         | — 0.82 | 2              | 12 | 7       |
| $\mu$ Herculis .....       | 62. 12                  | 37.35         | 37.73         | — 0.38 | 3              | 12 | 10      |
| $32$ Vulpeculæ .....       | 62. 29                  | 50.34         | 49.99         | + 0.35 | 2              | 6  | 6       |
| $\alpha$ Coronæ .....      | 62. 48                  | 18.63         | 18.64         | — 0.01 | 6              | 15 | 17      |
| $\mu$ Leonis .....         | 63. 20                  | 35.76         | 34.80         | + 0.96 | 3              | 5  | 8       |
| $18$ Vulpeculæ .....       | 63. 31                  | 52.39         | 52.32         | + 0.07 | 1              | 1  | 2       |
| $\omega^1$ Cancri .....    | 64. 13                  | 19.57         | 18.74         | + 0.83 | 1              | 2  | 3       |
| B. A. C. 7444 .....        | 64. 26                  | 4.38          | 6.00          | — 1.62 | 1              | 1  | 2       |
| $16$ Pegasi .....          | 64. 44                  | 30.69         | 29.05         | + 1.64 | 1              | 4  | 3       |
| $\iota$ Pegasi .....       | 65. 21                  | 49.91         | 48.89         | + 1.02 | 2              | 3  | 5       |
| $\epsilon$ Leonis .....    | 65. 34                  | 26.81         | 27.30         | — 0.49 | 1              | 2  | 3       |
| $\alpha$ Vulpeculæ .....   | 65. 37                  | 13.13         | 13.43         | — 0.30 | 2              | 5  | 6       |
| $\mu$ Pegasi .....         | 66. 9                   | 51.08         | 50.96         | + 0.12 | 4              | 7  | 10      |
| $\alpha$ Arietis .....     | 67. 13                  | 39.71         | 40.49         | — 0.78 | 5              | 10 | 13      |
| $\nu$ Pegasi .....         | 67. 23                  | 38.43         | 39.03         | — 0.60 | 3              | 4  | 7       |
| $\eta$ Geminorum .....     | 67. 27                  | 24.81         | 23.41         | + 1.40 | 1              | 1  | 2       |
| $\delta$ Geminorum .....   | 67. 46                  | 35.76         | 37.18         | — 1.42 | 1              | 11 | 4       |
| $\delta$ Leonis .....      | 68. 42                  | 56.31         | 56.79         | — 0.48 | 7              | 9  | 16      |
| $\eta$ Cancri .....        | 69. 5                   | 46.50         | 46.83         | — 0.33 | 2              | 4  | 5       |
| $\beta$ Arietis .....      | 69. 53                  | 16.72         | 17.30         | — 0.58 | 2              | 5  | 6       |
| Arcturus .....             | 70. 5                   | 35.74         | 36.07         | — 0.33 | 7              | 23 | 21      |
| $\gamma$ Herculis .....    | 70. 31                  | 38.16         | 39.27         | — 1.11 | 5              | 7  | 12      |
| $\delta$ Arietis .....     | 70. 49                  | 47.80         | 48.31         | — 0.51 | 3              | 7  | 8       |
| $\eta$ Boötis .....        | 70. 53                  | 19.61         | 20.34         | — 0.73 | 2              | 5  | 6       |
| $\epsilon$ Tauri .....     | 71. 8                   | 16.35         | 18.53         | — 2.18 | 1              | 4  | 3       |
| $83$ Cancri .....          | 71. 42                  | 42.16         | 42.68         | — 0.52 | 1              | 10 | 4       |
| $\tau$ Boötis .....        | 71. 50                  | 2.93          | 2.66          | + 0.27 | 1              | 4  | 3       |
| Aldebaran .....            | 73. 47                  | 47.53         | 48.38         | — 0.85 | 2              | 6  | 6       |
| $\gamma$ Serpentis .....   | 73. 52                  | 20.37         | 19.86         | + 0.51 | 1              | 1  | 2       |
| $\alpha$ Delphini .....    | 74. 35                  | 12.23         | 11.72         | + 0.51 | 2              | 5  | 6       |
| $\epsilon$ Aquilæ .....    | 75. 7                   | 18.00         | 18.46         | — 0.46 | 4              | 8  | 11      |
| $\eta$ Piscium .....       | 75. 23                  | 17.78         | 15.17         | + 2.61 | 1              | 11 | 4       |
| $\alpha$ Herculis .....    | 75. 27                  | 40.10         | 41.59         | — 1.49 | 1              | 7  | 3       |
| $\sigma$ Arietis .....     | 75. 30                  | 20.62         | 20.62         | 0.00   | 3              | 5  | 8       |
| $\zeta$ Aquilæ .....       | 76. 21                  | 40.40         | 41.37         | — 1.97 | 1              | 10 | 4       |
| $\alpha$ Ophiuchi .....    | 77. 20                  | 1.07          | 1.03          | + 0.04 | 1              | 12 | 4       |
| Regulus .....              | 77. 20                  | 26.42         | 25.98         | + 0.44 | 4              | 20 | 13      |
| $f$ Tauri .....            | 77. 33                  | 10.31         | 10.81         | — 0.50 | 2              | 3  | 5       |
| $\alpha$ Cancri .....      | 77. 36                  | 43.44         | 43.66         | — 0.22 | 2              | 4  | 5       |
| $\omega$ Aquilæ .....      | 78. 39                  | 28.46         | 29.14         | — 0.68 | 1              | 4  | 3       |
| $\gamma$ Aquilæ .....      | 79. 44                  | 48.90         | 48.15         | + 0.75 | 6              | 18 | 18      |
| $\theta$ Tauri .....       | 81. 28                  | 26.11         | 26.61         | — 0.50 | 1              | 2  | 3       |

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For the purpose of discovering with greater accuracy the law followed by the differences given above, they have been grouped for convenient intervals of North Polar Distance, and the means of the differences corresponding to the means of the North Polar Distances have been taken, the weight for each group being the sum of the weights attributed to the separate values of  $R - D$ .

The results are contained in the following Table:—

EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS FROM GROUPS OF STARS OBSERVED WITH THE TRANSIT-CIRCLE, 1858.

| Extent of Group.                                   | Weight. | Mean<br>N. P. D. | Mean<br>Value of<br>$R-D$ . |
|----------------------------------------------------|---------|------------------|-----------------------------|
| $\lambda$ Ursæ Minoris S.P. to B. A. C. 7299 .     | 24      | 6. 50            | + 0.44                      |
| B. A. C. 4112 to 6 Ursæ Minoris . . . . .          | 47      | 13. 25           | + 0.45                      |
| B. A. C. 6752 to 46 Cassiopeiæ . . . . .           | 82      | 20. 33           | + 0.45                      |
| $\sigma^2$ Ursæ Majoris to B. A. C. 1001 . . . . . | 103     | 23. 31           | + 0.17                      |
| 26 Cephei to B. A. C. 5917 . . . . .               | 70      | 27. 33           | + 0.04                      |
| 11 Lacertæ to $\mu$ Andromedæ . . . . .            | 38      | 49. 23           | — 0.36                      |
| $\delta$ Boötis to $\alpha$ Coronæ . . . . .       | 119     | 60. 17           | — 0.02                      |
| $\mu$ Leonis to $\eta$ Cancri . . . . .            | 89      | 66. 34           | — 0.13                      |
| $\beta$ Arietis to $\gamma$ Serpentis . . . . .    | 71      | 70. 55           | — 0.62                      |
| $\alpha$ Delphini to $\epsilon$ Tauri . . . . .    | 87      | 77. 12           | + 0.14                      |

This table indicates with tolerable clearness the law of the values of  $R-D$ , the signs being, without exception, positive for stars north of the Zenith, and, with one exception, negative for stars south of the Zenith, so that a negative correction is required to Direct observations of Stars south of the Zenith, and a positive correction to Reflexion-observations. By assuming, as in former years, that the formula may be moderately well represented by a formula involving the sine of the Zenith Distance, it is found by calculation, that the following expression, when tabulated, will give the values which best agree with the errors in the table above, namely,

For direct observations

$$+ 0''.05 - 0''.28 \times \sin Z. D. \text{ South.}$$

For reflexion-observations

$$- 0''.05 + 0''.28 \times \sin Z. D. \text{ South.}$$

For use, the formulæ have been tabulated as follows; and the corrections have been applied to all the observations of Zenith Distance made throughout the year; that is,

DISCORDANCE OF DIRECT AND REFLEXION RESULTS;  
AND CORRECTION TO ASSUMED COLATITUDE.

