ON THE INSTRUMENTS IN USE IN AN ASTRONOMICAL OBSERVATORY.

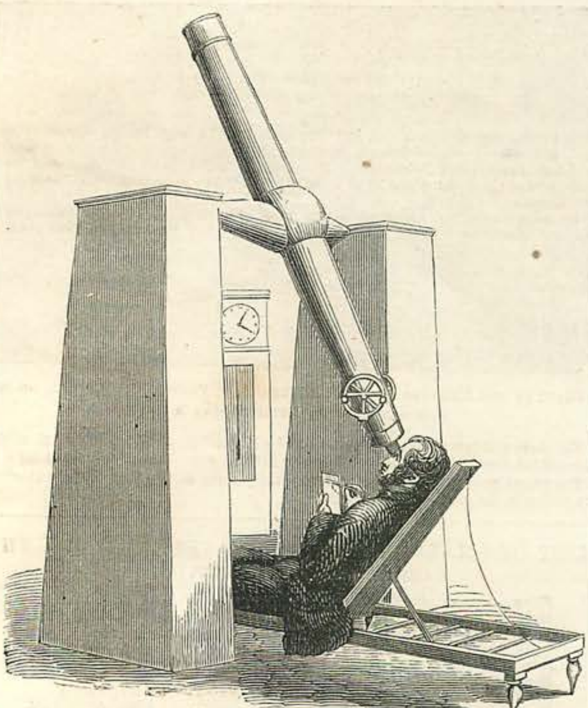
In the various volumes of this work, frequent reference has been made to the Right Ascensions and Declinations, or North Polar Distances of the Heavenly Bodies, for the purpose of pointing out the places in the heavens then occupied by them, and indicating the place to which the eye of the observer or a telescope should be directed for their observation; also the data for showing their places on a globe, and tracing their paths among the stars.

The position of a body on a plane surface, as this sheet of paper, is defined by its distances from two definite points, or two fixed lines, generally at right angles to each other, in the same plane. In a similar manner, the position of a body on a round or spherical surface, may be defined by means of its angular distances from two points, or from two points situated in two great circles of the sphere; as the longitude of a place on the earth's surface, is its angular distance from an assumed meridian, and its latitude the angular distance from the Equator. The intersection of these two lines determines the exact position of any proposed point on the Earth's surface; so, in like manner, the right ascension of a heavenly object is its angular distance measured along the Equator from that point in the heavens, where the plane of the Ecliptic intersects that of the Equator, and which point is called the first point of Aries.

The Declination is the angular distance of the object from the Equator, and is north or south according as the position of the object is north or south of the Equator; the intersection of this distance with that of the right ascension indicates the place of the heavenly body. The angular distance from the Pole is called the polar distance, and if measured from the North Pole, the north polar distance. The Pole is a better point to measure from than the Equator, as there is no consideration respecting north and south. It is the main business of an Astronomical Observatory to determine these two elements, viz., right ascension and declination, or north polar distance of the Sun, Moon, planets, stars, and comets.

Perhaps it would be well to speak here of the instruments employed, and to describe popularly the method of their use.

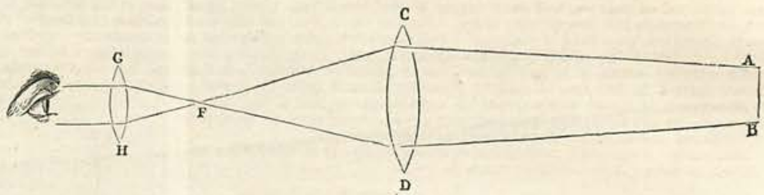
If we visit an Observatory, we shall find in one apartment the Transit Instrument, which is devoted to the determination of one of these elements; and in another apartment the Mural Circle, which instrument is devoted to the determination of the other element.



