GREENWICH

ASTRONOMICAL OBSERVATIONS,

1862.

INTRODUCTION.

I. *Personal Establishment and Arrangements.*

During the year 1862, the establishment of Assistants in the Astronomical department of the Observatory has consisted of the following persons:—Edward James Stone, Esq., M.A., Fellow of Queens' College, Cambridge, First Assistant; Mr. Edwin Dunkin, Mr. William Ellis, Mr. George Stickland Criswick, Mr. William Thynne Lynn, B.A. Univ. London, and Mr. James Carpenter.

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

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

Mr. Dunkin has the superintendance of the Altazimuth, which is specially devoted to extrameridional observations of the Moon. The observations necessary for the determination of the errors of division, of the form of the pivots, and of the flexure of the telescope of the Transit-Circle were also made by him. The observations with both these instruments have been generally made by Mr. Dunkin, Mr. Ellis, Mr. Criswick, and Mr. Carpenter; occasionally observations have been made by Mr. Lynn. The initials of these observers are D., E., C., J.C. and L. Other persons who have occasionally observed with these instruments are:—Mr. William Carpenter Nash, Mr. Mondeford Reginald Dolman, Mr. Ernest Augustus John Kerschner, Mr. Edward Roberts, and Mr. Thomas Henry Chappell. These gentlemen are employed as computers in the Observatory; their signatures are N., M.D., K., R., and T.C.

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

With regard to the reduction of the observations.—The First Assistant is always charged with the duty of making the examination of observations, as entered in the Books of First Calculations, in order to ascertain that no error has crept into the records of individual wire-transits or individual microscope-readings. Mr. Criswick usually translates the chronograph-barrel-readings into figures, and occasionally is employed on the examination of Zenith Distances. Mr. Dunkin superintends the reduction of the Altazimuth-observations, and also the reading of the proof-sheets of these observations and reductions when printed. But the great mass of calculations and of reading proof-sheets, resulting from the Meridional observations, is effected by supernumerary computers under the direction of the Superintendant of Calculations. This office is held by Mr. Lynn.

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

Mr. James Glaisher, F.R.S., Second Assistant, in addition to his duties as Superintendant of Magnetical and Meteorological Observations (the records of which for 1862 are published in a separate volume), has also the general charge of the Observatory Library. Mr. Ellis and Mr. Carpenter keep the Manuscripts in order. Mr. Ellis also arranges the Money Accounts of the Observatory.

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 by the instruction 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^h mean time (3 o'clock in the morning) to the next 15^h; although it is sometimes found necessary (especially during the latter part of the Lunation, when the Moon passes the meridian in early morning), to appoint separate observers for the morning and the evening. It is established as a rule, to be adhered to as closely as circumstances permit, that no Assistant be occupied on two successive days with astronomical observations. And it is always arranged, if possible, when the Moon's time of transit passes 15^h, that the same Assistant should not be required to observe the Moon and accompanying stars late in the night when the Moon passes last before 15^h, and early in the morning when the Moon passes first after 15^h.

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 α Aquilæ and α Cygni, formerly attached respectively to the West side of the pier of Troughton's Mural Circle, and to the Quadrant pier, are now, with proper labels, suspended on brackets on the Western wall of the Transit-Circle Room.

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

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

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

The Instruments now in use are the following:—

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

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

A detailed description of the instrument, illustrated by Plates, is given in Appendix I. of the volume for 1852. The following particulars may be given here. The center of the instrument is about 5½ 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 several series of most careful observations, of which the last was on 1860, October 18, 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. The field of view is illuminated by the light from a central gas-light (to be mentioned hereafter) which enters the axis, and is reflected by an internal annular reflector; by inclining the reflector, the illumination is diminished and finally destroyed; and by inclining it still more, the light is thrown in such a manner as to illuminate the wires, leaving the field dark.

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. A gas-light is carried by each pier, and by means of an adjustible mirror, the light is thrown into the eye-end of the telescope. In order to prevent any disturbance of the supports of the telescopes by the radiation from the gas flames, the supports were effectually shielded by boards and double tin-plates. Still there was reason to think that a small disturbance really occurred; and at length, by a course of experiments in 1860, November, the cause of this was discovered to be the radiation upon a small part of each of the stone slabs bearing the telescope-supports. Those parts were then protected by double tin-plates, attached on November 12; and the disturbance appears to have ceased entirely. 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 $2\frac{3}{4}°$, two other parallel wires at right angles to the former, and therefore inclined to the horizontal line at the same angle (the intersection of this pair with the former producing a square), and a fifth wire parallel to the two last mentioned, and at a distance from the nearest of about ten times the side of the square. The middle, of that portion of the 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 by the other, it is necessary to raise the transit-circle so far that there shall be no impediment to a direct view. A mechanical apparatus is provided for the express purpose of sufficiently raising the transit-circle.

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

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 $5\frac{1}{2}°$ to those of the other. By means of the micrometer screw of the South Collimator, the middle of one nearly vertical side (the fine-wire side) of the square of the South Collimator is made to coincide with the image of that of the North Collimator, 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, in the positions in which the wires are now left, the axes of the two telescopes are in the same line, or at least are strictly parallel to each other: and, therefore, when the transit-telescope is employed to view the 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.—This adjustment is made on the Monday of each week.

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 image 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-wire 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 Section of printed Transit Observations.

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

The graduated vertical circle for zenith-distance-observations is fixed on the cylindrical basis of the axis-cone on the west side of the central cube. It is 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 inner 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 seven illuminating holes corresponding to the seven microscopes; and this light is reflected from the divided limb accurately into the microscopes without any need of illuminating-reflectors; the inclination of the divided limb being that which causes the light, on the usual law of specular reflexion, to enter the microscopes parallel to their axes. A lining of double tin plates (fixed on 1860, November 26) is inserted in the central opening of the pier, which effectually screens, from the radiation of the gas flame, the stone pier, the micrometers and their eyepieces, and the brass plate which carries them.

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

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

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

Other explanations necessary for the understanding of the process of reduction of the observations will be given under the proper heads. In this place it may be 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 the reading of $20^{rev.}$, the clamping circle is fastened. The transit of the star is then observed over the vertical wires in the usual way, either by galvanic touch or by eye and ear; and, during the transit, by means of the micrometer-screw which acts on the horizontal wire, that wire is made to bisect the star near the passage of the central vertical wire, if practicable. The telescope-micrometer, and the pointer and the six microscope-micrometers, are afterwards read, and the observation is complete. If the star be too faint to allow of illumination of the field, the wires are illuminated, and the observation is made in a field perfectly dark.

For observations of stars by reflexion, the telescope is placed, some minutes previously to the transit of the star, in the direction which is proper for viewing the reflected image of the star; and the mercury-trough is carefully placed in the requisite position; and the microscope-micrometers are read after the instrument is clamped. The observer then ascends to the eyepiece of the telescope, and, by means of the micrometer-screw which carries the horizontal wire, bisects the reflected image of the star near the passage of the first vertical wire (if the star has large polar-distance), or near the second or third wire (if the star is circumpolar), and reads the telescope-micrometer. He then descends rapidly into the pit, unclamps the instrument, turns the telescope to the position proper for direct view of the star, and fastens the clamping circle; bisects the star near its passage over one 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 two 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, when near the reading $20^{rev.}$; then the instrument is clamped, and the horizontal wire is moved, by means of the micrometer-screw which carries it, to touch the limb while passing one 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 had commenced to read the micrometers as soon as the instrument was clamped. The instrument is then unclamped, the telescope is directed to the other limb (lower or upper), the instrument is clamped, the telescope-micrometer is turned to place its wire upon the limb, 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.

For the Moon before opposition, (that is, when the transit of the first limb is observed,) after the transit is completed, the telescope is moved till the limb (upper or lower), which is to be observed in Zenith Distance, is brought near to the middle of the field; the instrument is clamped; and the horizontal telescope-micrometer-wire is brought repeatedly upon the limb (upper or lower) at its passage over the seven original vertical wires at wide intervals, the telescope-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; the instrument is set with care, and is clamped; 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 limbs are very nearly full at the opposition of the Moon, another person is employed to read the microscope-micrometers as in the case of the Sun; and the mode of observation will be readily understood from the preceding explanations, applying to the observation of the Sun. In this case, however, the aid of one person is sufficient.

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

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

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

One of the prickers is devoted to the register of seconds of the 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 by the following mechanism. 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 upon the revolving barrel. In the month of November 1856, one of the teeth in the wheel before mentioned was 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, and to the Great Equatoreal; on each of which 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 34½ feet South of the old Transit-Instrument, and about 47 feet West and 29 feet South of the new Transit-Circle. Within the Tower is built a three-rayed pier; the rays being carried up nearly to the floor of the Dome, and a central cylindrical mass, 3 feet in diameter, being carried through the floor. Upon this cylindrical mass is planted the Azimuthal Circle, on which the lower pivot for azimuthal rotation rests. For the support of the upper pivot, a horizontal iron triangle is carried by the three-rayed pier; on each side of this there is mounted a vertical iron triangle; and the three vertices of these are connected by an upper horizontal iron triangle: three radial iron bars, supported on its angles, carry, at their point of union, the Y in which the upper pivot of the vertical axis turns. The frame revolving in azimuth consists of a top and bottom connected by two vertical cheeks, all of cast iron: the microscopes for viewing the divisions of the horizontal circle are cast in the same flow of metal with the bottom piece, and those for viewing the divisions of the vertical circle are cast in the same flow with one of the vertical cheeks. The vertical circle and telescope are of gun-metal; the side of the circle which carries the graduated limb, the ends of the telescope, and one of the pivots, being cast in one flow; and the other side of the circle with its pivot being cast in another flow. The diameter of each of the two circles (horizontal and vertical) is 3 feet; the length of the telescope is 5 feet; the aperture of its object-glass 3¾ inches. The top carries two spirit-levels, and the bottom carries two spirit-levels, parallel to the axis of the vertical circle: the vertical cheek which carries the microscopes carries also two spirit-levels parallel to the plane of the vertical circle. No important parts are connected by small screws; and no part whatever admits of adjustment; except that the coarse screws on the ends of the upper radial bars are sometimes touched, to bring the vertical axis to a position conveniently near to exact verticality.

The instrument can be firmly clamped in azimuth; and the vertical circle can be firmly clamped; but neither clamp is furnished with a slow motion. For each movement, however, there is a moderately-slow motion, by rack and pinion.

For a detailed account of this Instrument, illustrated by engravings, and for a description of the processes gone through in its adjustment, I refer to the Volume of Astronomical Observations for 1847.

As a fixed mark of reference, and as an object for facilitating the determination of the zenith-point of the vertical circle and the collimation-error for horizontal transits, a collimator is used. 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 24½-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 Chronometer-Room above the Computing-Room, below the ridge of the roof of the Passage-Room (part of the ancient Quadrant-Room). The mounting of the mark is thus entirely protected from the Sun and from the weather: and although the separation of the mark and the collimator-object-glass on two unconnected buildings is not unobjectionable, yet the other circumstances of mounting are here as favourable as it is possible to find. The perforation is illuminated by a small gas-light: and its image as viewed through the telescope of the Altazimuth then appears as a very well-defined round point, admitting of most accurate bisection by a wire either in the horizontal or in the vertical direction, surrounded at a little distance by a fainter ring of light. For viewing this mark, the telescope of the Altazimuth is pointed downwards at an inclination of 12°. 18′ below the horizon.

By means of the branches of the galvanic wires leading from the galvanic magnet of one pricker of the Chronographic Barrel to contact-pieces upon 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. On 1861, February 7, a new system of six horizontal wires for observation by galvanic contact was inserted, the middle interval of wires being much larger than either of the other four intervals.

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

The 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°, and through a considerable horizontal extent to the altitude of 53°, is concealed by the Octagon Room. The position of the instrument is about 52 feet West and 90 feet North of the old Transit-Instrument, or 71 feet West and $97\frac{1}{2}$ feet North of the new Transit-Circle. This Equatoreal is one of that class in which the two pivots of the polar axis are at the two extremities of the polar axis, and the two pivots of the declination-axis are at the two extremities of the declination-axis: the telescope and declination-circle being between the pivots of the declination-axis, and the declination-axis being within the frame of the polar axis, and the complete polar axis and hour-circle being between the polar supports. The whole length of the polar axis, between the extremities of the pivots, is about 9 feet. These pivots turn in Y's (having proper adjustments), which are carried by two piers within the Dome, one being a lofty pier on the North side, the other, a pier of small elevation on the South side. The North pivot is at the center of a circular frame; the South pivot is at the apex of a cone; and the polar frame consists of six pillars, connecting the base of this cone with the circular frame. Three pillars are united by intervening bars to form the Eastern side of the polar frame, and three to form the Western side: they carry the Y's for the declination-axis and the microscopes for reading the declination-circle. The length of the declination-axis between the extremities of its pivots is about 2 feet 2 inches; the diameter of the declination-circle is 4 feet, and the circle is divided to 5′ of arc. The telescope is 5 feet 4 inches in length, and has an object-glass of 4·1 inches aperture. The hour-circle is connected with the cone; its diameter is 4 feet, and it is divided to 10′ of arc: these divisions are read by fixed micrometer-microscopes. The graduations of the hour-circle had become very indistinct, and the circle was therefore redivided by Mr. James Simms in the month of November, 1860.

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

This instrument was erected in the year 1838. The aperture of the object-glass is about 6·7 inches, and its focal length about 8 feet 2 inches. The object-glass was made by M. Cauchoix, of Paris, and was presented to the Observatory by the late Rev. R. Sheepshanks. Its definition is good: a small quantity of colour from the secondary spectrum, and a diffusion of light from brilliant objects, being the principal defects.

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

The Great Equatoreal, constructed by Messrs. Ransomes and Sims as Engineers, and Mr. Simms as Instrument Maker and Optician. It is my intention, as soon as circumstances shall permit, to prepare a complete description of this instrument. In the meantime, the following account will give information on its principal peculiarities. It is to be premised that the form of the instrument is the "English Equatoreal;" the polar axis turning on pivots at its extreme ends, and including between its two sides the telescope and declination-circle attached to it; the frame which carries the telescope and declination-circle having its pivots at opposite extremities of the declination axis.

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

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

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

The Polar Axis consists of two braced skeleton-prisms, each about 22 feet long, 2 feet apart, united at the bottom and at the top by ovals about 8 feet long (in the direction parallel to the declination-axis), and 5 feet broad (in the transverse direction). The pivot of the lower oval, projecting downwards, is long enough to carry the Hour-Circle, which is a cast-iron circle 6 feet in diameter, revolving freely on the long pivot, but admitting of being connected with the lower oval by clamp and slow-motion-screw. The circumference of this circle is racked, and the worm or endless screw, to which motion is given by the Clock Movement, acts in it. The circle bears two graduations:

one which is viewed by a fixed microscope (attached to the iron foundation-frame), whose reading, when the circle has been properly placed and the Clock Movement is properly adjusted, always gives True Sidereal Time; another, which is viewed by two microscopes carried by the lower oval, and whose reading (when the Clock-Movement, &c., are adjusted) always gives the Right Ascension of the Object under view. There are also independent means of fixing the lower oval, when the use of the Clock-Movement is not desired. The upper oval is cut through on one side as far as its pivot, to allow the telescope to view the pole. Its pivot is perforated to allow the passage of a gas pipe, by which lights on various parts of the instrument are supplied; and it carries insulated galvanic rings, touched by springs which are attached to the lofty iron frame, and which are attached to wires that communicate with the galvanic magnets of one pricker upon the Chronographic Barrel.

The declination-axis is supported on brackets, which are carried nearly at the middle of the prisms' length, in such a position that the telescope, when parallel to the earth's axis, is so far removed from the imaginary axis joining the two pivots of the Polar Axis, that it can view the pole through the cutting of the upper oval already mentioned. The telescope in its declination-axis nearly represents a transit-instrument. It carries on one side a graduated circle 5 feet in diameter, which is viewed by two microscopes attached to one of the prisms of the polar axis. On the other side it carries a clamp and slow-motion screw, which connects it with a circle affixed to the other prism. One pivot is perforated for a gas pipe: it also carries rings for galvanic contact; wires are led from these rings through the telescope-tube to a touching-piece at the eye-end, and a contact made there produces a puncture upon the Chronographic Barrel. The telescope-tube is of mahogany; it is square in the middle of its length, and octagonal at the ends. The focal length of the object-glass, made by Messrs. Merz and Son of Munich, is about 16 ft. 6 in. Messrs. Merz originally contemplated the supply of an object-glass of greater focal length, in consequence of which the whole frame of the instrument is made in larger dimensions than are necessary for the object-glass actually supplied. The clear aperture of the object-glass is about 12½ inches. Its definition, as shown by examination of close double stars, is very fine; the components of the small star of γ Andromedæ being widely separated; and there is very little stray colour.