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to the mean result for N.P.D. of each star, and to the North Polar Distances of the Sun, Moon, and Planets in the section of Planetary Results.

| N. P. D. | Corrections<br>to Results of Direct<br>Observations. | Corrections<br>to Results of Reflexion<br>Observations. |
|----------|------------------------------------------------------|---------------------------------------------------------|
| — 40     | + 0'32                                               | — 0'32                                                  |
| 30       | + 0'31                                               | — 0'31                                                  |
| 20       | + 0'29                                               | — 0'29                                                  |
| — 10     | + 0'26                                               | — 0'26                                                  |
| 0        | + 0'22                                               | — 0'22                                                  |
| + 10     | + 0'18                                               | — 0'18                                                  |
| 20       | + 0'14                                               | — 0'14                                                  |
| 30       | + 0'09                                               | — 0'09                                                  |
| 40       | + 0'04                                               | — 0'04                                                  |
| 50       | — 0'01                                               | + 0'01                                                  |
| 60       | — 0'05                                               | + 0'05                                                  |
| 70       | — 0'10                                               | + 0'10                                                  |
| 80       | — 0'14                                               | + 0'14                                                  |
| 90       | — 0'17                                               | + 0'17                                                  |
| 100      | — 0'20                                               | + 0'20                                                  |
| 110      | — 0'22                                               | + 0'22                                                  |
| 120      | — 0'23                                               | + 0'23                                                  |

Although these numbers have been used in the final reductions of the results, it cannot be said that their introduction is quite satisfactory. The correction for astronomical flexure of the telescope, inferred from the accordant results of direct experiment mentioned in page xlvii, and incorporated with the corrections applied to every mean of microscope-readings, ought to have cancelled all terms depending on the sine of zenith-distance. The origin of the difference of results of direct-observations and reflexion-observations is yet obscure.

The observations of circumpolar stars have, as usual, been favourable to the determination of latitude; yet there is still a difference greater than might be expected between the resulting colatitude and that which has been assumed in the reduction of the observations, namely, 38°. 31'. 22".00.

In the following table the weights are approximately determined by multiplying  $\frac{a b}{a + b}$  (where  $a$  is the number of observations above the pole, and  $b$  the number below) by the number 50 for the first star, 49 for the second, 48 for the third, &c. and assuming numbers proportional to those thence resulting.

CORRECTION TO ASSUMED LATITUDE.

| Star's Name,<br>and<br>Mode of Observation. | Number<br>of Obs. | N. P. D.<br>Uncorrected. | Result<br>Corrected<br>for Dis-<br>cordance. | Number<br>of Obs. | Concluded<br>N. P. D.<br>on assumed<br>Latitude. | Number<br>of Obs. | Algebraic<br>Sum of<br>Determina-<br>tions. | Weight. | Product. |
|---------------------------------------------|-------------------|--------------------------|----------------------------------------------|-------------------|--------------------------------------------------|-------------------|---------------------------------------------|---------|----------|
| λ Ursæ Minoris . . . D.                     | 9                 | 1. 6. 56'40              | 56'62                                        | 9                 | 56'62                                            | 23                | + 0'52                                      | 27      | + 14'04  |
| S.P. D.<br>R.                               | 13<br>1           | — 1. 6. 56'34<br>55'63   | — 56'12<br>— 55'85                           | 14                | — 56'10                                          |                   |                                             |         |          |

## CORRECTION TO ASSUMED LATITUDE—continued.

| Star's Name,<br>and<br>Mode of Observation. | Number<br>of Obs. | N. P. D.<br>Uncorrected. | Result<br>Corrected<br>for Dis-<br>cordance. | Number<br>of Obs. | Concluded<br>N. P. D.<br>on assumed<br>Latitude. | Number<br>of Obs. | Algebraic<br>Sum of<br>Determina-<br>tions. | Weight. | Product. |
|---------------------------------------------|-------------------|--------------------------|----------------------------------------------|-------------------|--------------------------------------------------|-------------------|---------------------------------------------|---------|----------|
| Polaris.....D.                              | 123               | 1. 26. 51. 53            | 51. 74                                       | 123               | 51. 74                                           |                   | "                                           |         | "        |
| S.P....D.                                   | 106               | - 1. 26. 51. 13          | -50. 90                                      | 106               | -50. 90                                          | 229               | + 0. 84                                     | 279     | +234.36  |
| Cephei 51 (Hev.). D.                        | 18                | 2. 45. 0. 00             | 0. 21                                        | 18                | 0. 21                                            |                   | "                                           |         | "        |
| S.P....D.                                   | 33                | - 2. 45. 0. 30           | - 0. 07                                      | 33                | - 0. 07                                          | 51                | + 0. 14                                     | 56      | + 7. 84  |
| δ Ursæ Minoris... D.                        | 29                | 3. 23. 56. 23            | 56. 44                                       | 29                | 56. 44                                           |                   | "                                           |         | "        |
| S.P....D.                                   | 13                | - 3. 23. 56. 29          | -56. 06                                      | 13                | - 56. 06                                         | 42                | + 0. 38                                     | 42      | +15. 96  |
| ε Ursæ Minoris .. D.<br>R.                  | 4<br>1            | 7. 44. 8. 94<br>9. 76    | 9. 13<br>9. 57                               | 5                 | 9. 22                                            |                   | "                                           |         | "        |
| S.P....D.                                   | 8                 | - 7. 44. 9. 09           | - 8. 84                                      | 8                 | - 8. 84                                          | 13                | + 0. 38                                     | 14      | + 5. 32  |
| ζ Ursæ Minoris ... D.<br>R.                 | 7<br>4            | 11. 46. 14. 79<br>14. 46 | 14. 96<br>14. 29                             | 11                | 14. 72                                           |                   | "                                           |         | "        |
| S.P....D.                                   | 11                | -11. 46. 15. 26          | -15. 00                                      | 11                | -15. 00                                          | 22                | - 0. 28                                     | 25      | - 7. 00  |
| β Ursæ Minoris .. D.<br>R.                  | 7<br>1            | 15. 15. 50. 95<br>52. 51 | 51. 11<br>52. 35                             | 8                 | 51. 27                                           |                   | "                                           |         | "        |
| S.P....D.                                   | 7                 | -15. 15. 51. 00          | -50. 72                                      | 7                 | -50. 72                                          | 15                | + 0. 55                                     | 16      | + 8. 80  |
| β <sup>2</sup> Cephei.....D.<br>R.          | 7<br>3            | 20. 3. 43. 87<br>44. 62  | 44. 01<br>44. 48                             | 10                | 44. 15                                           |                   | "                                           |         | "        |
| S.P....D.                                   | 3                 | -20. 3. 44. 24           | -43. 95                                      | 3                 | -43. 95                                          | 13                | + 0. 20                                     | 10      | + 2. 00  |
| ε Draconis .....D.<br>R.                    | 17<br>7           | 20. 5. 38. 18<br>38. 54  | 38. 32<br>38. 40                             | 24                | 38. 34                                           |                   | "                                           |         | "        |
| S.P....D.                                   | 4                 | -20. 5. 37. 82           | -37. 53                                      | 4                 | -37. 53                                          | 28                | + 0. 81                                     | 14      | +11. 34  |
| ρ Draconis .....D.<br>R.                    | 11<br>7           | 22. 31. 53. 10<br>52. 22 | 53. 23<br>52. 09                             | 18                | 52. 79                                           |                   | "                                           |         | "        |
| S.P....D.                                   | 4                 | -22. 31. 52. 56          | -52. 27                                      | 4                 | -52. 27                                          | 22                | + 0. 52                                     | 13      | + 6. 76  |
| π Draconis .....D.<br>R.                    | 2<br>1            | 24. 33. 31. 22<br>32. 55 | 31. 34<br>32. 43                             | 3                 | 31. 70                                           |                   | "                                           |         | "        |
| S.P....D.                                   | 7                 | -24. 33. 31. 09          | -30. 79                                      | 7                 | -30. 79                                          | 10                | + 0. 91                                     | 8       | + 7. 28  |
| ξ <sup>1</sup> Cephei .....D.               | 6                 | 26. 3. 44. 99            | 45. 10                                       | 6                 | 45. 10                                           |                   | "                                           |         | "        |
| S.P....D.                                   | 3                 | -26. 3. 46. 93           | -46. 63                                      | 3                 | -46. 63                                          | 9                 | - 1. 53                                     | 8       | -12. 24  |
| ξ <sup>2</sup> Cephei .....D.               | 5                 | 26. 3. 47. 54            | 47. 65                                       | 5                 | 47. 65                                           |                   | "                                           |         | "        |
| S.P....D.                                   | 3                 | -26. 3. 48. 25           | -47. 95                                      | 3                 | -47. 95                                          | 8                 | - 0. 30                                     | 7       | - 2. 10  |

## CORRECTION TO ASSUMED LATITUDE.

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## CORRECTION TO ASSUMED LATITUDE—concluded.