The Transit Instrument is represented in the above Drawing; it consists of an achromatic telescope, to which is firmly fixed a doubly conical and horizontal axis, at right angles to the optical axis of the telescope; the extremities of the axis are even-turned pivots of steel or bell-metal, which rest on angular bearings called Y's, firmly attached to the inner faces of two solid stone piers, in such positions that the axis of the instrument is horizontal, or nearly so, and such that the telescope can move in the meridian only, or very nearly so. The axis has two adjustments, one for making it horizontal, and the other for adjusting the telescope to the meridian. Two circles are placed near the eye end of the telescope, furnished with verniers, to which a small level is attached, the purpose of which is to enable the observer to direct the telescope to any meridian altitude.*

On looking into the telescope a set of vertical lines (technically called wires) is seen, five or seven in number, and crossed at right angles by one or two horizontal wires. These lines are fine cobwebs, or fine threads, fixed in the telescope to a wire-plate, very near the eye: the stars are seen to pass them successively from one to the other, and across the field.

Near the transit instrument is placed a clock, called the Transit Clock, adjusted to sidereal time, by making its indications of twenty-four hours correspond, or very nearly so, with the interval of time between the consecutive passages of the same star over the meridian; one duty of the transit instrument is to regulate the clock. On looking at an object through a telescope, the object itself is not seen, but only its image formed at the focus of the object-glass. This image, in respect to the object, is inverted; and thus the upper or lower limb of the Sun, Moon, or planets, &c., appears the lower and upper respectively, as seen through the telescope; also the direction of their motions is reversed, causing all heavenly bodies to appear to move from west to east. This is explained by the following diagram :—

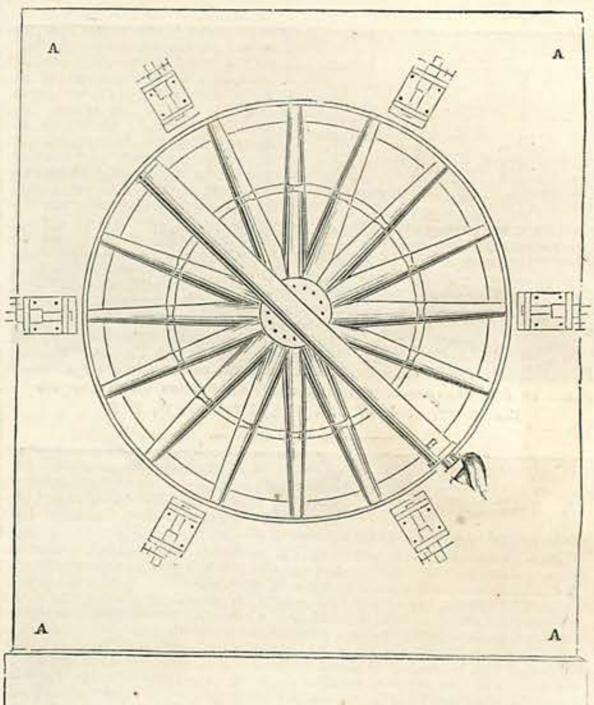


Let A B be a distant object, C D an object glass, F the focus, G H the eye-glass. A ray of light proceeding from A B falls on the object-glass, is refracted or bent by it, and turned in the direction F. The ray from A proceeds as above described, and meets the eye-glass at its lower part; in like manner that at B meets the eye-glass at its higher part: thus the image of the object A B is inverted. In like manner rays proceeding from the sides of the object are inverted, and hence the motions of the heavenly bodies are reversed.

On looking at a star with the naked eye (to the south) the star passes from left to right, but on looking into the telescope, the image of the star is seen to enter at the right hand, and to pass over the wires in succession from right to left. The motion of all stars, as magnified by the telescope, is sensible; those situated near the Equator move very quickly.

On a star approaching the meridian, the observer having directed the telescope to that part of the heavens over which it will pass, looks in and sees both the wires and the image of the star. He then listens to and counts the beats of the clock, recording the second and tenth part of the second in a recording-book, held in his hand, as the star passes each of the separate wires (see the Illustration). By taking the mean or average of these times, the time is determined when the star was on the meridian. In a similar manner he observes the Sun, Moon, planets, &c., and thus finds the time of the clock at which they severally pass the meridian. If now the instrument and the clock were all without error, these times would be the right ascensions of the objects observed, conditions, however, which are never fulfilled; to the times thus found small corrections are to be applied, for the deviations of the instrument from perfect adjustment, and for clock errors.

The clock time at which a well-known star passes the meridian being thus found, the error of the clock is ascertained by comparing this time with its tabular right ascension, published in the "Nautical Almanack," and based upon



THE MURAL CIRCLE.

all the observations made upon that star for many years. Such stars are called clock stars; and the difference found between the clock time and the right ascension of the star gives the error of the clock, and so true time is found.