The Clock-Movement is fixed in the ground-floor story, upon a frame which is attached to the south pier. The power is given by the flow of water, received from the water pipes which supply the Observatory under a pressure of 100 feet, acting through a turbine, which is made to revolve four times in one sidereal second. The spindle of this turbine rises through the lower and middle rooms, and acts by an endless screw in a wheel of 480 teeth, which revolves in two minutes, and whose axis carries an endless screw which acts in the rack of the hour-circle. Very great care was taken in the preparation and examination of this large endless screw. The supply of water to the turbine is determined by the construction called "Siemens' Chronometric Governor," in which the first of three wheels of a train is connected with the turbine, the third maintains the motion of a conical pendulum (so arranged by water-resistance that its arc is sensibly invariable), and the axis-frame of the second or intermediate wheel is moveable, and is connected with the throttle-valve of the water-supply. If the supply accelerates the turbine too much, its excess of motion is immediately impressed on the frame of the second wheel, and the supply of water is diminished.

This description of the Equatoreal will probably suffice in reference to the observations contained in the present volume.

The Double-Image Micrometer.—The general form of the double-image eyepiece, together with the mode of use, and the advantages and disadvantages attending the use of it, are described fully in the preceding volumes, for 1840 and for 1843 to 1849, to which it is sufficient in this place to refer.

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

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

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

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

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

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

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

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

For the support of the quicksilver, the following method has, after several trials, been adopted:—A well was dug to the depth of ten feet below the surface, or seven feet below the deepest foundation of the walls of the Observatory, and was filled with incoherent rubbish. When a stage was placed upon it, the tremor (which had been intolerable while the quicksilver-trough rested on the solid ground) was sensibly diminished. Afterwards from this stage, No. 1, there was suspended by straps of vulcanized caoutchouc, a stage, No. 2, and from this, in like manner, a stage, No. 3, on which the quicksilver was placed. The habitual tremor was now destroyed, but the image slowly floated or oscillated. Finally, this last defect was corrected by connecting the trough horizontally in two directions by shreds of vulcanized caoutchouc with stage No. 1, and by this means the floating was nearly destroyed, leaving the image practically almost perfect. The experiments were concluded in May 1856, and from that time the use of the instrument has been continuous, and no difficulty has been experienced in making observations of γ 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 $\frac{d^2 x}{d t^2} = m^2 (y - x)$, where m is small; and if $y = a$. cosine $n t$, where n is large; the corresponding term in x will be $\frac{-m^2}{n^2 - m^2} \times$ a . 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 onc of exceedingly short period; and therefore the disturbances, horizontal and vertical, given to the suspended stages, are exceedingly small. The duplication of the apparatus again diminishes the disturbance the second time in nearly the same proportion as at the first time.

Two detached telescopes, one of which is 46 inches in focal length, and the other 30 inches; the former is usually kept in the Octagon Room, and the other in the Magnetic Observatory. The diameters of the object-glasses of these telescopes are 3·6 inches and 2·7 inches respectively. The telescope formerly belonging to the Western Equatoreal has also been mounted for use as a detached telescope; its focal length is 36 inches, and the aperture of its object-glass 3·6 inches. 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. Mention has already been made (p. x) of the apparatus now connected with the escape-wheel-arbor for the purpose of completing a galvanic circuit at every second of the Transit-Clock, by which a puncture is impressed at every second on the Chronograph-Barrel. 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 "Arnold 2," at present placed in the Middle Room of the South East Dome; one marked "Graham 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^h, but now occasionally 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 Transit Clock, and the other ordinary clocks in daily use, are wound up every Monday.

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. It is a clock of Messrs. Shepherd's construction, in which the swing of the pendulum completes certain galvanic circuits: by one of these, the movement of the pendulum is maintained, independently of any train of wheels; by others, a frame of magnets is made to oscillate and thus to give motion to the seconds-wheel, and, through it, to the other wheels. The wire which carries the current that produces that oscillation is led through corresponding parts of six similar clocks, whose movements are therefore necessarily synchronous with those of the motor clock. 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 (of the dimensions of a Chronometer) is upon the desk of the Superintendent of Clocks and Galvanism; one is in the hall of the Astronomer Royal's dwelling house; and one is at the Royal Hospital Schools. Another clock at the South-Eastern Railway Station, London Bridge, is regulated by the Motor Clock, according to the method of Mr. R. L. Jones (slightly modified), and is used 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 each hour, causing hourly time-signals to be distributed on different wires to the principal telegraph companies and on some of the most important lines of railway. That at 1^h, by the intervention of electro-magnets pulls automatically the trigger of the ball-apparatus and drops the Signal-Ball; at the same instant galvanic currents pass, one to the Signal-Ball at Deal, and one to that in the Strand, London (the property of the Electric and International Telegraph Company); both balls being discharged automatically by their galvanic currents. The current received at noon by the Electric and International Telegraph Company passes to the General Post Office, London, and regulates daily several of the clocks in that building. Currents are sent to the Clock Tower of the Westminster Palace, for the guidance of the Superintendent of the Clock in bringing it to accurate time. The motor clock also so changes the connections of wires that they are competent to transmit currents to the Royal Observatory, and thus the drop of the ball at Deal, and the indications of the Post Office clocks and the Westminster clock, are made visible at the Royal Observatory.

A sympathetic system of chronometers is also connected with the transit-clock. By means of the wheel on the escape-wheel-arbor (described in page x), 59 currents are sent through another pair of springs every minute, and act upon galvanic chronometers whose dial-plate has a seconds' circle of 59 equal parts, one special division corresponding to two consecutive seconds. One of these chronometers is upon the desk of the Superintendent of Clocks and Galvanism; and the comparison of this Chronometer with the Chronometer upon the same desk which is synchronous with the Motor Clock (as mentioned in the last paragraph) is, in fact, a comparison of the Transit Clock with the Motor Clock. The error of the Motor Clock is thus ascertained; and then, by means of a turn-plate on the same desk, the Superintendent completes the circuit of a galvanic current which accelerates or retards the Motor Clock as long as may be necessary for its correction. The six clocks connected with the Motor Clock necessarily receive the same correction. Another such chronometer is carried on the end of the great tube of the telescope of the Great Equatoreal, close to the eye piece, and always in view of the observer. The same current, which drives these, regulates, in the manner introduced by Mr. R. L. Jones, the pendulum of a half-seconds clock placed on the foundation-frame upon the south pier of the Great Equatoreal, near to the Time-Microscope, and causes it always to exhibit the same time as the Transit Clock.

III. *Subjects of Observation in the Year* 1862.

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^h, excepting at times when the Moon passes the meridian later than 15^h. The small Planets have been observed only when the time of meridian passage is earlier than 14^h. The observations of all Planets are intermitted on Sundays.

In the meridional observations of the stars, it has been considered as the first object to establish with indisputable accuracy the places of those included in the Nautical Almanac list (as far as they are visible in this latitude). For this purpose the number of observations of each star made in the two preceding years was ascertained, and the additional number necessary to make up this to fifteen was in 1862 considered to be the number due from that year. In far the greater number of instances this number is exceeded: in a few (especially of stars too near the pole to be used for clock-error), the just number is not completed.

The other stars observed are principally: A list of 83 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 to the end of the list in the

Nautical Almanac 1865; Stars whose occultations by the Moon have been observed at Greenwich; Stars observed with Comets; variable Stars from Mr. Pogson's list; Stars which pass near the North and South Horizon; Stars suspected or known to have large Proper Motions; Stars to be used in future, for the determination of Azimuthal Errors; Stars compared with Sirius; Stars observed with Mars at the opposition of 1862; and Stars of which observations have been requested by Astronomers for special purposes.

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

The Reflex Zenith-Tube has been used throughout the year 1862 for observations of γ Draconis. The observations are made at every opportunity (Sundays excepted) unless when γ Draconis passes the meridian between three and four in the morning. In these cases the observation is only made when the Moon also passes in the early morning.

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

The South-East, or Great, Equatoreal, has been used for observations of differences in R.A. of Mars and neighbouring Stars near the time of his opposition; for observing occasionally Occultations of Stars by the Moon, and the phenomena of Jupiter's Satellites, and for several careful drawings (by Mr. Carpenter) of Saturn, during the disappearance of the rings.

IV. *Explanation of the Printed Transit Observations.*

§ 1. *Transits observed with the Transit-Circle, and Computations of Apparent Right Ascension*, page [2] to [69].

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

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

The *third* column contains the name of the object observed. With respect to the Sun, Moon, and Planets, the limb whose transit is observed is always mentioned. If no limb is mentioned it is to be understood that the estimated center was observed. The center is observed only when the planet's disc is so small and so round as to make it easier to estimate the center than to determine with accuracy the place of the limb. With regard to the stars, 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 N°, with the name of the constellation.
3. The N° in the Catalogue of the British Association.

4. Piazzi's hour and N°.
5. The N° in Groombridge's Catalogue.
6. The N° in Bessel's Bradley.
7. The N° in Baily's edition of Flamsteed's Catalogue.
8. The N° in Santini's Catalogue of 1677 Stars, published in the Memoirs of the Royal Astronomical Society, vol. xii.
9. The hour and N° in Weisse's Catalogue of the Stars in Bessel's Zones.
10. The N° in the Catalogues of Lalande and Lacaille, published by the British Association.
11. The N° in Rümker's Catalogue of 12,000 Stars.
12. The N° in Oeltzen's Catalogues of Argelander's Zone Observations, between 45° and 80° North Declination, and between 15° and 31° South Declination.
13. The N° in the Radcliffe Catalogue of Stars.
14. The N° in Carrington's Red Hill Catalogue of 3735 Circumpolar Stars.
15. 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 it.

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 are, however, observed by eye-and-ear over the wires intended for the galvanic transits. The wires used for galvanic transits are denoted by the letters P, Q, R, S, T, U, V, W, X; P, T, and X, being wires of the original system, and Q, R, S, U, V, W, being new wires inserted between P, T, and X. The intervals P–Q, Q–R, R–S, U–V, V–W, W–X, are nearly equal; the intervals, S–T, T–U, are nearly double of the former, for convenience of easily distinguishing the central wire.

In observing by galvanic contact, the observer merely makes contact of the galvanic spring at the instant of the object passing the wire. Occasionally, when no object is under observation, he makes contacts in any arbitrary number, recording in his book their number and the time by the transit clock; and thus the numeration of hours and minutes on the punctured sheets is easily established. The punctured sheets are examined the next day, the numeration of minutes and seconds is written upon them, and the transits are read into the transit-book.

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

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 had been reduced separately to the center wire. When transits have been observed over all the wires, the same process of correction is used, but the amount of correction for the mean is very small.

For the determination of the intervals of the original wires, the South Collimator was employed in the following manner:—The eyepiece of the Transit-Circle was turned round through an angle of 90°, 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 results are contained in the following Tables:—

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

		s
For wire N	+	41·472
O	+	27·602
P	+	13·794
T		0·000
X	−	13·852
Y	−	27·643
Z	−	41·416

The Equatoreal intervals of the nine wires used for the Chronographic Observations were, at the end of 1861, determined from a discussion of the transits of Polaris and Polaris S.P., observed during the year 1861. From the nature of the process, these intervals are necessarily corrected for the effects of refraction. The results are contained in the following Tables :—

For wire P	+	13·834
Q	+	11·029
R	+	8·261
S	+	5·505
T		0·000
U	—	5·558
V	—	8·301
W	—	11·057
X	—	13·818

These intervals have been used during the year 1862.

Hence, for the usual circumpolar stars, the intervals in time from any wire to the center wire, which are the same as the star's hour-angle from the meridian, were calculated by means of the formula,

$$\text{Sine of star's hour-angle} = \frac{\text{sin distance in arc}}{\text{sin Star's N.P.D.}}$$

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

and the results are as follows :

For λ Ursæ Minoris, assuming its declination = 88°. 53′ + n'':

		m s	s
Wire P	+	11. 50·18	+ n × 0·179
Q	+	9. 26·09	+ n × 0·143
R	+	7. 3·96	+ n × 0·108
S	+	4. 42·50	+ n × 0·071
T		0·00	
U	—	4. 45·22	— n × 0·071
V	—	7. 6·02	— n × 0·108
W	—	9. 27·53	— n × 0·143
X	—	11. 49·36	— n × 0·179

For Polaris, assuming its declination = 88°. 34′ + n'':

		m s	s
Wire P	+	9. 13·21	+ n × 0·109
Q	+	7. 20·99	+ n × 0·087
R	+	5. 30·29	+ n × 0·065
S	+	3. 40·09	+ n × 0·044
T		0·00	
U	—	3. 42·21	— n × 0·044
V	—	5. 31·89	— n × 0·065
W	—	7. 22·11	— n × 0·087
X	—	9. 12·56	— n × 0·109

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

		m s	s
Wire P	+	4. 46·62	+ n × 0·029
Q	+	3. 48·50	+ n × 0·023
R	+	2. 51·15	+ n × 0·017
S	+	1. 54·05	+ n × 0·012
T		0·00	
U	—	1. 55·15	— n × 0·012
V	—	2. 51·98	— n × 0·017
W	—	3. 49·08	— n × 0·023
X	—	4. 46·29	— n × 0·029

For δ Ursæ Minoris, assuming its declination = 86°. 35′ + n'':

Wire P	+	3^m. 52^s·14 + n × 0^s·019
Q	+	3. 5·07 + n × 0·015
R	+	2. 18·62 + n × 0·011
S	+	1. 32·37 + n × 0·008
T		0·00
U	−	1. 33·26 − n × 0·008
V	−	2. 19·29 − n × 0·011
W	−	3. 5·54 − n × 0·015
X	−	3. 51·87 − n × 0·019

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

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

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

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

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

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

the multiplication 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 to the computed interval between the mean of wires and the center wire the amount of the planet's increase of Right Ascension for that interval, which is very readily determined from the numbers given in the Nautical Almanac.

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

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

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

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

I = Var. in R. A. for 1^h of Longitude.	$\frac{3600 + I}{3600}$ Nat. Number.	$\frac{3600 + I}{3600}$ Log.	I = Var. in R. A. for 1^h of Longitude.	$\frac{3600 + I}{3600}$ Nat. Number.	$\frac{3600 + I}{3600}$ Log.
s			s		
100	1·02778	0·01190	145	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

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

Error of Collimation.

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

The method of determining the position of the line of collimation by means of the north and south 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 [72]), 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 [73] to [75]); 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 geometrical error of collimation, with the sign as explained above. This excess is converted into arc at the rate of $14''\cdot78$ for one revolution of the micrometer. (This determination of the value of a revolution was made at the end of the year 1850, as is explained in the description of the Transit Circle, page {22}, Appendix I., of the Volume for 1852: a new investigation for verification of the value was made on 1854, June 27, the resulting value of a revolution being $14''\cdot76$, which is essentially identical with the preceding.) To the excess thus converted into arc is then applied $-0''\cdot19$ for diurnal aberration; and the result is the quantity which is given in the fifteenth column of the *Transits* as the Error of Collimation, and which is adopted for correction of the observed transits.

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

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

Error of Level.

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

The process of determining the error of level, by taking the reading of the transit-telescope-micrometer which makes the image of the wire as seen by reflexion from the surface of quicksilver to coincide with the wire as seen directly, 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 [76] to [78].

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

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

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

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, in 1858 (see *Greenwich Observations*, 1858, Introduction, page xxiv), at the end of long night watches, as well as at the commencement, so as to obtain a great change of temperature; and it appeared that every notable rise of temperature was accompanied with a diminution of Error of Level. There appears to be nothing whatever in the metallic structure of the instrument, or its mounting, which can explain this thermal change. The qualities of the stones, of which the two piers are built, are different; but I can scarcely imagine that such masses can so quickly receive the influence of change of temperature. In the observations of a single evening, something might be attributed to the radiation from the illuminating lamp; but this cannot explain the changes whose periods are long.

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 δ 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 δ Ursæ Minoris combined with those of other stars. The stars Cephei 51 (Hev.) and λ 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^h; and the difference, in seconds of time, between the altered first transit and the second transit (rejecting 12^h) is divided by 3·336 to obtain the azimuthal error in seconds of space.

If three transits have been observed, the difference between the first and second is taken (rejecting 12^h), and the difference between the second and third in like manner: and the mean between these is supposed to be independent of the change of R.A. and the clock's rate, and is then divided by 3·336.