| Star's Name,<br>and<br>Mode of Observation. | Number<br>of Obs. | N. P. D.<br>Uncorrected.             | Result<br>Corrected<br>for Dis-<br>cordance. | Number<br>of Obs. | Concluded<br>N. P. D.<br>on assumed<br>Latitude. | Number<br>of Obs. | Algebraic<br>Sum of<br>Determina-<br>tions. | Weight. | Product.       |
|---------------------------------------------|-------------------|--------------------------------------|----------------------------------------------|-------------------|--------------------------------------------------|-------------------|---------------------------------------------|---------|----------------|
| $\theta$ Cephei .....D.                     | 3                 | $27^{\circ} 28' 56'' \cdot 98$       | $57'' \cdot 08$                              | 3                 | $57'' \cdot 08$                                  |                   | "                                           |         | "              |
| S.P....D.                                   | 2                 | $-27.28.56 \cdot 87$                 | $-56 \cdot 56$                               | 2                 | $-56 \cdot 56$                                   | 5                 | $+ 0 \cdot 52$                              | 4       | $+ 2 \cdot 08$ |
| $\alpha$ Ursæ Majoris ...D.                 | 8                 | $27.29.0 \cdot 56$                   | $0 \cdot 66$                                 | 8                 | $0 \cdot 66$                                     |                   |                                             |         |                |
| S.P....D.                                   | 5                 | $-27.29.0 \cdot 43$                  | $-0 \cdot 12$                                | 5                 | $-0 \cdot 12$                                    | 13                | $+ 0 \cdot 54$                              | 11      | $+ 5 \cdot 94$ |
| $\alpha$ Cephei .....D.<br>R.               | 7<br>2            | $28.0.55 \cdot 34$<br>$55 \cdot 28$  | $55 \cdot 44$<br>$55 \cdot 18$               | 9                 | $55 \cdot 38$                                    |                   |                                             |         |                |
| S.P....D.                                   | 2                 | $-28.0.54 \cdot 77$                  | $-54 \cdot 46$                               | 2                 | $-54 \cdot 46$                                   | 11                | $+ 0 \cdot 92$                              | 6       | $+ 5 \cdot 52$ |
| $\eta$ Draconis .....D.                     | 4                 | $28.9.49 \cdot 49$                   | $49 \cdot 59$                                | 4                 | $49 \cdot 59$                                    |                   |                                             |         |                |
| S.P....D.                                   | 4                 | $-28.9.49 \cdot 80$                  | $-49 \cdot 49$                               | 4                 | $-49 \cdot 49$                                   | 8                 | $+ 0 \cdot 10$                              | 7       | $+ 0 \cdot 70$ |
| $\eta$ Cephei .....D.<br>R.                 | 8<br>3            | $28.42.43 \cdot 04$<br>$42 \cdot 41$ | $43 \cdot 14$<br>$42 \cdot 31$               | 11                | $42 \cdot 91$                                    |                   |                                             |         |                |
| S.P....D.                                   | 3                 | $-28.42.42 \cdot 67$                 | $-42 \cdot 36$                               | 3                 | $-42 \cdot 36$                                   | 14                | $+ 0 \cdot 55$                              | 8       | $+ 4 \cdot 40$ |
| $\epsilon$ Cephei .....D.                   | 4                 | $33.39.48 \cdot 67$                  | $48 \cdot 74$                                | 4                 | $48 \cdot 74$                                    |                   |                                             |         |                |
| S.P....D.                                   | 1                 | $-33.39.50 \cdot 10$                 | $-49 \cdot 79$                               | 1                 | $-49 \cdot 79$                                   | 5                 | $- 1 \cdot 05$                              | 3       | $- 3 \cdot 15$ |
| $\alpha$ Cassiopeiæ .....D.                 | 2                 | $34.14.30 \cdot 92$                  | $30 \cdot 99$                                | 2                 | $30 \cdot 99$                                    |                   |                                             |         |                |
| S.P....D.                                   | 1                 | $-34.14.31 \cdot 29$                 | $-30 \cdot 98$                               | 1                 | $-30 \cdot 98$                                   | 3                 | $+ 0 \cdot 01$                              | 2       | $+ 0 \cdot 02$ |
| $\beta$ Draconis .....D.                    | 5                 | $37.35.31 \cdot 58$                  | $31 \cdot 63$                                | 5                 | $31 \cdot 63$                                    |                   |                                             |         |                |
| S.P....D.                                   | 5                 | $-37.35.32 \cdot 33$                 | $-32 \cdot 01$                               | 5                 | $-32 \cdot 01$                                   | 10                | $- 0 \cdot 38$                              | 8       | $- 3 \cdot 04$ |
| $\theta$ Ursæ Majoris ...D.                 | 3                 | $37.40.41 \cdot 41$                  | $41 \cdot 46$                                | 3                 | $41 \cdot 46$                                    |                   |                                             |         |                |
| S.P....D.                                   | 9                 | $-37.40.43 \cdot 17$                 | $-42 \cdot 85$                               | 9                 | $-42 \cdot 85$                                   | 12                | $- 1 \cdot 39$                              | 7       | $- 9 \cdot 73$ |
| $\gamma$ Draconis.....D.                    | 4                 | $38.29.34 \cdot 39$                  | $34 \cdot 44$                                | 4                 | $34 \cdot 44$                                    |                   |                                             |         |                |
| S.P....D.                                   | 6                 | $-38.29.35 \cdot 54$                 | $-35 \cdot 22$                               | 6                 | $-35 \cdot 22$                                   | 10                | $- 0 \cdot 78$                              | 7       | $- 5 \cdot 46$ |
| $\eta$ Ursæ Majoris ...D.                   | 5                 | $39.58.36 \cdot 22$                  | $36 \cdot 26$                                | 5                 | $36 \cdot 26$                                    |                   |                                             |         |                |
| S.P....D.                                   | 4                 | $-39.58.37 \cdot 83$                 | $-37 \cdot 51$                               | 4                 | $-37 \cdot 51$                                   | 9                 | $- 1 \cdot 25$                              | 6       | $- 7 \cdot 50$ |
| $\alpha$ Persei .....D.                     | 7                 | $40.38.53 \cdot 15$                  | $53 \cdot 19$                                | 7                 | $53 \cdot 19$                                    |                   |                                             |         |                |
| S.P....D.                                   | 2                 | $-40.38.54 \cdot 27$                 | $-53 \cdot 95$                               | 2                 | $-53 \cdot 95$                                   | 9                 | $- 0 \cdot 76$                              | 4       | $- 3 \cdot 04$ |

If  $z$  be the correction to the assumed colatitude,  $2z +$  the algebraical sum of the determinations ought to be equal to 0. Combining the whole with the weights above attached to them,  $2z + 0'' \cdot 47 = 0$ , or  $z = - 0'' \cdot 24$ .

As this result for the colatitude differs, from that which has been assumed in the reductions as the most probably correct, by a quantity sufficient to cause anxiety, it has been thought worth while to exhibit the whole of the results for separate years since the institution of the Transit-Circle, that a better judgment may be formed of the nature of the discrepancy. These results are as follow :—

| For the Year. | Colatitude<br>from Observations<br>of Polaris. | Colatitude<br>from Observations of all<br>Circumpolar Stars. |
|---------------|------------------------------------------------|--------------------------------------------------------------|
| 1851          | 38°. 31'. 21".94                               | 38°. 31'. 21".95                                             |
| 1852          | 21'.92                                         | 21'.94                                                       |
| 1853          | 22'.10                                         | 22'.06                                                       |
| 1854          | 22'.16                                         | 22'.10                                                       |
| 1855          | 22'.11                                         | 21'.91                                                       |
| 1856          | 21'.89                                         | 21'.83                                                       |
| 1857          | 21'.60                                         | 21'.80                                                       |
| 1858          | 21'.58                                         | 21'.76                                                       |

The only imaginable source of error which might act differently in different years is in the temperatures used for computing the refractions ; and, therefore, with a view of determining the general accuracy of the readings of the circle-thermometer, its readings for the observations of Polaris have been compared with those taken at the same time at the Meteorological Observatory as far as they correspond, since the institution of the latter. It will be sufficient to give the mean of the readings for each year since the erection of the Transit-Circle ; and they are as follow :—

| Year. | Mean of the Readings of      |                            |
|-------|------------------------------|----------------------------|
|       | The Standard<br>Thermometer. | The Circle<br>Thermometer. |
| 1851  | 48°.9                        | 48°.9                      |
| 1852  | 50°.3                        | 49°.9                      |
| 1853  | 49°.0                        | 48°.6                      |
| 1854  | 49°.1                        | 49°.3                      |
| 1855  | 47°.2                        | 47°.1                      |
| 1856  | 50°.3                        | 50°.9                      |
| 1857  | 52°.1                        | 52°.2                      |
| 1858  | 49°.0                        | 48°.5                      |

By inspection of these results it will be seen that the accordance between the two sets of readings is very great, and that there is no difference which would at all account for the discrepancies in the values of the colatitude. As, however, the mean value of the colatitude derived from the eight years given above is 38°. 31'. 21".92, there is no reason to apply any correction at present to the final results of the observations of stars and planets which have been definitively given for those years, during which the colatitude has been assumed to be 38°. 31'. 22".00.

§ 7. *Observations of Azimuth with the Altazimuth*, page [ii] to [lix].