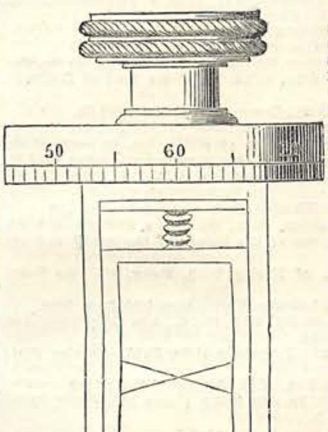
If the clock be so adjusted that the same time be shown at two consecutive passages of the same star, there is no clock-rate, and the error of the clock

* For description of astronomical instruments of different kinds, see the Report of Jury Class X. of the Great Exhibition of 1851.

would be applicable to every object observed between these times. But, if the clock does not exactly show 24 hours in this interval, the difference from 24 hours becomes known, and is the clock's daily rate, and we can calculate a due and proportionate part of this rate at the time of every observation, and thus obtain the same results as though the clock were accurately adjusted. The error of the clock becomes thus known at the time of every observation, and by its application to the clock time, the right ascension is determined.

In an adjoining apartment, in an Observatory, will be found the Mural Circle, which instrument we proceed to describe. The Engraving on the preceding page represents the instrument, in appearance like a wheel: A is a stone pier, several feet in thickness, upon which it is supported. The circle turns round an axis which passes through the pier; its edge, or cylindrical rim, is divided into 360 equal parts, called degrees, and each degree is subdivided into twelve equal parts, and therefore into five minutes of arc; thus the outer rim has engraved upon it 4320 lines, on a band of platinum. The accurate division of this band is a very severe test of the ability of the instrument-maker. To the circle a telescope is attached, which, fr m time to time, can be moved on the circle, so that different parts of its limb may be made to measure the same arc in the heavens. The telescope is furnished with a system of wires similar to that in the transit instrument. Its eye end is also furnished with a wire micrometer—an apparatus adapted to the measurement of small angular spaces.

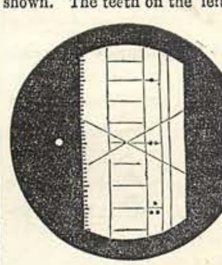
A Micrometer consists of a moving frame, across which one or more wires are stretched, as shown in the annexed figure:—



The whole is moved by the screw, and kept in position by an opposing spring (*b*); the screw carries a head divided into a certain number of parts (usually 60 or 100), one side of the box in which it is enclosed being removed, to show its action:—

The circle, with its telescope, turns round on an axis which passes through the pier, which faces to the east or west; and, consequently, the circle, with its telescope, like the transit instrument, can move only in the meridian; objects, therefore, can beseen only whilst they pass the meridian.

On the face of the pier are firmly attached six microscopes placed equidistant and around the circle. These microscopes are directed to the several divisions on the band of platinum; they are furnished with a wire micrometer, the heads of which are divided into sixty parts, as shown in the preceding figure, and are so adjusted that five turns of the micrometer screw carries the cross wire from one division on the limb to the next; as these divisions are separated by five minutes of arc, each revolution of the screw corresponds to one minute of arc. The micrometer head, carried by the screw, is divided into sixty parts, and, therefore, each part corresponds to one second of arc; the space between two of the parts the observer mentally subdivides into ten parts, and thus measures to the tenth part of a second of arc are noted. On looking through the microscopes at the divisions on the limb, the following is the appearance shown. The teeth on the left hand form what is technically called the comb-plate, and five of its notches correspond to the space of five minutes on the limb. The divisions on the limb of the circle are shown by the short horizontal lines; opposite to one of these divisions to the right is a single dot, opposite to another are two dots, and to a third three dots; and respectively show the value of those divisions to be fifteen minutes, thirty minutes, and forty-five minutes distant from the preceding whole degree. In reading, one angle of the cross wires of the micrometer is bisected by one of the divisions on the limb, as shown in the diagram.