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

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

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

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

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

The numerical values of the three corrections for the errors of collimation, level, and azimuth, have been obtained throughout the year 1862 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. $\frac{1}{15 \text{ Sin N.P.D.}}$	Level. $\frac{\text{Cos Z. D.}}{15 \text{ Sin N.P.D.}}$	Azimuth. $\frac{\text{Sin Z. D.}}{15 \text{ Sin N.P.D.}}$
° ′			
−45. 0	−0·094	−0·011	+0·094
−44. 0	−0·096	−0·013	+0·095
−43. 0	−0·098	−0·014	+0·096
−42. 0	−0·100	−0·016	+0·098
−41. 0	−0·102	−0·018	+0·100
−40. 0	−0·104	−0·021	+0·102
−39. 0	−0·106	−0·023	+0·104
−38. 0	−0·108	−0·025	+0·105
−37. 0	−0·111	−0·027	+0·107
−36. 0	−0·113	−0·030	+0·109
−35. 0	−0·116	−0·033	+0·111
−34. 0	−0·119	−0·036	+0·114
−33. 0	−0·122	−0·039	+0·116
−32. 0	−0·126	−0·042	+0·119
−31. 0	−0·129	−0·045	+0·121
−30. 0	−0·133	−0·049	+0·124
−29. 0	−0·138	−0·053	+0·127
−28. 0	−0·142	−0·057	+0·130
−27. 0	−0·147	−0·061	+0·133
−26. 0	−0·152	−0·065	+0·137
−25. 0	−0·158	−0·070	+0·141
−24. 0	−0·164	−0·076	+0·145
−23. 0	−0·171	−0·082	+0·150
−22. 0	−0·178	−0·088	+0·155
−21. 0	−0·186	−0·094	+0·160
−20. 0	−0·195	−0·102	+0·166
−19. 30	−0·200	−0·106	+0·170
−19. 0	−0·205	−0·110	+0·173
−18. 30	−0·210	−0·114	+0·176
−18. 0	−0·216	−0·119	+0·180
−17. 30	−0·222	−0·124	+0·184
−17. 0	−0·228	−0·129	+0·188
−16. 30	−0·235	−0·134	+0·192
−16. 0	−0·242	−0·140	+0·197
−15. 30	−0·249	−0·146	+0·202
−15. 0	−0·257	−0·153	+0·207
−14. 30	−0·266	−0·160	+0·213
−14. 0	−0·276	−0·168	+0·219
−13. 30	−0·286	−0·176	+0·225
−13. 0	−0·296	−0·184	+0·232
−12. 30	−0·308	−0·194	+0·240
−12. 0	−0·321	−0·204	+0·248
−11. 30	−0·334	−0·214	+0·256
−11. 0	−0·349	−0·227	+0·266
−10. 30	−0·366	−0·240	+0·276
−10. 0	−0·384	−0·254	+0·288
− 9. 30	−0·404	−0·270	+0·300
− 9. 0	−0·426	−0·288	+0·314
− 8. 30	−0·451	−0·308	+0·330
− 8. 0	−0·479	−0·330	+0·348
− 7. 30	−0·511	−0·355	+0·368

N.P.D.	Collimation. $\frac{1}{15 \text{ Sin N.P.D.}}$	Level. $\frac{\text{Cos Z. D.}}{15 \text{ Sin N.P.D.}}$	Azimuth. $\frac{\text{Sin Z. D.}}{15 \text{ Sin N.P.D.}}$
° ′			
− 7. 30	−0·511	−0·355	+0·368
− 7. 0	−0·547	−0·383	+0·390
− 6. 30	−0·589	−0·416	+0·417
− 6. 0	−0·638	−0·455	+0·447
6. 0	+0·638	+0·538	−0·343
6. 30	+0·589	+0·499	−0·312
7. 0	+0·547	+0·466	−0·286
7. 30	+0·511	+0·438	−0·263
8. 0	+0·479	+0·413	−0·243
8. 30	+0·451	+0·391	−0·226
9. 0	+0·426	+0·371	−0·210
9. 30	+0·404	+0·353	−0·196
10. 0	+0·384	+0·337	−0·183
10. 30	+0·366	+0·323	−0·172
11. 0	+0·349	+0·310	−0·161
11. 30	+0·334	+0·298	−0·152
12. 0	+0·321	+0·287	−0·143
12. 30	+0·308	+0·277	−0·135
13. 0	+0·296	+0·267	−0·128
13. 30	+0·286	+0·259	−0·122
14. 0	+0·276	+0·251	−0·116
14. 30	+0·266	+0·244	−0·111
15. 0	+0·257	+0·236	−0·105
15. 30	+0·249	+0·230	−0·099
16. 0	+0·242	+0·224	−0·093
16. 30	+0·235	+0·218	−0·088
17. 0	+0·228	+0·212	−0·084
17. 30	+0·222	+0·207	−0·080
18. 0	+0·216	+0·202	−0·076
18. 30	+0·210	+0·197	−0·072
19. 0	+0·205	+0·193	−0·068
19. 30	+0·200	+0·189	−0·065
20. 0	+0·195	+0·185	−0·062
21. 0	+0·186	+0·177	−0·056
22. 0	+0·178	+0·171	−0·051
23. 0	+0·171	+0·164	−0·046
24. 0	+0·164	+0·159	−0·041
25. 0	+0·158	+0·153	−0·037
26. 0	+0·152	+0·148	−0·033
27. 0	+0·147	+0·144	−0·029
28. 0	+0·142	+0·140	−0·026
29. 0	+0·138	+0·136	−0·023
30. 0	+0·133	+0·131	−0·020
31. 0	+0·129	+0·128	−0·017
32. 0	+0·126	+0·125	−0·014
33. 0	+0·122	+0·122	−0·012
34. 0	+0·119	+0·119	−0·009
35. 0	+0·116	+0·116	−0·007
36. 0	+0·113	+0·113	−0·005
37. 0	+0·111	+0·111	−0·003

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

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

The *seventeenth* column contains the seconds of the tabular R.A. of the stars which are used for determining clock-errors. In addition to the list of stars taken from the Nautical Almanac, whose North Polar Distances exceed 50°, there has been used in the year 1862, as in preceding years, another list of 83 stars, selected and observed for this purpose, and lying within the same limit of Polar Distance. The tabular R.A. of Polaris, Cephei 51 (Hev.), δ Ursæ Minoris, and λ 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 " Seven-Year Catalogue of 2022 Stars, deduced from Observations, extending " from 1854 to 1860, at the Royal Observatory, Greenwich, and reduced to the " epoch 1860," which is printed as an Appendix to the present volume. To bring up the Mean Right Ascensions from the epoch of the Catalogue, viz., 1860, to the year 1862, the annual variations given in the Nautical Almanac have been used. The Right Ascensions of the Stars used for clock-error which are not included in the Nautical-Almanac-list are brought up from the Greenwich Seven-Year Catalogue for 1860, using the precessions of that Catalogue, and proper motions given by Mr. Main or by the British Association Catalogue in order of preference. It is to be remarked that, to improve the places of the Seven-Year Catalogue, places brought up from the Greenwich Catalogue of 1576 stars for 1850, have been incorporated for the following stars, viz., ι Ceti, δ Ceti, τ^1 Arietis, o^1 Eridani, α Leporis, κ Orionis, β Canis Majoris, ν Geminorum, γ Canis Majoris, 51 Geminorum, ξ Leonis, ε Corvi, 35 Virginis, ε Virginis, *m* Virginis, λ Ophiuchi, ε Herculis, 89 Herculis, ψ Sagittarii, σ Aquarii, δ Sculptoris. The corrections necessary to bring up the stars' Right Ascensions to the day of observation are computed by the formula $E e + F f + G g + H h + L + l - 300^s$, 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 1862, January 1, of all the stars which have been used in 1862 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 other stars very near the pole, which have been observed for the determination of azimuthal error throughout the year 1862.

RIGHT ASCENSIONS OF CLOCK STARS AND STARS FOR THE DETERMINATION OF AZIMUTHAL ERROR.

Star's Name.	Assumed Mean R. A. 1862, Jan. 1.	Correction to N.A.	Star's Name.	Assumed Mean R.A. 1862, Jan. 1.	Correction to N.A.
	h m s	s		h m s	s
α Andromedæ	0. 1. 15·61	+ 0·06	β Ceti	0. 36. 39·62	+ 0·07
γ Pegasi	0. 6. 7·95	+ 0·05	μ Andromedæ	0. 49. 6·22	
ι Ceti	0. 12. 23·74		ε Piscium	0. 55. 47·01	− 0·02
12 Ceti	0. 22. 59·76	− 0·03	β Andromedæ	1. 2. 0·87	
ε Andromedæ	0. 31. 16·19		Polaris	1. 8. 40·77	+ 0·35

RIGHT ASCENSIONS OF CLOCK STARS AND STARS FOR THE DETERMINATION OF AZIMUTHAL ERROR—*continued.*

Star's Name.	Assumed Mean R.A. 1862, Jan. 1.	Correction to N.A.	Star's Name.	Assumed Mean R.A. 1862, Jan. 1.	Correction to N.A.
	h m s	s		h m s	s
θ Ceti	1. 17. 7·52	+ 0·02	d^1 Cancri	8. 15. 27·50	
η Piscium	1. 24. 6·17	+ 0·05	η Cancri	8. 24. 43·44	+ 0·03
ν Piscium	1. 34. 15·10	+ 0·01	γ Cancri	8. 35. 17·72	
β Arietis	1. 47. 1·31	+ 0·01	ε Hydræ	8. 39. 27·94	− 0·02
α Arietis	1. 59. 24·01	+ 0·02	α Cancri	8. 50. 56·20	
67 Ceti	2. 10. 6·07	+ 0·04	κ Cancri	9. 0. 16·20	
ξ^2 Ceti	2. 20. 49·49	0·00	83 Cancri	9. 11. 16·48	+ 0·09
δ Ceti	2. 32. 24·73		α Hydræ	9. 20. 48·34	+ 0·04
γ Ceti	2. 36. 9·15	+ 0·05	ξ Leonis	9. 24. 30·23	
σ Arietis	2. 43. 52·66		ο Leonis	9. 33. 46·95	
α Ceti	2. 55. 4·08	+ 0·06	ε Leonis	9. 38. 0·76	+ 0·04
δ Arietis	3. 3. 44·57	+ 0·01	μ Leonis	9. 44. 54·56	
τ^1 Arietis	3. 13. 15·89		π Leonis	9. 52. 55·10	0·00
ο Tauri	3. 17. 23·41		Regulus	10. 1. 1·19	+ 0·03
f Tauri	3. 23. 15·50		γ^1 Leonis	10. 12. 21·59	0·00
ε Eridani	3. 26. 25·81		μ Hydræ	10. 19. 25·08	
11 Tauri	3. 32. 32·10		ρ Leonis	10. 25. 32·55	− 0·01
δ Eridani	3. 36. 38·34		34 Sextantis	10. 35. 29·83	
η Tauri	3. 39. 17·19	+ 0·06	*l* Leonis	10. 42. 0·06	+ 0·03
γ Eridani	3. 51. 35·49	+ 0·05	*d* Leonis	10. 53. 25·95	
ω^1 Tauri	4. 1. 7·83		χ Leonis	10. 57. 53·80	− 0·01
o^1 Eridani	4. 5. 7·82	− 0·01	δ Leonis	11. 6. 45·91	+ 0·02
γ Tauri	4. 11. 56·60		δ Crateris	11. 12. 26·60	+ 0·05
ε Tauri	4. 20. 33·69	0·00	τ Leonis	11. 20. 50·37	
Aldebaran	4. 28. 0·30	0·00	υ Leonis	11. 29. 52·98	− 0·03
μ Eridani	4. 38. 36·24		β Leonis	11. 42. 1·11	+ 0·05
ι Aurigæ	4. 48. 0·66	0·00	π Virginis	11. 53. 48·04	
ε Leporis	4. 59. 37·17	+ 0·04	ε Corvi	12. 3. 1·93	+ 0·03
Rigel	5. 7. 54·39	+ 0·02	η Virginis	12. 12. 50·77	+ 0·04
β Tauri	5. 17. 34·24	+ 0·05	δ Corvi	12. 22. 43·71	
δ Orionis	5. 24. 57·43	− 0·03	β Corvi	12. 27. 8·60	+ 0·14
α Leporis	5. 26. 38·69	0·00	35 Virginis	12. 40. 49·84	
ε Orionis	5. 29. 12·68	− 0·01	δ Virginis	12. 48. 39·20	
α Columbæ	5. 34. 39·15	− 0·15	ε Virginis	12. 55. 18·42	
κ Orionis	5. 41. 12·71		θ Virginis	13. 2. 48·43	+ 0·03
α Orionis	5. 47. 42·08	+ 0·02	Spica	13. 17. 55·57	+ 0·03
1 Geminorum	5. 55. 43·95		ζ Virginis	13. 27. 39·80	− 0·02
ν Orionis	5. 59. 41·56	− 0·02	*m* Virginis	13. 34. 22·32	
η Geminorum	6. 6. 32·89		τ Boötis	13. 40. 42·26	
μ Geminorum	6. 14. 36·69	+ 0·01	η Boötis	13. 48. 6·85	+ 0·04
β Canis Majoris	6. 16. 37·49		τ Virginis	13. 54. 37·51	+ 0·04
ν Geminorum	6. 20. 46·18		κ Virginis	14. 5. 32·29	
γ Geminorum	6. 29. 44·34	− 0·03	Arcturus	14. 9. 22·09	+ 0·06
Cephei 51	6. 34. 40·38	+ 2·28	*f* Boötis	14. 20. 2·25	
Sirius	6. 39. 3·95	− 0·17	ρ Boötis	14. 25. 52·95	0·00
θ Canis Majoris	6. 47. 46·70		ε Boötis	14. 38. 57·63	+ 0·08
ε Canis Majoris	6. 53. 12·17	+ 0·01	α Libræ	14. 43. 14·92	+ 0·03
γ Canis Majoris	6. 57. 30·91	− 0·02	ξ^2 Libræ	14. 49. 17·05	
51 Geminorum	7. 5. 26·71		ψ Boötis	14. 58. 31·99	− 0·02
δ Geminorum	7. 11. 52·74	0·00	β Libræ	15. 9. 35·06	+ 0·05
β Canis Minoris	7. 19. 39·92		o^2 Libræ	15. 15. 20·21	
Castor	7. 25. 47·42	+ 0·01	ζ^1 Libræ	15. 20. 28·72	
Procyon	7. 32. 4·63	+ 0·10	α Coronæ	15. 28. 50·77	+ 0·08
Pollux	7. 36. 52·05	+ 0·04	α Serpentis	15. 37. 28·34	+ 0·07
ξ Navis	7. 43. 29·39		ε Serpentis	15. 43. 56·32	
6 Cancri	7. 55. 2·25	− 0·09	γ Serpentis	15. 50. 4·85	
15 Argûs	8. 1. 40·05	+ 0·01	β^1 Scorpii	15. 57. 25·03	+ 0·04
β Cancri	8. 9. 1·77		δ Ophiuchi	16. 7. 6·95	+ 0·05

RIGHT ASCENSIONS OF CLOCK STARS AND STARS FOR THE DETERMINATION OF AZIMUTHAL ERROR—*concluded.*

Star's Name.	Assumed Mean R.A. 1862, Jan. 1.	Correction to N.A.	Star's Name.	Assumed Mean R.A. 1862, Jan. 1.	Correction to N.A.
	h m s	s		h m s	s
γ Herculis	16. 15. 49 ·93		λ Ursæ Minoris	20. 2. 1 ·17	− 0 ·37
Antares	16. 20. 57 ·03	+ 0 ·02	θ Aquilæ	20. 4. 10 ·98	
λ Ophiuchi	16. 23. 57 ·34		α^2 Capricorni	20. 10. 23 ·70	+ 0 ·07
ζ Ophiuchi	16. 29. 33 ·73		β Capricorni	20. 13. 15 ·27	
ζ Herculis	16. 36. 5 ·08	+ 0 ·02	ρ Capricorni	20. 20. 59 ·11	+ 0 ·14
κ Ophiuchi	16. 51. 8 ·23	− 0 ·04	ε Delphini	20. 26. 37 ·16	
ε Herculis	16. 55. 0 ·65		α Delphini	20. 33. 13 ·70	
η Ophiuchi	17. 2. 27 ·94		ε Aquarii	20. 40. 12 ·14	
α Herculis	17. 8. 21 ·38	+ 0 ·10	32 Vulpeculæ	20. 48. 40 ·77	+ 0 ·05
θ Ophiuchi	17. 13. 32 ·21	+ 0 ·06	θ Capricorni	20. 58. 11 ·10	
σ Ophiuchi	17. 19. 40 ·09		ζ Cygni	21. 7. 3 ·85	+ 0 ·08
α Ophiuchi	17. 28. 31 ·78	+ 0 ·08	α Equulei	21. 8. 55 ·43	
β Ophiuchi	17. 36. 39 ·34		ι Capricorni	21. 14. 33 ·48	
μ Herculis	17. 41. 3 ·54	+ 0 ·06	β Aquarii	21. 24. 17 ·48	+ 0 ·04
89 Herculis	17. 49. 51 ·21		ξ Aquarii	21. 30. 24 ·15	
72 Ophiuchi	18. 0. 48 ·43		ε Pegasi	21. 37. 24 ·50	+ 0 ·04
μ Sagittarii	18. 5. 30 ·61	+ 0 ·06	δ Capricorni	21. 39. 25 ·17	
η Serpentis	18. 14. 10 ·16		16 Pegasi	21. 46. 47 ·08	+ 0 ·02
δ Ursæ Minoris	18. 16. 51 ·52	− 0 ·19	α Aquarii	21. 58. 41 ·67	+ 0 ·05
λ Sagittarii	18. 19. 27 ·25		ι Pegasi	22. 0. 35 ·28	
α Lyræ	18. 32. 15 ·98	+ 0 ·07	θ Aquarii	22. 9. 32 ·93	− 0 ·01
2 Aquilæ	18. 34. 42 ·96		γ Aquarii	22. 14. 31 ·64	
β Lyræ	18. 44. 59 ·13	+ 0 ·11	σ Aquarii	22. 23. 20 ·48	
ε Aquilæ	18. 53. 21 ·55		η Aquarii	22. 28. 15 ·81	0 ·00
ζ Aquilæ	18. 59. 4 ·02	+ 0 ·13	ζ Pegasi	22. 34. 34 ·78	+ 0 ·08
ψ Sagittarii	19. 7. 4 ·54		μ Pegasi	22. 43. 20 ·71	
ω Aquilæ	19. 11. 20 ·32	+ 0 ·04	λ Aquarii	22. 45. 24 ·74	
δ Aquilæ	19. 18. 32 ·36	+ 0 ·03	Fomalhaut	22. 50. 1 ·04	+ 0 ·03
α Vulpeculæ	19. 22. 57 ·82		α Pegasi	22. 57. 53 ·30	+ 0 ·03
μ Aquilæ	19. 27. 20 ·85		γ Piscium	23. 10. 0 ·68	0 ·00
h^2 Sagittarii	19. 28. 18 ·32	+ 0 ·10	κ Piscium	23. 19. 51 ·46	− 0 ·03
γ Aquilæ	19. 39. 41 ·92	+ 0 ·07	ι Piscium	23. 32. 51 ·16	− 0 ·03
α Aquilæ	19. 44. 2 ·97	+ 0 ·04	δ Sculptoris	23. 41. 43 ·89	− 0 ·06
β Aquilæ	19. 48. 32 ·03	+ 0 ·05	ω Piscium	23. 52. 13 ·54	− 0 ·04
c Sagittarii	19. 54. 10 ·04		2 Ceti	23. 56. 40 ·04	