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 galvanic 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. Dunkin as a standard; and 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 Hardy, the Transit-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 Transit Clock is slow, is, before application, corrected by the quantity  $-0^s.03$  for the difference of longitude between the position of the Transit-Circle and that of the Altazimuth. This difference of longitude is obtained by measurement on the plan of the Observatory, of which a reduced copy is attached to the volume for 1845.

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. 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  $7^{\text{rev.}}.8 - p$  of micrometer  $a$ ,  $7^{\text{rev.}}.7 - q$  of micrometer  $b$ ,  $7^{\text{rev.}}.9 - r$  of micrometer  $c$ , and  $8^{\text{rev.}}.0 - s$  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

$$\frac{5'}{4} \times \left\{ \frac{w}{7.8-p} + \frac{x}{7.7-q} + \frac{y}{7.9-r} + \frac{z}{8.0-s} \right\}$$

or

$$\frac{5'}{4} \times \left\{ \frac{w}{7.8} + \frac{x}{7.7} + \frac{y}{7.9} + \frac{z}{8.0} \right\} + \frac{5'}{4} \times \left\{ \frac{w}{7.8} \cdot \frac{p}{7.8} + \frac{x}{7.7} \cdot \frac{q}{7.7} + \frac{y}{7.9} \cdot \frac{r}{7.9} + \frac{z}{8.0} \cdot \frac{s}{8.0} \right\}$$

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From the near equality of  $\frac{w}{7.8}$ ,  $\frac{x}{7.7}$ , &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

$$w \times \frac{5'}{4 \times 7.8} + x \times \frac{5'}{4 \times 7.7} + y \times \frac{5'}{4 \times 7.9} + z \times \frac{5'}{4 \times 8.0} \\ + \frac{1}{4} \left\{ w \times \frac{5'}{4 \times 7.8} + x \times \frac{5'}{4 \times 7.7} + y \times \frac{5'}{4 \times 7.9} + z \times \frac{5'}{4 \times 8.0} \right\} \times \frac{p+q+r+s}{7.85}$$

If the quantity  $\frac{1}{4} \times \frac{100''}{7.85} \times (p+q+r+s)$  be called *Correction for Runs for 100''*, then the expression is

$$w \times \frac{5'}{4 \times 7.8} + x \times \frac{5'}{4 \times 7.7} + y \times \frac{5'}{4 \times 7.9} + z \times \frac{5'}{4 \times 8.0} \\ + \frac{1}{100} \left\{ w \times \frac{5'}{4 \times 7.8} + x \times \frac{5'}{4 \times 7.7} + y \times \frac{5'}{4 \times 7.9} + z \times \frac{5'}{4 \times 8.0} \right\} \times \text{Correction for Runs for 100''}.$$

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 with the sliding rule).

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 angular distances from the several wires to the mean, which were used throughout the year 1858, were the following, the designations of wires being the same as in preceding years: and 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 galvanic observations,—

|          |          |
|----------|----------|
| Wire $s$ | — 119.95 |
| $t$      | — 73.83  |
| $u$      | — 23.96  |
| $v$      | + 23.82  |
| $w$      | + 72.34  |
| $x$      | + 121.58 |

For wires used in observations by eye and ear—

|          |          |
|----------|----------|
| Wire $q$ | — 602.41 |
| $r$      | — 361.27 |
| $s$      | — 120.07 |
| $x$      | + 121.46 |
| $y$      | + 360.87 |
| $z$      | + 601.41 |

## SMALL CORRECTIONS FOR AZIMUTHS OBSERVED WITH THE ALTAZIMUTH. lxvii

These values were obtained in 1854 by placing each wire successively upon the image of the collimator-mark, and reading the Horizontal Circle of the instrument, the operation being repeated five times. The means of all the readings corresponding to the separate wires were then taken and were successively subtracted from the mean of all the readings, and these differences were finally multiplied by  $\cos 12^\circ. 18'$  (that being the apparent depression of the collimator-mark).

For observation of the image of the collimator, it is necessary to make use of a single wire, and the wire *v* has in nearly all cases been employed for this purpose. The angular depression of the collimator below the horizon being  $12^\circ. 18'$ , the correction to be made to the Circle Reading is  $\pm 23''.82 \times \secant 12^\circ. 18' = \pm 24''.38$ . This value is strictly applicable for reduction to the mean of wires *s*, *t*, *u*, &c.; but, as will be seen above, the mean of the system *s*, *t*, *u*, &c., and that of *q*, *r*, *s*, &c. used occasionally with eye and ear, coincide so exactly, that the same correction for *v* may be employed with both.

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  $\times$  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 Co-efficient 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 proper 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 that each division on the four levels represents one second of arc; 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, and 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 [lxii] to [cii].

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

## CONCLUDED AZIMUTH, AND ZENITH-DISTANCE-OBSERVATIONS WITH THE ALTAZIMUTH. lxix

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 colatitude 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 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 passes one wire, and if  $\delta c$  (expressed in parts of the radius), or  $\delta c_s \times \sin 1''$  ( $\delta c_s$  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

$$C + \delta C_s \times 15 \sin 1'' = C + \frac{dC}{dc} \cdot \delta c + \frac{d^2C}{dc^2} \cdot \frac{\delta c^2}{2}$$

$$\text{Now } \cos a \cdot \cos b + \sin a \cdot \sin b \cdot \cos C = \cos c$$

$$\text{Therefore } \sin a \cdot \sin b \cdot \sin C \cdot \frac{dC}{dc} = \sin c$$

$$\text{And } \sin a \cdot \sin b \left\{ \cos C \cdot \left( \frac{dC}{dc} \right)^2 + \sin C \cdot \frac{d^2C}{dc^2} \right\} = \cos c$$

$$\text{Whence } \frac{dC}{dc} = \frac{\sin c}{\sin a \cdot \sin b \cdot \sin C}$$

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

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

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

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

Substituting this in the last term we have

$$C + \delta C_s \times 15 \sin 1'' = C + \frac{\sin c}{\sin a \cdot \sin b \cdot \sin C} \delta c - \frac{\cot C}{2} \cdot \delta C_s^2 \cdot 15 \sin 1''^2$$

or putting  $C_s$  for the value of  $C$  in seconds of time,

$$C_s + \delta C_s = C_s + \frac{\sin c}{\sin a \cdot \sin b \cdot \sin C_s \cdot 15 \sin 1''} \delta c - \frac{\cot C_s}{2} \cdot \delta C_s^2 \cdot 15 \sin 1''$$

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 =

$$C_s + \frac{\sin c}{6 \sin a \cdot \sin b \cdot \sin C_s \cdot 15 \sin 1''} \Sigma \cdot \delta c - \frac{\cot C_s \cdot 15 \sin 1''}{12} \cdot \Sigma \cdot \delta C_s^2$$

As  $c$  refers to the point which is the mean of the six wires,  $\Sigma \cdot \delta c = 0$ . 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,  $\delta C_s = -\frac{5}{10} I$ ; for the second,  $\delta C_s = -\frac{3}{10} I$

for the third,  $\delta C_3 = -\frac{1}{10} I$ ; for the fourth,  $\delta C_4 = +\frac{1}{10} I$ ; for the fifth it is  $+\frac{3}{10} I$ ; for the sixth,  $+\frac{5}{10} I$ . Hence the equation becomes,

$$\begin{aligned} \text{Mean of observed hour-angles in seconds of time} &= \\ C_3 - \frac{\cot C \cdot 15 \sin 1''}{12} \cdot \frac{70}{100} \times I^2 \\ &= C_3 - \frac{7}{8} \cdot \sin 1'' \times \cot C \times I^2 \end{aligned}$$

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:—

$$+ \frac{7}{8} \cdot \sin 1'' \times \cot C \times I^2$$

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 three wires are observed, if  $I_3$  be the interval in seconds of time from the first to the third, the correction in seconds of time will be  $+\frac{5}{4} \sin 1'' \times \cot C \times (I_3)^2$ .

When four wires are observed, if  $I_4$  be the interval from the first to the fourth, the correction will be  $+\frac{25}{24} \sin 1'' \times \cot C \times (I_4)^2$ .

When five wires are observed, if  $I_5$  be the interval from the first to the fifth, the correction will be  $+\frac{15}{16} \sin 1'' \times \cot C \times (I_5)^2$ .

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. Dunkin 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

$$\begin{array}{cc} A & D \\ B & C \end{array}.$$

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

## SMALL CORRECTIONS FOR ZENITH DISTANCES OBSERVED WITH THE ALTAZIMUTH. lxxi

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 is:

For the wires used in galvanic observations,—

|      |          |   |                      |
|------|----------|---|----------------------|
| Wire | <i>S</i> | — | 59 <sup>''</sup> ·21 |
|      | <i>T</i> | — | 35·85                |
|      | <i>U</i> | — | 12·44                |
|      | <i>V</i> | + | 11·12                |
|      | <i>W</i> | + | 36·57                |
|      | <i>X</i> | + | 59·82                |

For wires used in observations by eye and ear,—

|      |          |   |                       |
|------|----------|---|-----------------------|
| Wire | <i>Q</i> | — | 300 <sup>''</sup> ·99 |
|      | <i>R</i> | — | 181·24                |
|      | <i>S</i> | — | 59·12                 |
|      | <i>X</i> | + | 59·91                 |
|      | <i>Y</i> | + | 180·81                |
|      | <i>Z</i> | + | 300·62                |

These numbers were obtained by means of the collimator, in the year 1854, by placing each wire successively upon the image of the collimator-mark, and reading the Vertical Circle; and then taking the difference of the mean reading for each wire from the mean of all the readings.