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^h sidereal, as found by the following process. The observations are divided into groups, defined by bars across this column (in all instances the same as the limits of the observations of each observer). The mean of the clock-errors given by all the clock-stars in each group is then taken, and this is held to be the clock-error corresponding to the mean of all the times of transit of those stars. The next step is to investigate the clock-rate, making allowance for personal equation between the transits of successive observers; and it will be sufficient to explain the personal equation existing between any two observers, but more especially between Mr. 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. Suppose then that transits have been observed on successive days by Mr. Dunkin and Mr. Ellis, and that, for the set of observations on each day, the mean is taken as described above. It will be seen by one of the tables in the Introduction to the *Greenwich Observations*, 1861, page xlv, that the clock-error given by Mr. Ellis's observations is greater than that given by Mr. Dunkin's observations by $0^s \cdot 13$, as deduced from observations suitable for the determination of this quantity in the year 1861; and this is the last determination of personal equation which is available for the daily reduction of observations in 1862. The quantity $0^s \cdot 13$ is therefore subtracted from Mr. Ellis's clock-errors, and it is then considered that we have two sets of clock-errors (namely, Mr. Dunkin's as unaltered, and Mr. Ellis's as modified) justly comparable amongst themselves. Each mean clock-error, properly modified, is now compared with that which precedes and with that which follows; a preceding rate and a following rate are thus found, and by these the computer is guided in adopting the clock-rate to be used through the group of observations: this adopted clock-rate is set down in the nineteenth column. For facility of calculation, the proportional part of this rate, corresponding to the mean sidereal time or mean of all the times of transit for the group, is applied with changed sign to the mean clock-error; and thus the clock-error at 0^h sidereal is found. If it happen that any observations included in the same group are made in the sidereal day preceding or following that for which the mean error has been found, the whole adopted daily rate is subtracted from or added to the error found for 0^h; and thus the error for 0^h of the preceding or the following sidereal day is obtained. These errors at 0^h for all the different sidereal days are also set down in the nineteenth column. It is to be remarked that, in the application of these errors, if the observations of small stars and planets have been made by the same person as the observations of the clock-stars (whether it be Mr. Dunkin or Mr. Ellis), no further computation is necessary for obtaining the right ascensions of those objects than the application, to the time of transit, of the clock-error at 0^h, and of a proportional part of the clock-rate corresponding to the right ascension of the object: but, if the clock-stars are observed by Mr. Ellis, and the other object by Mr. Dunkin, a further correction $-0^s \cdot 13$ must be applied: if the clock-stars are observed by Mr. Dunkin, and the object by Mr. Ellis, $+0^s \cdot 13$ must be applied. The personal equations are *not* applied in the column of *Apparent Right Ascensions from the Observations* in this Section.

In the preceding years, observations were exhibited which gave the relative personal equations of the different observers of transits, as far as means existed for determining them. In the year 1862 the following sets of observations have been found available for determining personal equations in the use of the galvanic method of recording transits. They have been treated in the same manner as in preceding years, by comparing the clock-error at the same sidereal hour given by two different groups of stars observed by different persons.

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

Day, 1862.		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.
			h			s	s	s
August	18	S and D	5	S	D	55·91	55·84	− 0·07
November	11		0	S	D	44·71	44·57	− 0·14
,,	24		3	D	S	56·97	56·93	− 0·04
February	18	S and E	0	S	E	23·71	23·83	+ 0·12
March	8		0	S	E	31·87	31·93	+ 0·06
,,	12		0	E	S	40·23	40·14	− 0·09
July	14		4	E	S	13·91	13·95	+ 0·04
December	10	S and C	3	S	C	15·67	15·29	− 0·38
February	18	S and JC	2	S	J C	23·71	23·40	− 0·31
July	18		0	S	J C	18·38	18·13	− 0·25
August	3		0	J C	S	38·00	37·61	− 0·39
,,	11		0	J C	S	47·15	46·91	− 0·24
November	11		2	S	J C	44·71	44·62	− 0·09
December	10		0	S	J C	15·67	15·57	− 0·10
July	13	S and MD	1	S	M D	13·00	12·80	− 0·20
July	13	S and R	4	S	R	13·00	12·96	− 0·04
January	11	D and E	0	E	D	53·62	53·66	+ 0·04
,,	13		1	D	E	58·67	58·80	+ 0·13
,,	17		0	D	E	9·91	10·08	+ 0·17
February	6		0	E	D	67·82	68·06	+ 0·24
March	10		0	E	D	35·76	35·85	+ 0·09
April	29		0	E	D	62·62	62·78	+ 0·16
May	1		2	E	D	5·46	5·58	+ 0·12
October	11		0	E	D	37·42	37·57	+ 0·15
,,	28		0	D	E	29·99	30·15	+ 0·16
,,	30		0	D	E	26·85	26·93	+ 0·08
November	12		6	E	D	45·11	45·20	+ 0·09

OBSERVATIONS FOR PERSONAL EQUATION—*continued.*

Day, 1862.		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.
			h			s	s	s
January	4	D and C	0	D	C	34·88	34·75	− 0·13
,,	8		1	C	D	46·32	46·10	− 0·22
May	4		0	D	C	8·66	8·59	− 0·07
,,	16		4	C	D	59·43	59·46	+ 0·03
June	2		0	C	D	52·22	52·03	− 0·19
July	31		1	C	D	34·26	34·12	− 0·14
August	2		1	D	C	36·72	36·63	− 0·09
,,	6		0	D	C	41·14	41·00	− 0·14
,,	8		1	C	D	43·39	43·16	− 0·23
,,	18		0	D	C	55·70	55·54	− 0·16
November	9		4	C	D	42·02	41·65	− 0·37
September	6	D and L	3	D	L	16·87	16·66	− 0·21
,,	10		0	D	L	22·11	21·97	− 0·14
November	11	D and JC	5	D	JC	44·57	44·62	+ 0·05
August	28	D and MD	1	D	MD	7·47	7·41	− 0·06
November	12	D and R	3	R	D	45·11	45·02	− 0·09
May	16	D and TC	0	D	TC	59·43	59·53	+ 0·10
October	14		0	TC	D	39·83	39·91	+ 0·08
,,	17		6	TC	D	42·56	42·67	+ 0·11
December	1		3	D	TC	3·97	4·06	+ 0·09
April	20	E and C	3	C	E	47·71	47·37	− 0·34
September	9		0	E	C	20·97	20·79	− 0·18
,,	15		0	E	C	26·57	26·32	− 0·25
November	10		1	E	C	43·92	43·69	− 0·23
,,	27		1	C	E	60·01	59·60	− 0·41
December	1		3	C	E	4·23	3·79	− 0·44
October	2	E and L	1	L	E	28·63	28·23	− 0·40
,,	17		6	E	L	42·82	42·38	− 0·44

OBSERVATIONS FOR PERSONAL EQUATION—*continued.*

Day, 1862.		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.
			h			s	s	s
January	3	E and JC	0	J C	E	32 ·41	32 ·06	— 0 ·35
,,	7		0	J C	E	43 ·58	43 ·35	— 0 ·23
February	18		4	E	J C	23 ·83	23 ·40	— 0 ·43
July	30		1	E	J C	33 ·21	32 ·93	— 0 ·28
November	10		0	E	J C	43 ·92	43 ·68	— 0 ·24
December	11		4	E	J C	16 ·35	16 ·33	— 0 ·02
,,	24		2	E	J C	23 ·85	23 ·69	— 0 ·16
June	3	E and MD	0	E	M D	53 ·05	52 ·94	— 0 ·11
July	7		3	E	M D	36 ·84	36 ·67	— 0 ·17
,,	9		1	M D	E	44 ·91	44 ·72	— 0 ·19
May	15	E and R	2	E	R	57 ·94	57 ·94	0 ·00
June	7		0	E	R	53 ·16	53 ·21	+ 0 ·05
September	14		5	E	R	25 ·54	25 ·49	— 0 ·05
,,	30		0	R	E	26 ·89	26 ·83	— 0 ·06
October	8		0	E	R	35 ·00	34 ·92	— 0 ·08
November	12		0	R	E	45 ·20	45 ·02	— 0 ·18
December	11		0	E	R	16 ·35	16 ·35	0 ·00
March	4	E and TC	2	E	T C	27 ·56	27 ·60	+ 0 ·04
April	11		2	E	T C	42 ·64	42 ·64	0 ·00
,,	13		0	T C	E	43 ·56	43 ·63	+ 0 ·07
May	23		4	T C	E	37 ·65	37 ·45	— 0 ·20
June	13		0	T C	E	57 ·90	57 ·90	0 ·00
October	16	E and N	1	N	E	41 ·94	41 ·72	— 0 ·22
January	14	C and JC	1	C	J C	61 ·14	61 ·19	+ 0 ·05
,,	16		0	J C	C	7 ·00	6 ·99	— 0 ·01
,,	18		0	J C	C	12 ·76	12 ·86	+ 0 ·10
March	3		0	C	J C	25 ·89	25 ·86	— 0 ·03
,,	7		0	C	J C	29 ·97	29 ·97	0 ·00

OBSERVATIONS FOR PERSONAL EQUATION—*continued.*

Day, 1862.		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.
			h				s	s
April	2	C and JC	0	J C	C	13·68	13·80	+ 0·12
,,	12		4	C	J C	42·65	42·61	− 0·04
,,	14		0	C	J C	43·47	43·50	+ 0·03
,,	16		0	J C	C	43·67	43·77	+ 0·10
,,	20		4	J C	C	47·37	47·36	− 0·01
November	10		6	J C	C	43·69	43·68	− 0·01
December	10		5	J C	C	15·29	15·57	+ 0·28
,,	13		6	C	J C	17·31	17·46	+ 0·15
January	22	C and MD	2	M D	C	23·83	24·02	+ 0·19
May	12		0	M D	C	16·37	16·56	+ 0·19
December	13	C and K	1	K	C	17·31	17·48	+ 0·17
January	22	C and R	1	C	R	23·83	23·97	+ 0·14
November	3		1	R	C	33·23	33·47	+ 0·24
December	10		3	C	R	15·29	15·65	+ 0·36
,,	14		4	R	C	17·83	18·10	+ 0·27
May	16	C and TC	5	C	T C	59·46	59·53	+ 0·07
August	14		0	T C	C	50·79	51·19	+ 0·40
November	5	C and N	0	C	N	35·91	36·24	+ 0·33
,,	13		0	N	C	45·41	45·60	+ 0·19
December	29		0	C	N	27·44	27·58	+ 0·14
August	13	L and JC	0	L	J C	49·40	49·53	+ 0·13
October	14	L and MD	1	M D	L	39·52	39·80	+ 0·28
July	1	L and R	0	R	L	30·73	31·00	+ 0·27
,,	11		0	R	L	10·48	10·72	+ 0·24
,,	16		5	L	R	15·66	15·94	+ 0·28
October	14		5	L	R	39·52	39·96	+ 0·44
September	19	L and TC	4	T C	L	26·91	27·04	+ 0·13

OBSERVATIONS FOR PERSONAL EQUATION—*continued.*

Day, 1862.		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.
			h			s	s	s
October	9	L and N	2	L	N	35·56	35·83	+ 0·27
June	28	JC and MD	0	M D	J C	57·68	57·86	+ 0·18
December	13	JC and K	6	K	J C	17·47	17·48	+ 0·01
December	11	JC and R	4	R	J C	16·33	16·35	+ 0·02
July	20	JC and TC	2	T C	J C	20·33	20·58	+ 0·25
January	22	MD and R	3	M D	R	24·02	23·97	− 0·05
July	13		3	M D	R	12·80	12·96	+ 0·16
October	14		6	M D	R	39·80	39·96	+ 0·16
December	12	MD and TC	0	T C	M D	16·93	17·08	+ 0·15
September	17	R and TC	1	T C	R	28·28	28·23	− 0·05

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 S.

		s
3 (S − D)	=	+ 0·25
4 (S − E)	=	− 0·13
S − C	=	+ 0·38
6 (S − J C)	=	+ 1·38
S − M D	=	+ 0·20
S − R	=	+ 0·04

For D.

3 (D − S)	=	− 0·25
11 (D − E)	=	− 1·43
11 (D − C)	=	+ 1·71
2 (D − L)	=	+ 0·35
D − J C	=	− 0·05

For D.—*continued.*

		s
D − M D	=	+ 0·06
D − R	=	+ 0·09
4 (D − T C)	=	− 0·38

For E.

4 (E − S)	=	+ 0·13
11 (E − D)	=	+ 1·43
6 (E − C)	=	+ 1·85
2 (E − L)	=	+ 0·84
7 (E − JC)	=	+ 1·71
3 (E − MD)	=	+ 0·47
7 (E − R)	=	+ 0·32
5 (E − T C)	=	+ 0·09
E − N	=	+ 0·22

For C.

		s
C − S	=	− 0·38
11 (C − D)	=	− 1·71
6 (C − E)	=	− 1·85
13 (C − J C)	=	− 0·73
2 (C − M D)	=	− 0·38
C − K	=	− 0·17
4 (C − R)	=	− 1·01
2 (C − T C)	=	− 0·47
3 (C − N)	=	− 0·66

For L.

2 (L − D)	=	− 0·35
2 (L − E)	=	− 0·84
L − J C	=	− 0·13
L − M D	=	− 0·28
4 (L − R)	=	− 1·23
L − T C	=	− 0·13
L − N	=	− 0·27

For J C.

6 (J C − S)	=	− 1·38
J C − D	=	+ 0·05
7 (J C − E)	=	− 1·71
13 (J C − C)	=	+ 0·73
J C − L	=	+ 0·13
J C − M D	=	− 0·18
J C − K	=	− 0·01
J C − R	=	− 0·02
J C − T C	=	− 0·25

For M D.

M D − S	=	− 0·20
M D − D	=	− 0·06
3 (M D − E)	=	− 0·47
2 (M D − C)	=	+ 0·38

For M D.—*continued.*

		s
M D − L	=	+ 0·28
M D − J C	=	+ 0·18
3 (M D − R)	=	− 0·27
M D − T C	=	− 0·15

For K.

K − C	=	+ 0·17
K − J C	=	+ 0·01

For R.

R − S	=	− 0·04
R − D	=	− 0·09
7 (R − E)	=	− 0·32
4 (R − C)	=	+ 1·01
4 (R − L)	=	+ 1·23
R − J C	=	+ 0·02
3 (R − M D)	=	+ 0·27
R − T C	=	+ 0·05

For T C.

4 (T C − D)	=	+ 0·38
5 (T C − E)	=	− 0·09
2 (T C − C)	=	+ 0·47
T C − L	=	+ 0·13
T C − J C	=	+ 0·25
T C − M D	=	+ 0·15
T C − R	=	− 0·05

For N.

N − E	=	− 0·22
3 (N − C)	=	+ 0·66
N − L	=	+ 0·27

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

16 S − 4 E − C − 6 J C − M D − R	= + 2^{s}·12
46 E − 4 S − 6 C − 2 L − 7 J C − 3 M D − 7 R − 5 T C − N	= + 7·06
43 C − S − 6 E − 13 J C − 2 M D − K − 4 R − 2 T C − 3 N	= − 7·36
12 L − 2 E − J C − M D − 4 R − T C − N	= − 3·23
32 J C − 6 S − 7 E − 13 C − L − M D − K − R − T C	= − 2·64
13 M D − S − 3 E − 2 C − L − J C − 3 R − T C	= − 0·31
2 K − C − J C	= + 0·18
22 R − S − 7 E − 4 C − 4 L − J C − 3 M D − T C	= + 2·13
15 T C − 5 E − 2 C − L − J C − M D − R	= + 1·24
5 N − E − 3 C − L	= + 0·71

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 :—

S = + 0^{s}·14	E = + 0·15	C = − 0^{s}·15	L = − 0^{s}·21	J C = − 0^{s}·08
M D = + 0·01	K = − 0·03	R = + 0·09	T C = + 0·10	N = + 0·03

or, restoring D :—

D − S = − 0^{s}·14	D − E = − 0^{s}·15	D − C = + 0^{s}·15	D − L = + 0^{s}·21
D − J C = + 0·08	D − M D = − 0·01	D − K = + 0·03	D − R = − 0·09
D − T C = − 0·10	D − N = − 0·03		

The observations by eye and ear in the years 1860, 1861, and 1862 are insufficient in number to give a trustworthy determination of the personal equations of transits observed by that method. Those determined in 1858 and 1859 (Introduction to *Greenwich Observations*, 1858, page xl, and 1859, page xlii,) have been adopted for use in the year 1862. The numbers employed are the following :—

D − E	=	+ 0^{s}·03
D − C	=	+ 0·01
D − L	=	+ 0·38
D − J C	=	+ 0·14

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 1862.

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, and Mercury, 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 1862, is

$$0^{s}\cdot04 + 0\cdot004 \times \text{tabular duration of passage of semidiameter.}$$

For Mars a correction has been applied, derived from the transits of both limbs at and near the opposition of 1862. From twenty-seven observations, extending from 1862, September 16 to December 10, both inclusive, the mean error of the time of transit of the diameter given in the Nautical Almanac was found to be $-0^{s}\cdot26$, corresponding to a tabular time of transit equal to $1^{s}\cdot25$. Hence, the correction to be applied additively to the tabular time of transit of semidiameter is found to be $+0\cdot206 \times$ 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 by applying to the value given in the Nautical Almanac, a correction derived from a few of the neighbouring observations. The elements of computation are given in the notes.

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

The *twenty-first* column contains the correction with its proper sign, as it is to be applied for reducing the apparent right ascension of each star at the time of observation to the mean right ascension on the 1st of January 1862. 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 the case of Polaris, Cephei 51 (Hev.), δ Ursæ Minoris, and λ 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

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

which is derived from the well-known formula,

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

or its equivalent,

$\frac{A}{15}$ cos R. A. cosec N. P. D. + $\frac{B}{15}$ sin R.A. cosec N.P.D. + C sin R. A. cotan N.P.D. × numb. log. 0·1259 + $\frac{D}{15}$ cos R.A. cot N.P.D. + C × 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 Introduction to 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 × E − 1·2 × F − 25 × G − 1·2 × H, l = 210 − 25 × e − 25 × f − 1·2 × g − 25 × h. The values of the day-constants log. E, log. F, log. G, log. H, and L, are given in the Nautical Almanac. The values of the star-constants, log. e, log. f, log. g, log. h, and l, for stars contained respectively in the "Twelve-Year-Catalogue" and the "Catalogue of 1576 Stars" are printed in those Catalogues. For other Stars, the star-constants will be found in the annual Catalogues for the years 1854 to 1861, or in that included in the present volume. 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: for other stars, the values of log. e, log. f, log. g, log. h, l, are computed independently.

The sign of the computed quantity is changed before application.

§ 2. *Observations of the Collimators, and of the Reflected Image of the Central Vertical Wire of the Transit-Circle, for the Determination of the Errors of Collimation, and Level*, page [71] to [78].

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

OBSERVATIONS FOR COINCIDENCE OF COLLIMATORS.

These observations are made on 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 xxix). 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 $-0''\cdot19$ for diurnal aberration, the Errors of Collimation actually used will be deduced. For determination of the sign of the Error, it must be observed that the micrometer-head is East, and that the readings of the micrometer increase as the wire moves towards the head.

DETERMINATION OF THE LEVEL ERROR.

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

§ 3. *Apparent Right Ascensions of* α^1 *Ursæ Minoris, Polaris, and* δ *Ursæ Minoris; and Mean Right Ascensions of Stars observed in the Year* 1862, page [79] to [93].

The apparent right ascensions of α^1 Ursæ Minoris, Polaris, and δ Ursæ Minoris, are extracted without alteration from the *twentieth* column of the *Transits observed*, &c.

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

The corrections for personal equation have been 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 observer.

The rules for the nomenclature of stars are the same as those in the section of the *Transits observed*, detailed in page xxiii, 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 (1) to (84).

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

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

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

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

NAME OF OBJECT.—The nomenclature of stars follows the same general rule as in the section of *Transits observed*, &c., except that, as a last resource, the place of the star is defined by its right ascension, which is generally accurate to 1^s. The letters N.L. and S.L. denote north and south limbs of planets, and N.C. and S.C. the north and south cusps of Mercury or Venus. [By a mistake of the copier, these letters have sometimes been used in reference to the gibbous disk of Mars and other planets.] 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 $\frac{A,\ C,\ E}{B,\ D,\ F}$: from which form they are easily changed into the order of printing. Each pair of adjacent readings, therefore, is the pair of readings at the opposite ends of a diameter. The number of integral revolutions is given in the fifth column only. Occasionally the number of revolutions expressed in this column does not apply unchanged to all the microscopes, on account of the difference of their readings; but since the readings never differ by more than four or five tenths of a revolution, and the order of the more conspicuous differences is noted at the bottom of the page, this will occasion no ambiguity. 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 sexagesimal seconds. It is evident thus that the number of nominal seconds to be attached to the nominal minute will be found by simply adding together the subdivisions on the micrometer-heads, and shifting the decimal point.

From the ordinary observations of runs (those for the year 1862 being given at page (85) &c., of the present volume), it is known that the screws of the micrometers are so sensibly equal that, in the reduction of the observations, it is sufficient to take the mean of the six readings, and to apply to it the mean correction for runs. To do this, the following process is employed. The sum of the runs for the six microscopes never differs materially from $29^{r}\cdot 3$. 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 $\frac{50}{51} \times 30^{r}\cdot 000$, or $29^{r}\cdot 4118$. 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 $29^{r}\cdot 412 - x$. Then the true reading in seconds of space, corresponding to a nominal reading of r'' (including the value both of the nominal minutes and of the subdivisions of the nominal minute) will be

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

or

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

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

From December 1 to December 8 the microscopes C D E and F were alone used; the microscope A having been accidentally injured. The mean run for 5′ is given in the notes.

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

READING OF TELESCOPE-MICROMETER.—This column contains the reading of the micrometer in the eyepiece 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 determined in June 1857, was found to be $29''\cdot 602$. This value has been used from that time to the present.

In order to test the accuracy of the Micrometer Screw in respect of two important points, observations were made in the latter part of 1859.

1859, November 21. The following experiments were made by Mr. Dunkin with the view of ascertaining whether there is any sensible difference between the readings of the micrometer when the screw is turned forwards and when it is turned backwards.

The telescope was directed to the South Collimator, and the instrument was firmly clamped. The micrometer-wire was then placed upon the image of the nearly horizontal wire of the Collimator, the screw being turned alternately forwards and backwards.

	Micrometer head turned so that readings increase.		Micrometer head turned so that readings diminish.
	r		r
Separate readings	19·950	....	19·947
	·942	....	·943
	·942	....	·947
	·945	....	·944
	·941	....	·945
	·939	....	·940
	·940	....	·938
	·937	....	·942
Means..	19·942	....	19·943

It is evident that there is no sensible difference of reading depending on the direction in which the screw is turned. This has become so well known, in the daily use of the micrometer, that the observers have long ceased to confine themselves to any rule as to the direction of turning the screw.

The structure of the screw, with the remarkable depth and flatness of its threads (as in all the micrometer-screws of this instrument), and the excellence of the bearing part, afford sufficient *à priori* evidence of this agreement. The screws are perhaps the finest in the world. They were cut by a new engine, introduced by Mr. Simms in 1850.

November 23. Mr. Dunkin made the following observations for comparing the values of several successive half-turns of the Telescope-micrometer.

The object used for this purpose was the image of the nearly horizontal wire of the North Collimator. It was found that the interval of half a revolution of the Telescope-micrometer corresponded nearly to $0^{r}\cdot460$ of the Collimator-micrometer; and in all the subsequent experiments, the Collimator-micrometer was placed (by an assistant) at the readings ·140 and ·600 alternately. The Transit-Circle was clamped in such a position that, with the Collimator-reading ·600, the Telescope-micrometer read $18^{r}\cdot5$ nearly; six readings of the Telescope-micrometer were taken; then the Collimator-micrometer was turned to ·140, and six readings of the Telescope-micrometer were taken. After this, the Transit-Circle was moved, so that $19^{r}\cdot0$ of the Telescope-micrometer fell nearly on ·600 of the Collimator-micrometer, and similar observations were made; and so to the end of the first series. A second series commenced at 18r·25. The means of readings are as follows:—

Readings of Collimator-micrometer.	Readings of Telescope-micrometer.	Intervals.	Readings of Collimator-micrometer.	Readings of Telescope-micrometer.	Intervals.
	r	r		r	r
·600	18·493	0·498	·600	18·259	0·497
·140	18·991		·140	18·756	
·600	18·991	0·496	·600	18·761	0·495
·140	19·487		·140	19·256	
·600	19·494	0·493	·600	19·241	0·498
·140	19·987		·140	19·739	
·600	20·010	0·494	·600	19·755	0·490
·140	20·504		·140	20·245	
·600	20·500	0·496	·600	20·241	0·498
·140	20·996		·140	20·739	
·600	20·998	0·493	·600	20·738	0·495
·140	21·491		·140	21·233	
·600	21·500	0·494	·600	21·245	0·498
·140	21·994		·140	21·743	

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

VERTICAL WIRE AT WHICH OBSERVATION IS MADE.—Omitting, in this Section, all reference to the wires Q, R, S, U, V, W, (page xxiv) 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 14s for transit of an equatoreal star (Table, page xxv), 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

h 2

will suffice, therefore, to give the table containing the final result for errors of division for every degree: ($1^r = 61''\cdot 4$ nearly). The errors are always considered in the nature of reading too much.

Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.
°	r	°	r	°	r	°	r	°	r	°	r	°	r	°	r	°	r	°	r
0	0·050	36	0·058	72	0·054	108	0·058	144	0·081	180	0·056	216	0·043	252	0·047	288	0·051	324	0·088
1	·046	37	·052	73	·053	109	·061	145	·073	181	·063	217	·045	253	·051	289	·068	325	·082
2	·049	38	·046	74	·053	110	·054	146	·065	182	·063	218	·048	254	·060	290	·068	326	·082
3	·049	39	·045	75	·053	111	·046	147	·073	183	·061	219	·052	255	·064	291	·070	327	·079
4	·051	40	·049	76	·060	112	·048	148	·082	184	·059	220	·042	256	·067	292	·074	328	·086
5	·046	41	·049	77	·054	113	·049	149	·082	185	·046	221	·041	257	·063	293	·076	329	·085
6	·048	42	·052	78	·052	114	·060	150	·078	186	·038	222	·044	258	·067	294	·084	330	·072
7	·042	43	·053	79	·051	115	·065	151	·077	187	·045	223	·044	259	·070	295	·081	331	·067
8	·049	44	·050	80	·059	116	·063	152	·083	188	·048	224	·046	260	·081	296	·073	332	·064
9	·051	45	·044	81	·057	117	·069	153	·085	189	·052	225	·045	261	·085	297	·067	333	·070
10	·049	46	·047	82	·068	118	·071	154	·091	190	·041	226	·050	262	·080	298	·067	334	·087
11	·048	47	·053	83	·071	119	·070	155	·090	191	·043	227	·059	263	·099	299	·073	335	·075
12	·052	48	·065	84	·072	120	·077	156	·082	192	·043	228	·058	264	·094	300	·088	336	·072
13	·050	49	·064	85	·065	121	·082	157	·070	193	·043	229	·061	265	·089	301	·096	337	·067
14	·058	50	·051	86	·067	122	·084	158	·059	194	·041	230	·051	266	·090	302	·089	338	·062
15	·041	51	·048	87	·067	123	·084	159	·068	195	·036	231	·057	267	·085	303	·094	339	·062
16	·045	52	·051	88	·076	124	·091	160	·071	196	·039	232	·065	268	·087	304	·099	340	·070
17	·042	53	·063	89	·068	125	·088	161	·067	197	·033	233	·068	269	·086	305	·093	341	·063
18	·049	54	·064	90	·069	126	·092	162	·068	198	·033	234	·062	270	·082	306	·098	342	·074
19	·047	55	·069	91	·066	127	·086	163	·065	199	·041	235	·065	271	·073	307	·098	343	·065
20	·048	56	·064	92	·074	128	·084	164	·073	200	·040	236	·058	272	·065	308	·091	344	·057
21	·038	57	·057	93	·068	129	·081	165	·079	201	·042	237	·065	273	·064	309	·083	345	·070
22	·047	58	·062	94	·071	130	·072	166	·081	202	·049	238	·071	274	·061	310	·084	346	·066
23	·055	59	·067	95	·067	131	·076	167	·071	203	·053	239	·078	275	·073	311	·094	347	·059
24	·043	60	·065	96	·065	132	·074	168	·057	204	·048	240	·074	276	·074	312	·097	348	·067
25	·047	61	·063	97	·064	133	·064	169	·051	205	·046	241	·068	277	·079	313	·094	349	·065
26	·053	62	·068	98	·075	134	·072	170	·044	206	·050	242	·056	278	·091	314	·094	350	·049
27	·048	63	·063	99	·079	135	·074	171	·047	207	·049	243	·065	279	·084	315	·084	351	·056
28	·047	64	·067	100	·074	136	·080	172	·038	208	·041	244	·075	280	·082	316	·091	352	·057
29	·044	65	·057	101	·072	137	·078	173	·036	209	·045	245	·069	281	·077	317	·093	353	·059
30	·054	66	·057	102	·073	138	·072	174	·034	210	·056	246	·065	282	·082	318	·090	354	·046
31	·063	67	·056	103	·069	139	·075	175	·043	211	·060	247	·062	283	·083	319	·078	355	·041
32	·069	68	·056	104	·066	140	·075	176	·062	212	·051	248	·046	284	·078	320	·083	356	·044
33	·070	69	·057	105	·055	141	·075	177	·062	213	·044	249	·045	285	·071	321	·073	357	·059
34	·063	70	·061	106	·057	142	·082	178	·062	214	·045	250	·062	286	·064	322	·077	358	·055
35	·051	71	·061	107	·052	143	·086	179	·054	215	·042	251	·054	287	·052	323	·089	359	·049

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, was adopted for use. On 1860, August 23, a series of observations was made, giving for the value of the coefficient + 0″·92. On September 1, a series was made with the greatest care. Observations were not commenced until the state of the instruments, as affected by temperature, appeared perfectly tranquil; one collimator was observed with the other at the beginning, the middle, and the end, of the operation, and scrupulous attention was given to the use of the same points of the wires in all the observations. The value found for the coefficient was + 0″·67. Though this determination is undoubtedly superior to any one of the others, yet it has not been thought necessary at once to introduce it in preference to the mean of all. The quantity + 0″·56 has therefore still been adopted, and the product of this quantity by the sine of the zenith distance has been incorporated with the mean of those numbers in the preceding table which apply to the six divisions that are viewed simultaneously under the six microscopes. These resulting corrections, which are contained in the following Table, have been applied additively to all circle-readings throughout the year 1862.

DIVISION CORRECTION + FLEXURE CORRECTION.

(*Always Additive.*)

Pointer Reading.	Corr.	Pointer Reading.	Corr.	Pointer Reading.	Corr.	Pointer Reading.	Corr.	Pointer Reading.	Corr.	Pointer Reading.	Corr.	Pointer Reading.	Corr.	Pointer Reading.	Corr.	Pointer Reading.	Corr.	Pointer Reading.	Corr.
°	″	°	″	°	″	°	″	°	″	°	″	°	″	°	″	°	″	°	″
0	0·76	36	1·23	72	1·55	108	1·76	144	1·65	180	0·76	216	0·57	252	0·49	288	0·70	324	0·99
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	325	0·94
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	326	0·87
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	327	0·78
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	328	0·69
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	329	0·62
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	330	0·51
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	331	0·45
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	332	0·47
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	333	0·40
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	334	0·37
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	335	0·52
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	336	0·67
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	337	0·76
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	338	0·88
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	339	0·96
16	1·41	52	1·23	88	1·55	124	1·23	160	1·34	196	1·11	232	0·35	268	0·43	304	0·31	340	0·96
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	341	0·96
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	342	1·03
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	343	1·06
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	344	1·05
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	345	1·06
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	346	1·03
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	347	1·05
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	348	1·11
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	349	1·07
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	350	1·00
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	351	0·95
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	352	0·71
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	353	0·45
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	354	0·53
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	355	0·72
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	356	0·78
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	357	0·76
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	358	0·72
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	359	0·72

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° (whose errors are known from the preceding operations) would be brought under the microscope, and the errors of the intermediate divisions could be ascertained. This investigation was in preceding years esteemed unnecessary; but on repeating the general investigation of the errors of divisions of single degrees of the circle at the end of the year 1856, it was thought prudent to examine the 5′ divisions of those degrees of the circle which are under the microscopes in the 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 for 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 1862.