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 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 observation of the collimator, by applying 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 both levels, one division of the scale is assumed to be equal to a second of arc (the zeros of *E* and *G* being 0<sup>div.</sup>, and those of *F* and *H* being respectively 200<sup>div.</sup> and

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250<sup>div.</sup>), and then the mean of the four readings 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 adjustable bag and float: it is placed in a small recess of the dome. 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 window of the dome-staircase.

This Thermometer was compared with the Standard Thermometer in May 1858, and the following Table gives the results of the comparison:—

| Temperatures.       | Excess of Readings of<br>Altazimuth Thermometer. |
|---------------------|--------------------------------------------------|
| From 32 to 42 ..... | 0 <sup>o</sup> 2                                 |
| 43 to 45 .....      | 0 <sup>o</sup> 3                                 |
| 45 to 50 .....      | 0 <sup>o</sup> 4                                 |
| 51 to 55 .....      | 0 <sup>o</sup> 5                                 |
| 56 to 60 .....      | 0 <sup>o</sup> 6                                 |
| 60 to 65 .....      | 0 <sup>o</sup> 7                                 |
| 66 to 70 .....      | 0 <sup>o</sup> 8                                 |
| 70 to 75 .....      | 0 <sup>o</sup> 9                                 |
| 76 to 80 .....      | 1 <sup>o</sup> 0                                 |
| 80 to 83 .....      | 1 <sup>o</sup> 1                                 |
| 84 to 87 .....      | 1 <sup>o</sup> 2                                 |
| 88 to 90 .....      | 1 <sup>o</sup> 3                                 |

The readings being too high, the tube relatively to the scale was afterwards lowered by a quantity corresponding to 0<sup>o</sup> 5, which reduces the errors within ordinary limits of temperatures to insignificant quantities.

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°) as an Appendix to the Volume for 1853, giving the same results as the tables in the *Tabulæ Regiomontanæ*; with the alterations in the mean refractions for objects near the horizon authorized by Mr. Main's paper referred to at page liv. 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

TABULAR AZIMUTHS AND ZENITH DISTANCES FOR ALTAZIMUTH OBSERVATIONS. lxxiii

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 li.) 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 [cvi] to [cli].

The *three first* 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 formed: For stars, by applying to the places of the stars given in the Nautical Almanac corrections fundamentally deduced from the Right Ascensions given in the Greenwich Catalogue of 1576 Stars for 1850 (see page xxx); for other stars not given in the Nautical Almanac, the places are in general fundamentally deduced from the same Catalogue, or from subsequent annual Catalogues of Stars observed at Greenwich in the years 1854 to 1857, and their assumed Mean Right Ascensions for 1858, Jan. 1, are given in the general list of stars used for clock-error on pages xxx and xxxi; for the star  $\lambda$  Serpentis, which was observed inadvertently for  $\alpha$  Serpentis in one position of the Vertical Circle on April 30 and June 18, the place used on April 30 is obtained fundamentally from the Greenwich Twelve-Year-Catalogue, and that for June 18 from observations made expressly for the purpose in 1858; for the Moon, the Tabular R.A. of Center is formed by interpolating with second differences between the hourly places of the Moon in the Nautical Almanac, using as argument the Mean Solar Time of the fourth column. For a few observations of Donati's Comet made in September and October, the Tabular R.A. and N.P.D. used for comparison with the observed places are taken from an ephemeris computed by Mr. Lynn, which is printed at page lxxxiv of this Introduction.

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The Hour Angle in the *sixth* column is the difference (without respect of sign, but taken less than  $180^\circ$ ) 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 formed : For the stars, by applying to the places of the Nautical Almanac, corrections deduced from the N.P.D. given in the Greenwich Catalogue of 1576 Stars for the epoch 1850, with the exceptions mentioned above ; and for the Moon, by interpolating with second differences between the hourly places of the Nautical Almanac.

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,  $a \times [7\cdot7174788] \times \sin \text{Moon's N.P.D.}$  ; the angle which

it subtends as seen from the Moon will be  $\frac{a}{\text{Moon's distance}} \times [7\cdot7174788] \times \sin \text{Moon's}$

N.P.D.  $= [7\cdot7174788] \times \sin \text{Moon's hor. equat. parallax} \times \sin \text{Moon's N.P.D.}$  ; and the value of this in seconds of arc will be  $[3\cdot0319039] \times \sin \text{Moon's hor. eq. par.} \times \sin \text{Moon's N.P.D.}$  ; or  $[7\cdot7174788] \times \text{seconds of Moon's hor. eq. par.} \times \sin \text{Moon's N.P.D.}$ . In this manner the number in the ninth column has been computed. It is always subtractive.

The assumed colatitude  $38^\circ.31'.22''.14$  is the same as that formerly deduced from observations with the Mural Circle, corrected by the quantity  $+0''.34$  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  $38^\circ.31'.22''.14$  ; 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:—

$$\text{Log tan } \alpha = \text{log cos hour-angle} + \text{log tan Normal-centric N.P.D.}$$

$$\beta = \alpha - \text{co-latitude.}$$

$$\text{Log tan zenithal angle} = \text{log sin } \alpha + \text{log tan hour-angle} - \text{log sin } \beta.$$

$$\text{Log cotan zen. dist.} = \text{log cotan } \beta + \text{log cos zenithal angle.}$$

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

$$\text{Log sin zenithal angle} + \text{log sin zen. dist.} = \text{log sin hour-angle} + \text{log sin N.P.D.}$$

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, without alteration of its constant. (See Preface to N. A. for 1857, page vii.) 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  $a \times [7.71748] \times \cos \text{Moon's N.P.D.}$ , and therefore her angular semidiameter is diminished in the proportion of Moon's distance to Moon's distance— $a \times [7.71748] \times \cos \text{Moon's N.P.D.}$ , or  $1 : 1 - \sin \text{hor. eq. par.} \times [7.71748] \times \cos \text{Moon's N.P.D.}$ : or, using the mean parallax  $57'$ , the proportion is  $1 : 1 - [5.93708] \times \cos \text{Moon's N.P.D.}$ . 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, the only correction required being that for reduction to the foot of the Normal. This correction is  $-930'' \times [5.93708] \times \cos \text{Moon's N.P.D.}$ , and is readily tabulated.

For computation of the Parallax, 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 this 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  $= \frac{1}{a \sin l} \cdot \frac{a^2}{b^2} y = \frac{a}{\sqrt{b^2 \sin^2 l + a^2 \cos^2 l}}$ ; 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  $1 - [5.93708] \times \cos \text{Moon's N. P. D.}$ . These two corrections are embodied in one logarithmic table with argument N. P. D., the number for  $60^\circ$  being 0.0008664, that for  $90^\circ$  being 0.0008851, and that for  $120^\circ$  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,  $-\frac{P^3}{6} \sin^2 1'' \cdot \sin \text{zen. dist.} \cos^2 \text{zen. dist.}$  (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  $\sin \text{zen. dist.} \times \text{Airy's correction}$  as given in the section of Occultations. The table of corrections used is given in page liv.

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 [cliv] to [clxxviii].

In general, the times of the transits taken with the Altazimuth by means of the method of galvanic contact are those of the Transit-Clock (Hardy), and no comparisons of clocks are necessary. The errors of the Transit Clock are obtained for the time of each observation, and, after correction by  $-0^s.03$  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 Transit-Clock and the Clock (Graham 1) of the South Dome, used with the Altazimuth, are made by means of a solar chronometer, whose name is always mentioned. The chronometer is brought close to each of the clocks, and the time of accurate coincidence of beats is noted;

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the chronometer-interval between the comparisons, which is sensibly Solar Time, is converted into 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 (see page lxxv), 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 quantities for a low star. Then the true azimuth of the high star deduced from observation, Face Right, is

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

the computed azimuth corrected is

$$C_r + w;$$

hence this observation gives the equation

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

The true azimuth determined from observation, Face Left, is

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

and this observation therefore gives the equation,

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

Subtracting the first equation from the second,

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

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

A similar treatment of the observations of the low star gives

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

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

It has been already stated that, in 1850, a Collimator was mounted, admitting of accurate observation with the telescope of the Altazimuth, and requiring for its obser-

vation that the telescope be directed at an angle of  $12^{\circ}.18'$  below the horizon. It is evident that, for the instrumental adjustments, the Collimator may be used as an immovable star, and that, considered as the low star in the preceding investigation, its position is exceedingly favourable. The preceding formulæ apply with no other changes than the following: for  $d_r$  and  $d_l$  put  $102^{\circ}.18'$ , and for  $c_r$  and  $c_l$  put the same symbol  $c$ . It is by this use of the Collimator in combination with a high star that the error of collimation has been found throughout the year 1858.

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.

It is plain now that 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 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 error of collimation. Then the first equations are,

$$\begin{aligned} O'_r + L_r \cdot \cotan D_r - C_r &= +y \cdot \cotan D_r + z + w \\ O'_l - L_l \cdot \cotan D_l - C_l &= -y \cdot \cotan D_l + z + w \end{aligned}$$

Whence 
$$\frac{(O'_r + L_r \cdot \cotan D_r - C_r) - (O'_l - L_l \cdot \cotan D_l - C_l)}{\cotan D_r + \cotan D_l} = y.$$

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 comparison of these Level-Zeros with those relating to the Horizontal Axis, would give a set of differences; and the mean of these differences might then be applied to the individual Level-Zeros of the Vertical Axis; and thus another value of the quantity  $y$  would be obtained, which might be combined with that found from the azimuthal transits. This process has not been used at all in the year 1858, but the results of the comparison are given in a subsequent section. By inspection of these results, it will be seen that the relative difference between the two zeros has been steadily increasing, and is at the present time considerable, 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 will probably necessitate an instrumental correction of the error.

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 appeared, 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 very 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 during the year 1858 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 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

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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

$$\begin{aligned} O_r - Z &= \text{true zenith distance with Face Right} = C_r + e \\ Z - O_l &= \text{true zenith distance with Face Left} = C_l + e \end{aligned}$$

Subtracting the first from the second,

$$\begin{aligned} 2Z - (O_r + O_l) &= C_l - C_r \\ \text{or } Z &= \frac{(O_r + O_l) - (C_r - C_l)}{2} \end{aligned}$$

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

$$Z = \frac{O_r + O_l}{2}$$

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 have varied 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, 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,

$$\begin{aligned} \delta. Z &= -\sin S. \sin N. P. D. \times \delta. R. A. + \cos S \times \delta. N. P. D. \\ \delta. A &= -\frac{\cos S}{\sin Z} \cdot \sin N. P. D. \times \delta. R. A. - \frac{\sin S}{\sin Z} \times \delta. N. P. D. \\ \text{Let } \sin S &= p, \cos S = q, \frac{\cos S}{\sin Z} = r, \frac{\sin S}{\sin Z} = s; \text{ then} \\ \delta. Z &= -p \cdot \sin N. P. D. \times \delta. R. A. + q \times \delta. N. P. D. \\ \delta. A &= -r \cdot \sin N. P. D. \times \delta. R. A. - s \times \delta. N. P. D. \end{aligned}$$

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,

$$\begin{aligned} \Sigma (\delta. Z) &= -\delta. R. A. \times \sin N. P. D. \times \Sigma (p) + \delta. N. P. D. \times \Sigma (q) \\ \Sigma (\delta. A) &= -\delta. R. A. \times \sin N. P. D. \times \Sigma (r) - \delta. N. P. D. \times \Sigma (s) \end{aligned}$$

ZEROS OF Z. D.; MOON'S ERRORS IN R. A. AND N. P. D. WITH ALTAZIMUTH. lxxxix  
CATALOGUE OF STARS FROM MERIDIONAL OBSERVATIONS.

By solution of these equations,

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

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

A Table of double entry, appended to the Introduction to the *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 1858; and New Constants for Stars in the Catalogue, not observed in preceding Years;*  
page 2 to 15.

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. The annual variations for the Nautical Almanac Stars are taken from the Nautical Almanac. The geometrical precessions for all other stars are either taken from the Catalogue of the British Association, or are computed independently, with the elements given in the Nautical Almanac, 1834, 2nd edition, page xiii; which are taken from the *Tabulæ Regiomontanæ*, and which have been used for all the later volumes of the Nautical Almanac. The annual variations set down are the precessions thus computed, affected with the proper motions that are given in the British Association Catalogue, for stars contained in that 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  $15^\circ$ , the observations above and below the pole are considered equally good; from N. P. D.  $15^\circ$  to N. P. D.  $36^\circ$ , those below have the weight  $\frac{2}{3}$  for each observation; from N. P. D.  $36^\circ$  to N. P. D.  $41^\circ$ , those below have the weight  $\frac{1}{2}$ ; beyond  $41^\circ$  N. P. D., the observations are not combined.

The annual variations are taken from the Nautical Almanac, as far as its list extends: for other stars they are either taken from the British-Association-Catalogue, with the additions of the proper motions given in Mr. Main's paper (see page xxix); or are computed with the elements given in the Nautical Almanac, 1834, 2nd edition, page xiii.

The nomenclature of the stars is identical with that in the second section.

The new star-constants require no further explanation than what is given at pages xlii and lvi. They are computed 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 Tables, page 18 to 45.*

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 all the values of this error is  $+0^{\circ}07$ , agreeing nearly with the results of the three 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 all the values of this error is  $+0''92$ .

For the duration of the passage of the Moon's diameter, a correction is applied (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 unenlightened part of the disk (with respect to right ascension); the correction required is, duration of passage  $\times$  versed sine  $\theta$ . The duration of passage of the Moon's diameter has been observed five times in 1858, and the mean of the five values of the apparent error of the duration of transit given in the Nautical Almanac, is  $+0^{\circ}15$ .

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 lii). The mean of fifteen values of this error is  $+1''80$ .

The vertical diameters of Mercury and Venus 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 lii. 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

# MEAN TIME: DIAMETERS, R.A., AND N.P.D., OF SUN, MOON, AND PLANETS. lxxxiii

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 Transit of first point of Aries diminished by 4<sup>m</sup>.
3. 3<sup>m</sup>. 47<sup>s</sup>.00 — hours of Sid. Time + solar equiv. for hours.
4. 10<sup>s</sup>.00 — minutes of Sid. Time + solar equiv. for minutes.
5. 3<sup>s</sup>.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 1858 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, without correction. 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 xl).

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. When both limbs of the Moon are observed, the correction for defective illumination (page lxxxii) 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 R—D.

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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  $R - D$ , as has been previously explained. The tabular places are taken from the Nautical Almanac, for such planets as are given in that work. For the recently discovered small planets they are derived from the following sources: For Hebe, Flora, Parthenope, Egeria, Massilia, Themis, Euterpe, Amphitrite, Urania, and Lætitia, from the Berlin Ephemeris for 1860; for Iris, Melpomene, and Thalia, from Gould's Journal, Nos. 107, 102, and 107; for Eunomia, Fortuna, Lætitia, Psyche, Proserpine, Ariadne, Pomona, and Thetis, from the *Astronomische Nachrichten*, Nos. 1111, 1096, 1130, 1136, 1139, 1155, 1161, and 1167; and for Calliope from an Ephemeris by M. Allé.

For Neptune the tabular places were interpolated from the Ephemeris given in the Supplement to the Nautical Almanac for 1861.

For Donati's Comet the Ephemeris used for comparison of the places observed with the Altazimuth was computed in his leisure hours by Mr. Lynn from the Elements of Stampfer given in the *Astronomische Nachrichten*, No. 1163.

The following is the Ephemeris:—

## EPIHEMERIS OF DONATI'S COMET FROM 1858, SEPTEMBER 22 TO OCTOBER 12, CALCULATED FOR GREENWICH MEAN NOON.

| Day, 1858. |    | Apparent R.A. | Apparent N.P.D. | Log. Distance<br>from the Earth. |
|------------|----|---------------|-----------------|----------------------------------|
|            |    | h m s         | ° ' "           |                                  |
| September  | 22 | 11. 58. 22.60 | 54. 1. 10.68    | 9.98802                          |
|            | 23 | 12. 5. 12.26  | 54. 18. 9.19    | 9.97235                          |
|            | 24 | 12. 12. 28.62 | 54. 40. 27.68   | 9.95619                          |
|            | 25 | 12. 20. 13.69 | 55. 8. 54.50    | 9.93957                          |
|            | 26 | 12. 28. 28.67 | 55. 44. 26.96   | 9.92253                          |
|            | 27 | 12. 37. 14.39 | 56. 28. 8.87    | 9.90513                          |
|            | 28 | 12. 46. 31.31 | 57. 21. 10.08   | 9.88746                          |
|            | 29 | 12. 56. 19.55 | 58. 24. 43.95   | 9.86963                          |
|            | 30 | 13. 6. 38.54  | 59. 40. 6.82    | 9.85178                          |
|            |    |               |                 |                                  |
| October    | 1  | 13. 17. 26.83 | 61. 8. 35.90    | 9.83409                          |
|            | 2  | 13. 28. 42.61 | 62. 51. 21.04   | 9.81679                          |
|            | 3  | 13. 40. 22.81 | 64. 49. 23.38   | 9.80015                          |
|            | 4  | 13. 52. 23.47 | 67. 3. 26.62    | 9.78449                          |
|            | 5  | 14. 4. 40.33  | 69. 33. 41.40   | 9.77015                          |
|            | 6  | 14. 17. 8.35  | 72. 19. 43.85   | 9.75751                          |
|            | 7  | 14. 29. 41.91 | 75. 20. 27.30   | 9.74693                          |
|            | 8  | 14. 42. 15.15 | 78. 33. 49.17   | 9.73881                          |
|            | 9  | 14. 54. 42.63 | 81. 57. 8.65    | 9.73339                          |
|            | 10 | 15. 6. 59.26  | 85. 27. 12.31   | 9.73081                          |
|            | 11 | 15. 19. 0.24  | 89. 0. 16.72    | 9.73116                          |
|            | 12 | 15. 30. 41.11 | 92. 32. 19.09   | 9.73448                          |