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

The correction due to inclination of wire was found by bisections of stars (by the telescope-declination-micrometer) at the first and seventh vertical wires, made in March 1860, the readings for which are given in the foot-notes to the observations. The observations were repeated in 1861, January, and the result was sensibly the same. The correction for one interval of the wires, thus found, is used through the whole year 1862. Its numerical value, additive before transit, and subtractive after transit, for stars above the pole, is given in the foot-notes.

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

being the interval between the time of meridian passage and the time of transit expressed in seconds of time.

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

SECONDS OF CONCLUDED MERIDIONAL CIRCLE-READING.—The numbers in this column are found by adding together the mean of the microscope-readings corrected for runs, the equivalent for 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 $\frac{R+D}{2} \pm 90°$.

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 details of the computation of Zenith Point are given in a subsequent table, page (90) to (94). The adopted Correction for Zenith Point is given in the foot notes to this Section.

APPARENT ZENITH DISTANCE.—The numbers in this column are found by adding the Zenith-Point-Correction to the Concluded Meridional Circle-Reading; when the sum exceeds 270° (denoting that the object is between the zenith and the north horizon), the complement to 360° is taken, and the negative sign is attached to it; for stars observed by reflexion, the sum is subtracted from 180°, and the remainder, with its algebraical sign, is the apparent zenith-distance. When the 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 θ be the angle which the circle joining the cusps makes with the meridian; δ_s the Sun's declination, and δ_m the Moon's declination as seen at Greenwich: P the Sun's hour angle at the Moon's Transit: then

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

and the correction required will be

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

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

If the Moon be gibbous, as is the case in the greater number of instances, draw a great circle through the center of the Moon, at right angles to the meridian passing through the Moon, and let it meet the meridian passing through the Sun; then the intersection of this circle with the Sun's meridian will determine the place of a fictitious Sun, which would equally illuminate both limbs of the Moon when on the meridian; and the elevation or depression of the true Sun above or below the great circle joining the Moon and fictitious Sun, measured in a plane at right angles to that circle, will represent the angle by which the lowest or highest part of the illuminated hemisphere is distant from the limb, and therefore the angle whose versed sine multiplied into the Moon's 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 δ_1 be the declination of the fictitious Sun, θ_1 the arc joining the true and fictitious Suns, and θ the perpendicular arc before mentioned.

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

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

Also $$\text{Sin}\ \theta = \text{Sin}\ \theta_1\ .\ \text{Sin}\ MS_1P = \text{Sin}\ \theta_1 \frac{\text{Sin}\ MP}{\text{Sin}\ S_1P} = \text{Sin}\ \theta_1 \frac{\text{Cos}\ \delta_m}{\text{Cos}\ \delta_1}\ .$$

Whence θ 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 θ is positive, and the South limb if θ is negative.

In the cases of Mercury and Venus when gibbous, or of Mars and other planets sensibly gibbous, the investigation takes the following form. The angle θ 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 θ;

and therefore if φ be the apparent angular distance of the Sun from that plane as seen from the planet, the value of φ is determined by the equation

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

The angle φ 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

Planet's semidiameter × versin φ.

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 the same level. This construction is not well adapted to a merely meteorological instrument, which constantly requires a visible reference to the lower surface of the mercury, but it is exceedingly convenient for the barometer as an astronomical auxiliary, and entirely avoids the risk of error from inadvertent omission of the lower verification, or from friction of a floating index; and is, on the whole, the best that can be employed. From careful comparisons made between 1860, January 24, and March 4, 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 with the Standard Thermometer, made on 1861, January 31:—

Temperatures.	Excess of Reading of Circle Thermometer.
°	°
32·0	0·0
34·0	0·0
36·3	0·0
40·0	0·0
42·1	−0·1
45·1	−0·1
48·4	0·0
53·5	0·0
57·0	0·0
60·0	0·0
63·1	−0·1
67·7	+0·1
72·0	0·0
76·6	0·0
83·6	0·0
88·6	0·0
94·7	0·0

INTERIOR THERMOMETER.—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°, 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°, in which cases the computation is made generally by means of the Supplementary Table in the *Tabulæ*, which requires the use of the interior thermometer. From 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° no correction is needed to the results given in the *Tabulæ Regiomontanæ;* that, from 82° to 85° Zenith Distance, the Logarithms of the Mean Refractions of the *Tabulæ* require to be diminished by 0·00100; and finally, that, from 85° 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 1862, 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. parallax = log. sin. (zen. dist. − 11′. 12″) + 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—

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

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

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

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

For the computation of the parallaxes of the small planets, the distances are taken from the Supplement to the *Nautical Almanac,* as far as its list extends; in other cases, from the *Berliner Jahrbuch.*

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, Mars, Jupiter, and Saturn, 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 $+ 0''\cdot59 + 0\cdot004 \times$ tabular semidiameter, derived from an investigation mentioned at page xlv above, has been applied to the semidiameter given in the Nautical Almanac; and, for Mars, Jupiter and Saturn, a correction usually derived from neighbouring observations, and specified in the notes, has been similarly applied.

GEOCENTRIC N. P. D. OF CENTER.—The numbers in this column are found by combining the Apparent Zenith Distance with the Refraction, Parallax, Semidiameter, and Assumed Colatitude 38°. 31′. 21″·80.

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 1862, 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,

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

which is derived from the well-known formula

$$\text{A}\,a' + \text{B}\,b' + \text{C}\,c' + \text{D}\,d'$$

or its equivalent

$$\text{A}.\sin\text{N.P.D.} \times \text{numb.}(\log = 9\cdot6376) - \text{A}.\sin\text{R.A.}\cos.\text{N.P.D.} + \text{B}.\cos\text{R.A.}\cos\text{N.P.D.} + \text{C}.\cos\text{R.A.} \times \text{numb.}(\log = 1\cdot3020) - \text{D}.\sin\text{R.A.}$$

The formulæ for E, F, G, H, L, have been already given (page xlvi): $e' = a' + 1\cdot2$, $f' = b' + 1\cdot2$, $g' = c' + 25$, $h' = d' + 1\cdot2$, $l' = 210 - 25 \times e' - 25 \times f' - 1\cdot2 \times g' - 25 \times h'$. The values of the day-constants log. E, log. F, log. G, log. H, and L, are given in the Nautical Almanac. The values of the star-constants log. e', log. f', log. g', log. h', and l′, for all the stars in the "Greenwich Twelve-Year Catalogue" are given in the Twelve-Year Catalogue: those for all the stars in the Greenwich Catalogue of 1576 Stars for 1850 are printed in that Catalogue. For other stars the star-constants will be found in tables following the annual Catalogues of Stars for the years 1854 to 1861, 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* 1862; page (85) to (94).

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 $\frac{50}{51} \times 30^{r}\cdot000$, or to $29^{r}\cdot4118$; 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 $29^{r}\cdot4118$, is computed in the way that has been explained (page xlix).

On December 8 the microscope-micrometer A, was found to be injured; the runs of the opposite pairs of microscopes C, D, and E, F were taken, and the readings corrected in the ordinary way.

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

Whenever observations of stars have been made by reflexion, the results for zenith point derived from them have been combined with those derived from the observations of the reflected image of the wire. The results are always divided into three groups, viz.: those resulting from north stars, those from south stars, and those from wire-observations; and, to prevent too much weight being given to those divisions of the circle which are always under the microscopes for the wire-observations, to each result derived from a star-observation there is attributed three times the weight which is attributed to the result of a wire-observation. 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 lv, and is repeated here for the sake of clearness.

§ 6. *Mean North Polar Distances of Stars deduced from each Day's Observations, page (95) to (111).*

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, 1862.

Name of Star.	Approximate N. P. D.	Seconds of R.	Seconds of D.	R.—D.	Number of Obs. R.	Number of Obs. D.	Weight.
	° ′	″	″	″			
Cephei 51 S.P.	— 2. 45	12 ·36	12 ·56	+ 0 ·20	1	19	4
Polaris S.P.	— 1. 25	35 ·39	34 ·54	— 0 ·85	1	57	4
Polaris	1. 25	36 ·35	34 ·71	+ 1 ·64	2	55	8
δ Ursæ Minoris	3. 23	48 ·60	49 ·00	— 0 ·40	1	17	4
B. A. C. 4281	5. 35	54 ·36	54 ·17	+ 0 ·19	1	1	2
B. A. C. 8026	6. 23	33 ·58	33 ·00	+ 0 ·58	1	1	2
B. A. C. 2326	7. 20	6 ·48	6 ·87	— 0 ·39	1	1	2
B. A. C. 4050	8. 22	37 ·44	37 ·44	0 ·00	3	3	6
B. A. C. 2317	8. 30	13 ·40	11 ·62	+ 1 ·78	1	1	2
75 Draconis	9. 3	8 ·81	9 ·63	— 0 ·82	2	2	4
B. A. C. 1276	9. 30	54 ·26	52 ·72	+ 1 ·54	2	2	4
18 Ursæ Minoris	9. 35	14 ·20	13 ·63	+ 0 ·57	1	1	2
B. A. C. 1565	10. 56	14 ·65	14 ·09	+ 0 ·56	4	5	9
28 Cephei	11. 55	3 ·67	3 ·25	+ 0 ·42	2	2	4
θ Ursæ Minoris	12. 11	32 ·39	32 ·99	— 0 ·60	1	1	2
B. A. C. 3593	13. 34	42 ·30	41 ·05	+ 1 ·25	1	1	2
5 Ursæ Minoris	13. 41	26 ·76	24 ·97	+ 1 ·79	2	2	4
η Ursæ Minoris	13. 55	40 ·74	41 ·97	— 1 ·23	1	1	2
B. A. C. 7509	14. 12	11 ·27	10 ·59	+ 0 ·68	1	1	2
50 Draconis	14. 43	50 ·73	49 ·48	+ 1 ·25	2	2	4
B. A. C. 1706	15. 3	22 ·21	18 ·64	+ 3 ·57	1	1	2
β Ursæ Minoris	15. 16	49 ·65	49 ·60	+ 0 ·05	3	2	5
π Cephei	15. 21	28 ·97	31 ·20	— 2 ·23	1	1	2
B. A. C. 8314	16. 21	28 ·11	27 ·04	+ 1 ·07	2	2	4
31 Cephei	17. 4	22 ·21	21 ·36	+ 0 ·85	2	2	4
B. A. C. 1067	17. 7	34 ·46	33 ·90	+ 0 ·56	1	1	2
B. A. C. 5887	18. 3	53 ·67	53 ·69	— 0 ·02	1	2	3
24 Cephei	18. 20	16 ·27	17 ·17	— 0 ·90	1	1	2

EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS, FOR OBSERVATIONS OF ZENITH DISTANCE WITH THE TRANSIT-CIRCLE, 1862—*continued.*

Name of Star.	Approximate N. P. D.	Seconds of R.	Seconds of D.	R.—D.	Number of Obs. R.	Number of Obs. D.	Weight.
	° ′	″	″	″			
11 Cephei	19. 19	24·12	24·38	− 0·26	2	2	4
4 Draconis	20. 2	3·50	4·57	− 1·07	1	1	2
B. A. C. 8180	20. 23	57·75	56·45	+ 1·30	1	1	2
σ Draconis	20. 34	26·12	26·08	+ 0·04	7	7	14
B. A. C. 1980	20. 38	18·46	18·08	+ 0·38	1	1	2
A Draconis	20. 55	60·60	59·59	+ 1·01	1	1	2
ω Draconis	21. 10	43·65	42·95	+ 0·70	1	2	3
B. A. C. 1813	21. 34	30·74	31·59	− 0·85	1	1	2
ρ Ursæ Majoris	21. 50	11·81	9·38	+ 2·43	1	1	2
46 Cassiopeiæ	21. 59	41·87	41·80	+ 0·07	1	1	2
δ Draconis	22. 34	52·10	51·74	+ 0·36	8	8	16
ο Cephei	22. 38	36·24	34·90	+ 1·34	3	5	8
ω Cassiopeiæ	22. 39	25·56	25·57	− 0·01	2	2	4
B. A. C. 814	22. 45	54·58	55·26	− 0·68	3	4	7
B. A. C. 8273	22. 57	36·31	36·77	− 0·46	1	1	2
B. A. C. 1874	23. 0	22·70	22·59	+ 0·11	2	2	4
B. A. C. 744 (1st Star)	23. 13	15·59	14·55	+ 1·04	3	4	7
7 Cephei	23. 47	31·21	33·20	− 1·99	1	2	3
ζ Draconis	24. 6	54·85	52·28	+ 2·57	1	1	2
55 Cassiopeiæ	24. 7	30·81	29·48	+ 1·33	1	1	2
32 Ursæ Majoris	24. 12	17·76	18·74	− 0·98	1	1	2
B. A. C. 1001	24. 51	24·13	24·39	− 0·26	1	1	2
6 Ursæ Majoris	24. 52	20·51	18·14	+ 2·37	1	1	2
α Draconis	24. 57	49·90	48·93	+ 0·97	3	4	7
g Draconis	25. 8	56·05	55·48	+ 0·57	3	3	6
e Draconis	25. 33	53·63	53·31	+ 0·32	2	1	3
h Ursæ Majoris	26. 20	15·98	16·75	− 0·77	1	1	2
θ Cephei	27. 28	7·95	8·11	− 0·16	1	4	3
α Ursæ Majoris	27. 30	16·25	17·19	− 0·94	1	2	3
B. A. C. 5717	29. 24	58·13	57·50	+ 0·63	1	1	2
B. A. C. 3157	29. 38	25·69	24·90	+ 0·79	1	1	2
γ^1 Andromedæ	48. 20	3·64	4·16	− 0·52	1	7	4
12 Can. Ven. (2d Star)	50. 56	8·72	8·59	+ 0·13	1	1	2
α Lyræ	51. 20	33·36	34·81	− 1·45	1	3	3
μ Aurigæ	51. 40	58·47	60·27	− 1·80	1	1	2
τ Coronæ	53. 9	23·39	23·12	+ 0·27	2	3	5
21 Leonis Minoris	54. 5	4·07	2·28	+ 1·79	1	1	2
46 Leonis Minoris	55. 2	31·40	32·74	− 1·34	1	1	2
47 Cygni	52. 13	12·51	13·58	− 1·07	1	1	2
δ Trianguli	56. 24	32·75	34·74	− 1·99	1	1	2
χ Cygni	56. 35	29·11	29·45	− 0·34	2	2	4
β Lyræ	56. 47	43·27	43·39	− 0·12	1	4	3
20 Leonis Minoris	57. 23	57·23	57·58	− 0·35	1	1	2
ζ Herculis	58. 8	42·88	43·95	− 1·07	2	2	4
ο Persei	58. 9	8·11	7·95	+ 0·16	1	3	3
A Herculis	58. 37	36·26	36·30	− 0·04	2	5	6
ε Herculis	58. 52	5·22	5·87	− 0·65	3	3	6
ρ Boötis	59. 1	16·49	16·53	− 0·04	2	2	4
26 Aurigæ	59. 35	36·26	36·66	− 0·40	1	1	2
ζ Cygni	60. 20	14·70	14·24	+ 0·46	1	1	2
28 Andromedæ	61. 0	33·98	35·92	− 1·94	1	1	2
β Tauri	61. 30	46·90	46·95	− 0·05	4	11	12
31 Comæ	61. 42	27·91	26·91	+ 1·00	1	1	2
6 Cancri	61. 49	19·33	19·58	− 0·25	3	3	6
14 Comæ	61. 58	1·23	0·95	+ 0·28	1	1	2

EXCESS OF REFLEXION-RESULTS ABOVE DIRECT-RESULTS, FOR OBSERVATIONS OF ZENITH DISTANCE WITH THE TRANSIT-CIRCLE, 1862—*concluded.*