The R. A. and N. P. D. for the times of the Altazimuth Observations having been obtained by interpolation from this ephemeris, the Tabular Azimuths and Zenith-Distances were computed, and compared with the observed Azimuths and Zenith-Distances (formed by a process already described), and the tabular errors thence deduced were converted into errors of R. A. and N. P. D., which were supposed to apply to the mean of the times of the Altazimuth Observations. These errors then being applied to the tabular R. A. and N. P. D. computed for these times, form the observed R. A. and N. P. D., which are given in the respective columns.

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  $x \times \cos \odot \text{ longitude} + y \times \sin \odot \text{ longitude} + z$ . 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 in groups never 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, 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,

$$\begin{aligned} \text{Error of geoc. long.} = & \frac{R \times \cos \text{ hel. lat.} \times \cos (\lambda - L)}{\Delta \times \cos \text{ geoc. lat.}} \times \text{error of hel. long.} \\ & - \frac{\sin (\lambda - L)}{\Delta \times \cos \text{ geoc. lat.} \times \sin l''} \times \text{error of projection of planet's radius vector.} \end{aligned}$$

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$$\begin{aligned} \text{Error of Hcl. E. P. D.} &= \frac{\Delta \times \cos \text{hel. lat.}}{R \times \cos \text{geoc. lat.}} \times \text{error of geocent. E. P. D.} \\ &- \sin \text{hel. lat.} \times \cos \text{hel. lat.} \times \tan (\lambda - L) \times \text{error of geocent. long.} \\ &- \frac{r \times \tan \text{geoc. lat.} \times \cos (L - l)}{R^2 \cos (\lambda - L) \times \sin l''} \times \text{error of projection of planet's radius vector.} \end{aligned}$$

For the other planets, the following are used :—

$$\begin{aligned} \text{Error of geocent. long.} &= \frac{R \times \cos (\lambda - L)}{\Delta} \times \text{error of planet's heliocentric longitude} \\ &- \frac{\sin (\lambda - L)}{\Delta \times \sin l''} \times \text{error of projection of planet's radius vector} \\ &- \frac{r \times \cos (\lambda - l)}{\Delta} \times \text{error of Earth's heliocentric longitude} \\ &+ \frac{\sin (\lambda - l)}{\Delta \times \sin l''} \times \text{error of Earth's radius vector.} \end{aligned}$$

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

In the expressions above, different quantities are neglected for the small planets and for the other planets. For the small planets, it is not allowed to neglect the latitude 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  $\gamma$  Draconis, with the Reflex Zenith-Tube*; page 58 to 64.

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 xiv 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.

GEOCENTRIC AND HELIOCENTRIC ERRORS OF THE PLANETS.  
OBSERVATIONS OF  $\gamma$  DRACONIS WITH THE REFLEX ZENITH-TUBE.

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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  $\gamma$  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  $\gamma$  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  $15 \times$  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

$$\frac{\sin. 43'.38''.48}{156.017 \times \sin 1''} = 16''.784$$

and in the other case the value was

$$\frac{\sin. 50'.51''.71}{181.936 \times \sin 1''} = 16''.775.$$

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.

The wires used for the bisection of the Stars are those numbered "15" and "16," and the interval in arc between these wires, as determined in 1856, is  $3'.37''.738$ . This value has been used without alteration throughout the year 1858.

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

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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}  $\times$   $\{\frac{1}{2}$  sum of readings of level-scale $\}$   $\times$  {value of one division of level-scale}.

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

From statements made by Mr. 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 =  $0^{\text{in}}.25$  ; and that the value of one division of the level-scale =  $6''$  nearly. Also, the focal length of the object-glass, which is that of Troughton's transit instrument dismantled 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  $0''.00646 \times$  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 evening 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 evenings. 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 of the tabular arrangement are found.

§ 14. *Observations of N.P.D. of Cusps made with the North Equatoreal during the Solar Eclipse of 1858, March 14–15, pages 66 and 67.*

The weather was generally so bad during the time of this eclipse, not only at Greenwich, but at the other selected stations of observation, that in general the observations made were of little value. The observations of N.P.D. of cusps here printed are all that could be made with the North Equatoreal, notwithstanding the utmost vigilance of Mr. Dunkin, who observed with the telescope, and of Mr. Ellis and Mr. Criswick who were stationed to read the microscopes of the declination circle. They are only partially reduced, as being of little ultimate value. The time of each observation was recorded by the clock Arnold in the dome, this clock being compared with the Transit-Clock very nearly at the time of observation. For each observation the telescope-micrometer (a) was used, as well as the two microscopes of the declination circle, so that each observation gives the absolute N.P.D. of the cusp observed, subject to index correction. The runs of the microscopes were obtained on March 16, when it appeared that the correction for runs on an arc of 5' was, for Microscope A,  $-2''.47$ , and for Microscope B,  $-0''.60$ . No farther explanation is needed.

For an account of the organization established for making extensive series of observations at other stations selected by me on the line of totality, and on each side of it, namely, at Great Harrowden, Bedford, and Market Harborough, the Monthly Notice of the Royal Astronomical Society for 1858, June 11 (vol. xviii, No. 8), may be consulted.

§ 15. *Eclipse of the Moon; and 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 70 to 86.*

The observed times of the disappearance and reappearance of spots on the Moon's surface, and of the end of the eclipse of the Moon; and of occultations of stars by the Moon, and of eclipses, &c. of Jupiter's Satellites, need little explanation beyond that which is given in the tabular arrangement. The clock used is usually compared with the Transit-Clock near the time of the observation, and the mean solar time is computed in the usual way.

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

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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<br>the Vertical as<br>seen in an<br>inverting<br>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  $\varphi$  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;  $\varphi'$  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 shewn that

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

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

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

$$F = \log. \sin \text{star's hour-angle} + \log. \text{seconds of corrected eq. hor. parallax} + 9.4942224.$$

$$G = \log. \sin \text{star's N. P. D.} + \log. \sin \text{star's hour-angle} + \log. \text{seconds of corrected eq. hor. parallax} + 9.8913935.$$

(The former 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  $\vartheta'$ , in the following manner:—

$$\begin{aligned} \log. \frac{1}{2} (\vartheta - \vartheta') \text{ in seconds} &= F - \log. \sin \vartheta' + \log. \frac{\sin}{\text{arc}} \text{ for hor. parallax} \\ &+ \log. \frac{\text{arc}}{\sin} \text{ for } (\vartheta - \vartheta'). \end{aligned}$$

$$\begin{aligned} \log. 1^{\text{st}} \text{ number} &= G + \log. \secant \frac{1}{2} (\vartheta - \vartheta') + \log. \frac{\sin}{\text{arc}} \text{ for hor. parallax} \\ &+ \log. \frac{\text{arc}}{\sin} \text{ for } (\vartheta - \vartheta') - \log. \sin \frac{1}{2} (\vartheta + \vartheta'). \end{aligned}$$

$$\begin{aligned} \log. 2^{\text{nd}} \text{ number} &= \log. \frac{1}{2} (\vartheta - \vartheta') \text{ in seconds} + \log. \frac{\tan}{\text{arc}} \text{ for } \frac{1}{2} (\vartheta - \vartheta') \\ &+ \log. \sin (\vartheta + \vartheta' - 180^\circ) + \log. \cot \frac{1}{2} (\vartheta + \vartheta') + \log. \frac{\text{arc}}{\sin} \text{ for } (\vartheta - \vartheta'). \\ \vartheta - \vartheta' &= 1^{\text{st}} \text{ number} + 2^{\text{nd}} \text{ number.} \end{aligned}$$

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

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

$$\begin{aligned} \text{If } \log. \tan \psi &= \log. \text{diff. R. A. of Moon's center and corresponding point} + \frac{1}{2} \log. \\ &\sin \text{N. P. D. of Moon's center} + \frac{1}{2} \log. \sin \vartheta' - \log. \text{diff. N. P. D. of} \\ &\text{Moon's center and corresponding point;} \end{aligned}$$

$$\text{Then } \log. \text{dist.} = \log. \text{diff. N. P. D.} - \log. \cos \psi,$$

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

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,

$$\log. 1^{\text{st}} \text{ number} = 2 \log. \text{diff. R. A.} + \log. \sin (\text{sum of N. P. D.}) - \log. \text{dist.} + 4.0835.$$

$$\log. 2^{\text{nd}} \text{ number} = \log. \text{diff. N. P. D.} - \log. \text{distance.}$$

$$\text{Coefficient of variation of greater N. P. D.} = 1^{\text{st}} \text{ number} + 2^{\text{nd}} \text{ number.}$$

$$\text{Coefficient of variation of smaller N. P. D.} = 1^{\text{st}} \text{ number} - 2^{\text{nd}} \text{ number.}$$

$$\text{Log. coefficient of variation of diff. R. A.} =$$

$$\log. \text{diff. R. A.} + \log. \sin \vartheta' + \log. \sin \text{Moon's N. P. D.} - \log. \text{distance.}$$

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  $t$ , 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 =

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

This supposes that the star's place is correct. If the Moon's place were supposed correct, the factor, instead of  $15'' \times t$ , would be  $(15'' - \text{Moon's change of R. A.}) \times t$ .