Name of Star.	Approximate N. P. D.	Seconds of R.	Seconds of D.	R.—D.	Number of Obs. R.	Number of Obs. D.	Weight.
	° ′	″	″	″			
ϵ^2 Boötis	62. 20	31 ·82	32 ·04	− 0 ·22	2	4	5
32 Pegasi	62. 21	48 ·86	49 ·61	− 0 ·75	4	5	9
32 Vulpeculæ	62. 27	56 ·15	55 ·81	+ 0 ·34	3	3	6
ψ Boötis	62. 30	43 ·51	44 ·73	− 1 ·22	1	1	2
β Pegasi	62. 39	54 ·15	55 ·12	− 0 ·97	1	3	3
φ Tauri	62. 58	58 ·25	59 ·28	− 1 ·03	1	1	2
μ Leonis	63. 20	41 ·60	41 ·56	+ 0 ·04	1	1	2
89 Herculis	63. 55	33 ·01	33 ·03	− 0 ·02	2	2	4
16 Pegasi	64. 43	21 ·84	23 ·12	− 1 ·28	1	2	3
56 Pegasi	65. 16	33 ·57	33 ·22	+ 0 ·35	1	1	2
52 Arietis	65. 17	3 ·18	6 ·04	− 2 ·86	1	1	2
7 Comæ	65. 17	13 ·89	14 ·48	− 0 ·59	1	1	2
ι Pegasi	65. 19	38 ·99	40 ·61	− 1 ·62	1	1	2
ϵ Leonis	65. 35	31 ·84	32 ·42	− 0 ·58	3	3	6
α Vulpeculæ	65. 36	43 ·65	44 ·29	− 0 ·64	4	4	8
ψ Pegasi	65. 37	33 ·01	31 ·83	+ 1 ·18	2	2	4
μ Pegasi	66. 7	35 ·00	34 ·83	+ 0 ·17	4	6	10
η Tauri	66. 19	26 ·68	29 ·27	− 2 ·59	1	5	3
1 Geminorum	66. 43	59 ·61	59 ·31	+ 0 ·30	1	2	3
17 Vulpeculæ	66. 46	52 ·01	52 ·70	− 0 ·69	1	1	2
2 Boötis	66. 48	13 ·53	13 ·76	− 0 ·23	1	1	2
α Arietis	67. 11	31 ·23	31 ·42	− 0 ·19	2	7	6
μ Geminorum	67. 25	12 ·61	10 ·18	+ 2 ·43	1	8	4
η Geminorum	67. 27	24 ·61	25 ·47	− 0 ·86	1	6	3
δ Geminorum	67. 46	0 ·88	2 ·12	+ 1 ·24	1	4	3
71 Pegasi	68. 15	45 ·19	45 ·36	− 0 ·17	4	4	8
ν Arietis	68. 38	15 ·11	14 ·82	+ 0 ·29	3	5	8
β Arietis	69. 52	5 ·76	5 ·85	− 0 ·09	1	8	4
Arcturus	70. 5	51 ·98	51 ·62	+ 0 ·36	1	6	3
f Boötis	70. 9	3 ·85	2 ·98	+ 0 ·87	1	1	2
γ Herculis	70. 31	12 ·04	13 ·58	− 1 ·54	1	1	2
d^1 Cancri	71. 13	39 ·74	41 ·39	− 1 ·65	1	1	2
τ Boötis	71. 51	12 ·99	15 ·42	− 2 ·43	2	2	4
π Arietis	73. 6	42 ·53	43 ·76	− 1 ·23	1	5	3
Aldebaran	73. 46	17 ·80	17 ·64	+ 0 ·16	1	11	4
α Delphini	74. 34	22 ·12	21 ·75	+ 0 ·37	1	3	3
15 Orionis	74. 34	52 ·82	53 ·20	− 0 ·38	1	1	2
β Leonis	74. 39	23 ·42	23 ·75	− 0 ·33	1	1	2
ϵ Aquilæ	75. 6	59 ·13	59 ·65	− 0 ·52	2	5	6
α Herculis	75. 26	57 ·65	59 ·34	− 1 ·69	1	2	3
α Pegasi	75. 32	13 ·30	12 ·12	+ 1 ·18	1	2	3
ζ Aquilæ	76. 20	19 ·68	20 ·47	− 0 ·79	5	7	12
Regulus	77. 21	34 ·29	35 ·62	− 1 ·33	1	4	3
ξ Leonis	78. 5	27 ·61	28 ·09	− 0 ·48	1	1	2

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.

Extent of Group.	Weight.	Mean N. P. D.	Mean Value of R – D.
		° ′	″
Cephei 51 S.P. to δ Ursæ Minoris	20	0. 25	+ 0·45
B. A. C. 4281 to B. A. C. 1565.......	33	9. 1	+ 0·41
28 Cephei to B. A. C. 1067..........	39	14. 43	+ 0·66
B. A. C. 5887 to B. A. C. 8273.......	77	21. 27	+ 0·22
B. A. C. 1874 to α Draconis..........	31	24. 2	+ 0·60
g Draconis to B. A. C. 3157..........	21	26. 49	+ 0·11
γ^1 Andromedæ to β Lyræ............	31	53. 26	– 0·50
20 Leonis Minoris to 89 Herculis.....	86	61. 2	– 0·29
16 Pegasi to ν Arietis...............	81	66. 39	– 0·17
β Arietis to Aldebaran..............	24	71. 28	– 0·70
α Delphini to ξ Leonis..............	36	75. 50	– 0·54

This table indicates with tolerable clearness the law of R – D; the numbers being without exception positive for stars north of the Zenith, and 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. Assuming the correction to be represented by a formula involving the product of the square of the cosine of the Zenith-Distance into the sine of the Zenith-distance (which formula satisfies the condition of becoming = 0 at the horizon, as it ought to do, when the correction for flexure has been applied) we have the following corrections:

For direct-observations

$$+ 0''\cdot02 - 0''\cdot55 \text{ Sin Z. } \cos^2 \text{Z.}$$

For reflexion-observations

$$- 0''\cdot02 + 0''\cdot55 \text{ Sin Z. } \cos^2 \text{Z.}$$

For use, these 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, 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.

CORRECTION FOR DISCORDANCE OF DIRECT AND REFLEXION RESULTS, 1862.

N. P. D.	Corrections to Results of Direct-Observations.	Corrections to Results of Reflexion-Observations.
°	"	"
− 40	+ 0·04	− 0·04
30	+ 0·09	− 0·09
20	+ 0·15	− 0·15
− 10	+ 0·20	− 0·20
0	+ 0·23	− 0·23
+ 10	+ 0·22	− 0·22
20	+ 0·18	− 0·18
30	+ 0·10	− 0·10
40	+ 0·01	− 0·01
50	− 0·09	+ 0·09
60	− 0·15	+ 0·15
70	− 0·19	+ 0·19
80	− 0·18	+ 0·18
90	− 0·15	+ 0·15
100	− 0·09	+ 0·09
110	− 0·03	+ 0·03
+120	+ 0·01	− 0·01

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

The general system of corrections for R−D which has been followed for many years has been retained, though with a change of law, in the present volume. A careful examination of the different values obtained in different years has convinced me that the quantity is real, but I am still unable to explain perfectly its origin. So long as the evidence for its existence depended on the Mural Circle only, where the flexure of the telescope could not be independently ascertained, it might be attributed to flexure: but its persistent appearance in the observations with the Transit-Circle, where there is no sensible doubt on the magnitude of flexure of the telescope, and where the corresponding correction has been applied, seems to prove that it does not depend on mechanical disturbance of the instrument. The systematic preservation of sign under habitually definite atmospheric circumstances within the observing-room, and the change of sign when the atmospheric circumstances within the observing-room are changed (by different arrangements of the shutters), seem to point to some atmospheric cause. The results for latitude of Greenwich in different years are made most consistent by applying to the direct observations a correction rather greater than $\frac{R-D}{2}$. On these points I would refer the reader to the Introduction to the Seven-year Catalogue, attached to this Volume; or to a paper in volume xxxii. of the *Memoirs of the Royal Astronomical Society*, headed, "On the Discordance between "Reflexion and Direct Observations in Zenith Distance."

The observations of circumpolar stars have been reduced for the determination of latitude in the same manner as in preceding years. The computations below are directed to the determination of the quantity z which ought to be added to the colatitude which has been assumed in the reduction of the observations, namely, 38°. 31′. 21″·80.

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 14 for the first star, 13 for the second, 12 for the third, &c. and assuming numbers proportional to those thence resulting.

CORRECTION TO ASSUMED LATITUDE, 1862.

Star's Name, and Mode of Observation.	Number of Obs.	N. P. D. Uncorrected.	Result Corrected for Discordance.	Number of Obs.	Concluded N. P. D. on assumed Latitude.	Number of Obs.	Algebraic Sum of Determinations.	Weight.	Product.
		° ′ ″	″		″		″		″
Polaris..........D.	55	1. 25. 34·71	34·94	57	34·98	115	+ 0·63	402	+253·26
R.	2	36·16	35·93						
S.P....D.	57	− 1. 25. 34·54	−34·32	58	−34·35				
R.	1	35·39	−35·61						
Cephei 51....... D.	3	2. 45. 11·58	11·81	3	11·81	23	− 0·54	34	− 18·36
S.P....D.	19	− 2. 45. 12·56	−12·34	20	−12·35				
R.	1	12·36	−12·58						
δ Ursæ Minoris... D.	17	3. 23. 49·00	49·23	18	49·18	20	− 0·12	22	− 2·64
R.	1	48·60	48·37						
S.P. D.	2	− 3. 23. 49·52	−49·30	2	−49·30				
β Ursæ Minoris ...D.	2	15. 16. 49·60	49·80	5	49·59	7	− 0·65	16	− 10·40
R.	3	49·65	49·45						
S.P....D.	2	−15. 16. 50·41	−50·24	2	−50·24				
π Draconis.......D.	2	24. 33. 4·51	4·65	2	4·65	3	+ 0·41	7	+ 2·87
S.P....D.	1	−24. 33. 4·36	− 4·24	1	− 4·24				
ξ¹ Cephei ....D.	2	26. 2. 36·58	36·71	2	36·71	3	− 1·26	6	− 7·56
S.P....D.	1	−26. 2. 38·08	−37·97	1	−37·97				
ξ² Cephei ....D.	2	26. 2. 38·56	38·69	2	38·69	3	− 1·04	5	− 5·20
S.P....D.	1	−26. 2. 39·84	−39·73	1	−39·73				

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, $2z + 0''{\cdot}43 = 0$, or $z = -0''{\cdot}22$.

From this the colatitude = 38°. 31′. 21″·58. This is the smallest value that has been obtained for colatitude, being a very little less than that of 1861.

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

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

The *twelfth* column is occupied by the personal equation of each observer, referred to Mr. Dunkin as a standard, deduced from the observations of transits in the year 1861 (see Introduction to Greenwich Observations 1861, page xlvi), as the observations of 1862 are not available for the daily reductions of 1862. 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 $-0^{s}\cdot03$ for the difference of longitude between the position of the Transit-Circle and that of the Altazimuth. This difference of longitude has been obtained by measurement on the plan of the Observatory, of which a reduced copy is attached to the volume for 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

$$\frac{5'}{4}\times\left\{\frac{w}{7\cdot8-p}+\frac{x}{7\cdot7-q}+\frac{y}{7\cdot9-r}+\frac{z}{8\cdot0-s}\right\}$$

or

$$\frac{5'}{4}\times\left\{\frac{w}{7\cdot8}+\frac{x}{7\cdot7}+\frac{y}{7\cdot9}+\frac{z}{8\cdot0}\right\}+\frac{5'}{4}\times\left\{\frac{w}{7\cdot8}\cdot\frac{p}{7\cdot8}+\frac{x}{7\cdot7}\cdot\frac{q}{7\cdot7}+\frac{y}{7\cdot9}\cdot\frac{r}{7\cdot9}+\frac{z}{8\cdot0}\cdot\frac{s}{8\cdot0}\right\}.$$

From the near equality of $\frac{w}{7\cdot8}$, $\frac{x}{7\cdot7}$, &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

$$w \times \frac{5'}{4 \times 7\cdot8} + x \times \frac{5'}{4 \times 7\cdot7} + y \times \frac{5'}{4 \times 7\cdot9} + z \times \frac{5'}{4 \times 8\cdot0}$$
$$+ \frac{1}{4}\left\{w \times \frac{5'}{4 \times 7\cdot8} + x \times \frac{5'}{4 \times 7\cdot7} + y \times \frac{5'}{4 \times 7\cdot9} + z \times \frac{5'}{4 \times 8\cdot0}\right\} \times \frac{p+q+r+s}{7\cdot85}.$$

If the quantity $\frac{1}{4} \times \frac{100''}{7\cdot85} \times (p+q+r+s)$ be called *Correction for Runs for* 100″, then the expression is

$$w \times \frac{5'}{4 \times 7\cdot8} + x \times \frac{5'}{4 \times 7\cdot7} + y \times \frac{5'}{4 \times 7\cdot9} + z \times \frac{5'}{4 \times 8\cdot0}$$
$$+ \frac{1}{100}\left\{w \times \frac{5'}{4 \times 7\cdot8} + x \times \frac{5'}{4 \times 7\cdot7} + y \times \frac{5'}{4 \times 7\cdot9} + z \times \frac{5'}{4 \times 8\cdot0}\right\} \times \text{Correction for Runs for } 100''.$$

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 in the year 1862, 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.

From January 1 to June 18, the intervals were the same as in 1861, namely,—

For wires used in chronographic observations:—

		″
Wire *s*	−	119·80
t	−	71·86
u	−	23·27
v	+	23·78
w	+	71·80
x	+	119·39

For wires used in observations by eye and ear:—

		″
Wire *q*	−	600·65
r	−	360·51
s	−	120·82
x	+	119·20
y	+	360·23
z	+	602·55

These values were obtained in 1861 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°. 18′ (that being the apparent depression of the collimator-mark).

On 1862, June 14 and 16, two wires were found broken. A complete system of new wires was inserted on 1862, June 26.

The intervals of these wires were determined on 1862, July 10, and have been in use from 1862, July 2.

The following are the intervals:—

For wires used in chronographic observations:—

		″
Wire *s*	−	120·34
t	−	72·25
u	−	24·37
v	+	23·98
w	+	72·56
x	+	120·43

For wires used in observations by eye and ear:—

		″
Wire *q*	−	601·19
r	−	360·86
s	−	120·46
x	+	120·31
y	+	360·32
z	+	601·89

For daily observation of the image of the collimator, it is necessary to make use of a single wire, and the wire *u* has in nearly all cases been employed for this purpose. The angular depression of the collimator below the horizon being 12°. 18′, the correction to be made to the Circle Reading with the first system of wires, is ± 23″·27 × secant 12°. 18′ = ± 23″·82; and similarly with the other systems. 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 *u* 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 × cosecant of Zenith Distance. The sign will change according as the Face of the Vertical Circle is Right or Left. The value of Horizontal Correction or Coefficient of Correction for Collimation, Face Right, is given at the bottom of the page; the method by which it is obtained will be explained in a subsequent section.

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

The *twelfth* column contains the Concluded Level Indication. It is assumed 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 [xlviii] to [lxxviii].

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

The *twelfth* column contains a correction which exists theoretically in all cases, but which in the Azimuths is practically insensible, although for the Zenith Distances, more especially those which are observed near the Meridian, it sometimes becomes important. The nature of it is this: In the subsequent calculations it is tacitly assumed that at the mean of the observed times of passage across the six horizontal wires (supposed free from error of observation), the body was at the point which represents the mean of all the six wires. This, however, is true only on the supposition that the vertical movement of the body is uniform. The correction is investigated in the following manner. In the spherical triangle whose sides are a, b, c, and where C is the angle opposite to c, let a and b be respectively the 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 δC be the addition (expressed in parts of the radius), or $\delta C_s \times 15 \sin 1''$ (δC_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 δc (expressed in parts of the radius), or $\delta c_{\prime\prime} \times \sin 1''$ ($\delta c_{\prime\prime}$ 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

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

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

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

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

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

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

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

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

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

Substituting this in the last term, we have

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

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

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

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

Mean of observed hour-angles in seconds of time =

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

As c refers to the point which is the mean of the six wires, $\Sigma . \delta c = 0$. 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, $\delta C_{,} = -\frac{5}{10} \mathrm{I}$; for the second, $\delta C_{,} = -\frac{3}{10} \mathrm{I}$; for the third, $\delta C_{,} = -\frac{1}{10} \mathrm{I}$; for the fourth, $\delta C_{,} = +\frac{1}{10} \mathrm{I}$; for the fifth it is $+\frac{3}{10} \mathrm{I}$; for the sixth, $+\frac{5}{10} \mathrm{I}$. Hence the equation becomes,

Mean of observed hour-angles in seconds of time =

$$C_{s} - \frac{\cot C . 15 \sin 1''}{12} . \frac{70}{100} \times \mathrm{I}^2,$$

$$= C_{s} - \frac{7}{8} . \sin 1'' \times \cot C \times \mathrm{I}^2 .$$

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

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

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

When 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 $+\frac{5}{4} \sin 1'' \times \cot C \times (\mathrm{I}_3)^2$.

When four wires are observed, if I_4 be the interval from the first to the fourth, the correction will be $+\frac{25}{24} \sin 1'' \times \cot C \times (\mathrm{I}_4)^2$.

When five wires are observed, if I_5 be the interval from the first to the fifth, the correction will be $+\frac{15}{16} \sin 1'' \times \cot C \times (\mathrm{I}_5)^2$.

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

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

The *thirteenth* column is occupied by the personal equation (referred to Mr. 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 $\begin{matrix} A & D \\ B & C \end{matrix}$.

When the transits over any number of wires are omitted, the time of transit retained is the mean of the transits actually observed, corrected if necessary for personal equation; but a correction in arc is applied to the circle-reading, corresponding to the interval between the mean of the wires actually observed and the mean of the six wires. Calling the whole system of wires (including both the eye-and-ear and the galvanic wires) in the order in which a star on the West side of the meridian passes them when the Graduated Face of the Vertical Circle is Right, *Q*, *R*, *S*, *T*, *U*, *V*, *W*, *X*, *Y*, *Z*, then the correction to reduce each of the wires to the mean of either system of wires, employed from 1862, January 1 to June 18, is:

For the wires used in chronographic observations,—

Wire	*S*	−	61″·66
	T	−	42·15
	U	−	24·80
	V	+	25·54
	W	+	42·00
	X	+	61·05

For wires used in observations by eye and ear,—

Wire	*Q*	−	301″·34
	R	−	180·54
	S	−	60·03
	X	+	62·14
	Y	+	180·71
	Z	+	299·04

These numbers were obtained by means of the collimator, in the year 1861, 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.

On 1862, June 14 and 16, two wires were found broken. A complete system of new wires was inserted on 1862, June 26.

The intervals of these wires were determined on 1862, July 10, and have been in use from 1862, July 2.

The following are the intervals for wires used in chronographic observations,—

			″
Wire	*S*	−	62·97
	T	−	44·93
	U	−	27·44
	V	+	27·17
	W	+	45·82
	X	+	62·38

For wires used in observations by eye and ear,—

			″
Wire	*Q*	−	302·40
	R	−	180·33
	S	−	61·69
	X	+	63·66
	Y	+	180·72
	Z	+	300·06

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

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

The Barometer, whose reading is contained in the *eleventh* column, is by Simms, with adjustible bag and float: it is placed in a small recess of the dome. Comparisons with the Standard Barometer made between 1860, January 24 and March 11, appeared to indicate that at $29^{in}\cdot0$ the readings of the Altazimuth Barometer require a correction $-\ 0^{in}\cdot03$, and that at $30^{in}\cdot2$ they are correct.

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 Altazimuth Thermometer.
° °	°
From 32 to 42	0·2
43 to 45	0·3
45 to 50	0·4
51 to 55	0·5
56 to 60	0·6
60 to 65	0·7
66 to 70	0·8
70 to 75	0·9
76 to 80	1·0
80 to 83	1·1
84 to 87	1·2
88 to 90	1·3

The readings being too high, the tube was afterwards lowered relatively to the scale by a quantity corresponding to 0°·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 cited at page lviii. This refraction is always additive to the observed zenith distance, and therefore it is added to the Reading of the Vertical Circle when the Graduated Face is Right, and subtracted when it is Left.

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

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

In cases wherein both the upper and the lower limb of the Moon have been observed, one limb is usually defective through want of illumination. A correction for this defect is applied, computed by a method analogous to that used for correcting the zenith-distance of the defective limb of the Moon when observed on the meridian. (See page lvi.) 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 [lxxxi] to [cxvii].

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 thus formed. For stars in the list of the Nautical Almanac, there are applied, to the places given in the Nautical Almanac, corrections fundamentally deduced from the Right Ascensions given in the Greenwich Seven-year Catalogue of 2022 Stars for the epoch 1860 (see page xxxiv). For γ Orionis, observed on March 31, the tabular place was brought up from the Greenwich Seven-year Catalogue (attached to this volume). For the Moon, the Tabular R.A. of Center is formed by interpolating with second differences between the hourly places of the Moon given in the Nautical Almanac, using as argument the Mean Solar Time of the *fourth* column.

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

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

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 $y = \frac{b^2}{\sqrt{\{b^2 + a^2 \text{cotan}^2 l\}}}$; and the distance from the center of the spheroid to the foot of the normal, measured along the Earth's axis, is $\frac{a^2 - b^2}{\sqrt{\{b^2 + a^2 \text{cotan}^2 l\}}}$; or, in parts of the semi-major axis, it is $\frac{a^2 - b^2}{a \sqrt{\{b^2 + a^2 \text{cotan}^2 l\}}}$. 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, $a \times$ [7·7174788] $\times$ sin Moon's N.P.D.; the angle which it subtends as seen from the Moon will be $\frac{a}{\text{Moon's distance}} \times$ [7·7174788] $\times$ sin Moon's N.P.D. = [7·7174788] $\times$ sin Moon's hor. equat. parallax $\times$ sin Moon's N.P.D.; and the value of this in seconds of arc will be [3·0319039] $\times$ sin Moon's hor. eq. par. $\times$ sin Moon's N.P.D.; or [7·7174788] $\times$ seconds of Moon's hor. eq. par. $\times$ sin Moon's N.P.D. In this manner the number in the ninth column has been computed. It is always subtractive.

The assumed colatitude 38°. 31′. 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°. 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:—

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

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

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

The correction to Azimuth for Moon's Semidiameter, in the *first* column of the right hand page, is thus computed. The semidiameter is interpolated with second differences from the Nautical Almanac, without alteration of its constant. 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 $a \times [7{\cdot}71748] \times \cos$ Moon's N.P.D., and therefore her angular semidiameter is diminished in the proportion of Moon's distance to Moon's distance— $a \times [7{\cdot}71748] \times \cos$ Moon's N.P.D., or 1 : 1 − sin hor. eq. par. $\times [7{\cdot}71748] \times \cos$ Moon's N.P.D.: or, using the mean parallax 57′, the proportion is 1 : 1 − $[5{\cdot}93708] \times \cos$ Moon's N.P.D. The correction required is taken out from a small table. The Correction to Azimuth is computed by the formula $\frac{\text{Corrected semidiameter}}{\text{Sine Normal-centric Zenith Distance}}$; the term depending on the difference between the sine of semidiameter and the arc being insensible.

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

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

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

The Normal-centric Semidiameter for the Zenith Distances in the *sixth* column is interpolated from the Nautical Almanac, the only correction required being that for reduction to the foot of the Normal. This correction is $-930'' \times [5{\cdot}93708] \times \cos$ Moon's N.P.D., and is readily tabulated.

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

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

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 [cxx] to [cxxxix].

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 $-0^s{\cdot}03$ 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; the chronometer-interval between the comparisons, which is expressed as an interval of Solar Time, is converted into an interval of Sidereal Time; and the sidereal time at the comparison with the transit-clock, being found by correcting the transit-clock-time for error and rate of the transit-clock, for personal equation, and also for difference of longitude, the sidereal time at the comparison with the South Dome Clock is found, and thus the Error of that Clock is ascertained. From the successive Errors, rates of the Clock are deduced; and the Errors applicable to the observations, and which are given in the sections of Azimuth and Zenith Distance, are computed.

The instrumental constants of correction in Azimuth are thus investigated:—Let w be the correction to the computed tabular azimuth of a high star, depending upon the error in the star's assumed place: w will be an exceedingly small quantity, and will not sensibly vary between the observations made in reversed positions of the instrument. Let x be the constant of correction for error of collimation, taken with that sign which corresponds to the position of the instrument with Graduated Face Right; y the level-indication corresponding to horizontal position of the Horizontal Axis; and z the Zero of Azimuth. Also, let O_r and O_l be the Concluded Readings of Horizontal Circle from observations of a high star, with Face Right and Face Left; C_r and C_l the corresponding computed azimuths; L_r and L_l the level indications; D_r and D_l the zenith distances; and let o_r, o_l, c_r, c_l, l_r, l_l, d_r, d_l, be the similar quantities for a low star. Then the true azimuth of the high star deduced from observation, Face Right, is

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

the computed azimuth corrected is

$$C_r + w\,;$$

hence this observation gives the equation

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

The true azimuth determined from observation, Face Left, is

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

and this observation therefore gives the equation,

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

Subtracting the first equation from the second,

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

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

A similar treatment of the observations of the low star gives

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

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

It has been already stated that, in 1850, a Collimator was mounted, admitting of accurate observation with the telescope of the Altazimuth, and requiring for its observation that the telescope be directed at an angle of 12°. 18′ below the horizon. It is evident that, for the instrumental adjustments, the Collimator may be used as an immoveable 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°. 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 1862.

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, on account of the steadiness of collimation, it appears better to use a mean value of x throughout, a fresh investigation of y is afterwards made from every pair of observations. Thus, let O'_r, O'_l, be the concluded readings of horizontal circle corrected for the error of collimation. Then the first equations are,

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

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

The number y, it is to be observed, corresponds strictly with the horizontal position of the Horizontal Axis of the Vertical Circle, and has no relation whatever to the Level-Zero corresponding to a vertical position of the Vertical Axis of Azimuthal Rotation: except that, supposing the workmanship of the vertical pivots to be perfectly good, and the position of the horizontal axis in its Y's to be invariable, there ought to be a constant difference between them. The latter Level-Zero would be the mean of the level-indications in opposite positions of the instrument: and it would be found with sufficient accuracy for this purpose by taking the mean of the level-indications for positions used in successive observations of the same object (though the instrument was not exactly reversed). The following are the results of comparisons of these Level-Zeros since the erection of the Altazimuth. By inspection of these results, it will be seen that the relative difference between the two zeros had been steadily increasing, the pivot on the same side as the Graduated Face of the Vertical-Circle being too high. This difference may have arisen from a wear of one of the horizontal pivots, or in the bearing of a horizontal pivot, or in one of the vertical pivots. The inconvenience produced by large numerical corrections on account of this discordance became at length so great that an instrumental correction of the error was attempted in 1859, March.

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

Year.	Mean Excess.	Year.	Mean Excess.
	″		″
1848	+ 1·13	1856	+ 13·23
1849	+ 2·33	1857	+ 13·59
1850	+ 6·67	1858	+ 13·70
1851	+ 8·75	1859 Jan. & Feb.	+ 13·75
1852	+ 10·50	1859 Mar. to Dec.	− 4·23
1853	+ 11·36	1860	− 4·91
1854	+ 11·71	1861	− 5·48
1855	+ 12·51	1862	− 6·24

The comparison of the Observed Circle-Reading for a star, corrected for Collimation and Level, with the computed Azimuth for the same star, gives the Zero of Azimuth. Since the time of the establishment of the instrument, this Zero has been subject to greater and more sudden variations than any other element of reduction, and great pains have been taken to discover the source of the instability. In the Introduction to the volume for 1850 will be found an investigation, based on the Theory of Probabilities, for determining the relative stability of the Azimuthal Circle and of the Collimator, and the Error due to the transmission of time from the Transit-Instrument, on the assumption that there is no movement of the ground which carries both the Circle and the Collimator. From this investigation it seemed to be established that the Azimuthal Circle was the most stable part of the instrument, that the fluctuations of the position of the Collimators were somewhat greater, but that the principal source of errors was in the comparison of the circle-reading with the azimuth computed from the time-observation; and, in consequence, it became the practice to rely solely on the stability of the Azimuthal Circle, and, for a limited period, to use the same Zero of Azimuth, determined from the mean of all the separate determinations from star-observations on every day during that period, without special reference to the star-observations of the day of observation. In later years, however, the propriety of this proceeding has become questionable from two considerations; the first of which is that, since the introduction of the galvanic registration of transits, in which one source of error arising from the comparison of clocks is completely removed, the stability of the Zero of Azimuth does not seem at all to have improved; and the second, that there is now 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 1862 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 vertical circle corrected for level; C_r and C_l the computed zenith distances; e the possible error, which will be sensibly the same for both; Z the zenith point. Then we have

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

Subtracting the first from the second,

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

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

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

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 vary much, and the Errors of Tabular Right Ascension and Tabular North Polar Distance may be assumed to be invariable. It is also necessary to take into account, in arranging the form of calculation, that the Error of Tabular Azimuth and the Error of Tabular Zenith-Distance are never observed at the same time.

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

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

m 2

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

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

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

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

By solution of these equations,

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

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

A Table of double entry, appended to the Introduction to the *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* 1862; *and New Constants for Stars in the Catalogue, not observed in preceding Years;* page 1 to 14.

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

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

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

The new star-constants require no further explanation than what is given at pages xlv and lix. 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 Nautical Almanac: with the inferred position of the Ecliptic, the Geocentric Errors of the Sun, Moon, and Planets, in Longitude and Ecliptic Polar Distance, and the Equations between the Geocentric Errors of the Planets and the Heliocentric Errors of the Earth and Planets,* page 15 to 44.

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 81 measures of the value of this error is $+0^{s}\cdot13$, agreeing nearly with the results of the seven 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 87 measures of the value of this error is $+ 1''\cdot11$.

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 θ 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 θ.

The mean of the two errors of Moon's tabular duration of passage in 1862 is $+ 0^{s}\cdot08$.

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 lvi). The value found on June 12 was $+ 0''\cdot25$.

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

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

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

1. Sidereal Time.
2. Mean Solar Time of Transit of first point of Aries diminished by 4^{m}.
3. $3^{m}. 47^{s}\cdot00$ — hours of Sid. Time + solar equiv. for hours.
4. $10^{s}\cdot00$ — minutes of Sid. Time + solar equiv. for minutes.
5. $3^{s}\cdot00$ — 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 1862 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 xxxvi).

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 lxxxv) is first applied to the proper limb, and the mean of the two is then taken without any farther alteration.

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

The observed North Polar Distances of the Moon's Center are taken from the section of *Zenith Distances observed*, &c., corrected solely for the values of $\frac{1}{2}(R-D)$.

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

For all the planets, the Right Ascensions are extracted from the twentieth column of *Transits observed*, &c., with no alteration, except for personal equation when necessary: the North Polar Distances are taken from the last column in the upper part of the page of the *Zenith Distances observed*, &c., corrected for the values of $\frac{1}{2}(R - D)$, as has been previously explained. The tabular places are taken from the Nautical Almanac, for such planets as are given in that work and its appendixes. For all others, the tabular places are taken from the *Berliner Jahrbuch*, 1864.

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

For the *Mean Errors of the Tabular Geocentric Places of the Sun and Planets*, the observations have been collected into groups 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, Juno, and Vesta,

Let R = radius vector of planet, L = planet's heliocentric longitude,
Δ = planet's distance from Earth, λ = planet's geocentric longitude,
r = Earth's radius vector, l = Earth's heliocentric longitude.

Then,

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

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

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

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

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

For the other planets, the following are used:—

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

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

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

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

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

In the expressions above, different quantities are neglected for the small planets and for the other planets. For the small planets, 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 γ Draconis, with the Reflex Zenith-Tube;* page 45 to 48.

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 xix of the present Introduction. For the understanding of the tabular arrangement containing the successive steps of the reduction of the observations, the following explanation will suffice.

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

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

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

and in the other case the value was

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

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

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

The wires used for the bisection of the Star are usually those numbered "15" and "16," and the interval in arc between these wires, as determined in 1861, is 3′. 38″·00. This value has been used without alteration throughout the year 1862. For a few observations made on other wires, the intervals are given in the notes.

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

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

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

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

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

From statements made by 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 = $0^{in.}25$; 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 dismounted in the year 1851, is 116 inches.

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

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

§ 14. *Eclipses, Occultations, and Transits of Jupiter's Satellites, compared with the Nautical Almanac; and Occultations of Stars by the Moon, with the Equations deduced from the Occultations;* page 49 to 57.

The observed times of eclipses, &c. of Jupiter's Satellites, and of occultations by the Moon need little explanation beyond that which is given in the tabular arrangement. The clock used is in general 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 from the following Table, for the principles of the formation of which I refer to preceding volumes, from 1843 to 1849:—

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

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

Let now δ and θ 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; δ' and θ' 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

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

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

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

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

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

(The former 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 δ', in the following manner:—

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

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

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

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

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

When δ' and θ' are found accurately, the distance of the corresponding point from the Moon's center is thus found, by means of a subsidiary angle ψ:—

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

Then log. dist. = log. diff. N. P. D. − log. cos ψ,

or = log. diff. R. A + $\frac{1}{2}$ log. sin N. P. D. of center + $\frac{1}{2}$ log. sin δ' − log. sin ψ.

The coefficients of small variations of the North Polar Distance and of the Difference of Right-Ascension (in the expression for distance), are computed by the formulæ:—

log. 1st number = 2 log. diff. R. A. + log. sine (sum of N. P. D.) − log. dist. + 4·0835.

log. 2nd number = log. diff. N. P. D. − log. distance.

Coefficient of variation of greater N. P. D. = 1st number + 2nd number.

Coefficient of variation of smaller N. P. D. = 1st number − 2nd number.

Log. coefficient of variation of diff. R. A. =

log. diff. R. A + log. sin δ' + log. sin Moon's N. P. D. − log. distance.

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

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

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

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

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

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

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

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

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

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

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

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

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 × $\frac{n}{1000}$; and thus the final equation is formed.

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

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

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

§ 15. *Differential Observations in Right Ascension, East and West of the Meridian, between Mars and Stars, observed with the Great Equatoreal, near the opposition of* 1862, page 59 to 71.

In making the observations the instrument was firmly clamped in Right Ascension, Mars and the comparison stars were then observed over the wires by galvanic contacts. The first eighteen columns require no explanation. The nineteenth column contains the refraction in those cases only where the differences of refraction for Mars and the comparison stars are sensible; the twentieth column contains the application of the refraction to the time of transit. The twenty-first column contains the mean time of observation; the twenty-second the tabular right ascension of the center of Mars at the time of observation, interpolated from the Nautical Almanac, with second differences; the twenty-third column contains the factors of the Sun's mean horizontal parallax.

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 prickers of the galvanic magnets in registration of transits by the Chronographic method are also preserved. The proof sheets are read with the first skeleton forms in which the observations are entered; and in which, in fact, the examination for accidental errors, &c., is made.

G. B. AIRY.

Royal Observatory, Greenwich,
1864, *March* 11.