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  $t$ , will alter the correction for parallax in N. P. D. by the following quantity:—

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

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

|    | $\text{Log.} \left( \frac{\text{Arc.}}{\sin} \right)$ | $\text{Log.} \left( \frac{\sin}{\text{Arc.}} \right)$ |    | $\text{Log.} \left( \frac{\text{Arc.}}{\sin} \right)$ | $\text{Log.} \left( \frac{\sin}{\text{Arc.}} \right)$ |
|----|-------------------------------------------------------|-------------------------------------------------------|----|-------------------------------------------------------|-------------------------------------------------------|
| 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                                             |

|    | $\text{Log.} \left( \frac{\tan}{\text{Arc.}} \right)$ |    | $\text{Log.} \left( \frac{\tan}{\text{Arc.}} \right)$ |
|----|-------------------------------------------------------|----|-------------------------------------------------------|
| 1  | 0.0000000                                             | 14 | 0.0000024                                             |
| 2  | 0.0000001                                             | 15 | 0.0000027                                             |
| 3  | 0.0000002                                             | 16 | 0.0000031                                             |
| 4  | 0.0000003                                             | 17 | 0.0000035                                             |
| 5  | 0.0000004                                             | 18 | 0.0000039                                             |
| 6  | 0.0000006                                             | 19 | 0.0000044                                             |
| 7  | 0.0000008                                             | 20 | 0.0000049                                             |
| 8  | 0.0000010                                             | 21 | 0.0000054                                             |
| 9  | 0.0000012                                             | 22 | 0.0000059                                             |
| 10 | 0.0000015                                             | 23 | 0.0000063                                             |
| 11 | 0.0000018                                             | 24 | 0.0000071                                             |
| 12 | 0.0000021                                             | 25 | 0.0000077                                             |

§ 16. *Measures of the Diameters of the Planets Mercury, Mars, and Jupiter; and of the Distance and Position of the Components of  $\gamma$  Virginis: made with a Double-Image Micrometer upon the East Equatoreal; page 88.*

The general construction 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, from 1840 to 1849, to which it is sufficient in this place to refer.

The construction of the double-image eyepiece with which these observations were made 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. 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 value of one revolution of the micrometer-screw which has been used in reducing the measures is  $7''.247$ . This is the mean of five determinations, namely, of that on May 17, 1851, by three transits of Polaris, which gave the value  $7''.260$ ; of that on May 20, 1851, by two transits of Polaris, which gave  $7''.197$ ; of that on November 10, 1855, by three transits of Polaris, which gave  $7''.227$ ; of that on March 20, 1857, by four transits of Polaris, giving  $7''.253$ ; and, finally, of that on January 4, 1858, by four transits of Polaris, giving  $7''.264$ .

For the determination of the zero of position, or the reading of the Position-Circle corresponding to separation in the direction of the astronomical meridian, the eye-tube is attached with its wire nearly parallel to the direction of separation, the telescope is directed to a star, and the clock-work of the equatoreal is put in action; then the micrometer-screw is turned through a considerable number of revolutions backwards and forwards, and the eye-tube is turned by hand (without moving the rest of the eyepiece), till the moveable image of the star, as moved by the micrometer-screw, runs well upon the wire. Thus the position of the wire is made to correspond accurately to the direction of separation. The clock-work is then stopped, the star passes through the field by its diurnal motion, and the Position-Circle is turned (without independent

movement of the eyeglass-tube) till the diurnal motion makes the star run well along the wire; then the position of the wire, and consequently the direction of separation, coincides accurately with the direction of diurnal motion; and the reading of the Position-Circle, increased or diminished by  $90^\circ$ , is therefore the reading corresponding to separation of images in the direction of the meridian, or the reading for zero of position.

The zero of position thus determined, by observations of two small stars near Jupiter, on January 11, was  $1^\circ. 22'$ ; by  $\alpha$  Orionis, on April 19, it was  $3^\circ. 30'$ ; by the limb of Mars, on July 11, it was  $1^\circ. 5'$ ; and by  $\gamma$  Virginis, on June 25, it was  $0^\circ. 30'$ .

The measures of distance of  $\gamma$  Virginis have been made by the method ordinarily adopted for double stars, namely, by turning the eyepiece till the direction of separation of images coincides with the line joining the two components, and by turning the micrometer screw till the distance between the moveable image of the star which is nearest to the fixed images and the nearest star of the fixed images, is equal to the distance between the stars; and then repeating this operation with the images reversed in position, that is, with the moveable images on the other side of the fixed images. The mean of each pair of micrometer readings for reversed positions evidently corresponds to the coincidence of images, and the value of this coincidence-reading for a complete set of measures is applied as a zero to all the micrometer-readings, and the results in revolutions of the micrometer correspond to double the distance of the components. The mean of these results when divided by 2 and reduced to arc is equal to the distance of the components in arc.

The observations of the diameter of Mercury have been made by first turning the eyepiece till the line joining the cusps of one image is in the same straight line with that joining the cusps of the other image, and then, by means of the micrometer screw, bringing the cusps into contact alternately on opposite sides. The resulting diameter is compared with that given in the Nautical Almanac.

The observations of the diameters of Mars have been made in the usual way by bringing the images of the limbs into contact on opposite sides. One diameter was measured in the direction which seemed to be most nearly coincident with the polar diameter, and the other at right angles to it. The corrections to be applied for defect of illumination to the measured diameters are computed in the following manner:— Assuming Mars to be in the Ecliptic, as the deviations amounted to scarcely more than half a degree, the whole correction for phase is computed in the usual way, by multiplying his semidiameter by the versed sine of the difference between the geocentric and the heliocentric longitudes. The correction due to each measured diameter is then this quantity multiplied by the square of the cosine of the angle between the position of the ecliptic projected on the disk of the planet and the position of the measured diameter. These angles for the three days of observation were respectively  $43^\circ$ ,  $44^\circ$ , and  $45^\circ$ . The observed diameters thus corrected for phase are compared with those given in the Nautical Almanac.

The observations of the diameters of Jupiter were made in the same way as in former years, by contact of the images of opposite limbs. A correction for defective illumination of the equatoreal diameter is thus computed :—The angle made at the Planet by lines drawn to the Sun and the Earth (the difference of the planet's geocentric and heliocentric longitudes) being ascertained, the correction to the equatoreal diameter is, observed semidiameter  $\times$  versed sine of this angle.

The equatoreal and polar diameters thus measured and corrected are compared with those computed from Struve's elements in the *Memoirs of the Royal Astronomical Society*, vol. iii, page 301; namely,

$$\begin{aligned}\text{Equatoreal diameter} &= 38''\cdot327 \\ \text{Polar diameter} &= 35''\cdot538 \\ \text{The distance of Jupiter being} &5\cdot20279 \\ \text{Ellipticity} &= \frac{38\cdot327 - 35\cdot538}{38\cdot327} = \frac{1}{13\cdot7}\end{aligned}$$

The diameters at the times of observation are computed from these by the inverse proportion of distance. The results seem to show, as in former years, that Struve's ellipticity is too large.

§ 17. *Remarks on the Appearance of Comet V, 1858, (Donati's Comet,) as seen chiefly with the Telescope of the East or Sheepshanks' Equatoreal; pages 90 and 91.*

Donati's Comet was diligently watched at every opportunity, and the changes in the physical appearance of its nucleus, &c., carefully noted, but no further explanation is necessary here, the various appearances being fully described in the notes by the different observers.

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As a general remark, applying to every class of observation above mentioned, I may 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 prickings of the galvanic magnets in registration of transits by the Chronographic method are preserved. The proof sheets are read with the first skeleton form in which the observations are entered; and in which, in fact, the examination for accidental errors, &c., is made.

G. B. AIRY.

*Royal Observatory, Greenwich,  
1860, February 10.*

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