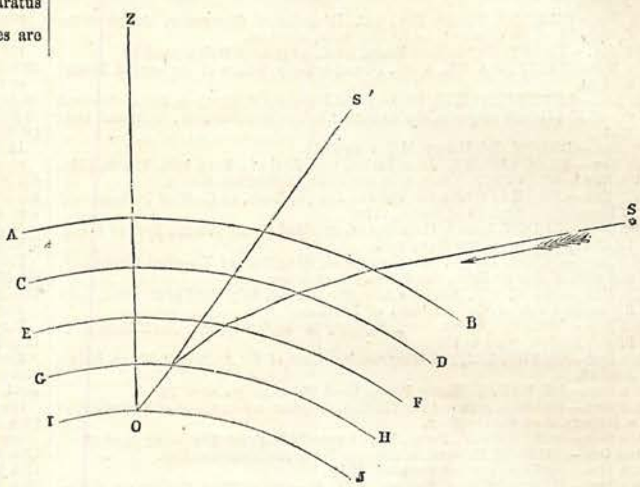


The use of the several microscopes is to avoid the error consequent on the use of one only, which might be caused by faulty divisions or imperfections in the form of the circle.

When a star or object is approaching the meridian, the observer directs his telescope to that part of the heavens over which it will pass, and bisects the star by the micrometer horizontal wire when it is situated on or near the middle wire, then by reading the several microscopes he ascertains the reading of the circle when the telescope was directed to this star. To render this observation available, it is necessary to know the reading of the circle when the telescope is directed to some definite place, as the horizon, the zenith, or the Pole: this point from which to measure is found by the use of a trough of mercury, and is as follows:—The mercury is so placed that on the star approaching the meridian its reflected image can be seen through the telescope, and an observation made as above described; by the time the star has passed the meridian, the telescope may be directed to the star itself, and a second observation made. In the former observation the telescope was directed to a point as much depressed below the horizon, as in the latter it was directed to a point elevated above the horizon; and, from these observations the reading of the circle when the telescope is directed to the horizon, may be found. If to this reading 90 deg. be applied the reading will be found when the telescope is directed to the zenith. If this be used as a starting-point from which to measure, then the difference between this reading and all others will give the apparent angular zenith distance of the several objects observed. It is necessary, however, to remark that every object in the heavens appears to be too high, in consequence of refraction.

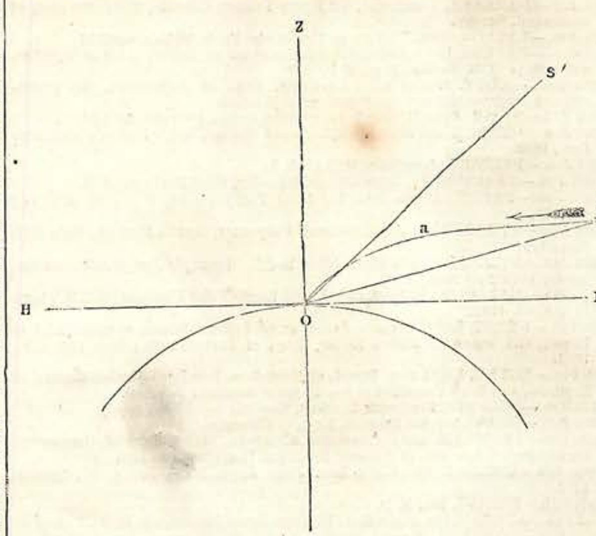
The theory of refraction it may be well to explain, and is as follows:—A ray of light as proceeding from a star, is bent, so as to form a smaller angle with a perpendicular to the surface of the earth, and this bending is increased till the ray reaches the earth's surface, and the object is seen in the direction of the last bend of the ray, causing all objects to appear higher than they really are. This will be understood by reference to the annexed diagram.

Let A B, C D, E F, G H, and I J, represent portions of concentric strata of atmosphere. A ray of light proceeding from a star S, meets successively the several strata, and is continually bent at a different angle; till, finally, it is seen in the direction of S O, and the object seems to occupy the position S'. The increase of density of the atmosphere on approaching the earth follows the law of continuity; so that the ray, in traversing the atmosphere, enters at every instant into a denser medium; its true path is, therefore, curved, as shown in the following diagram, where O represents the place of an observer on the surface of the earth, Z his zenith, H H his horizon, S the place of a star, the



path of the ray will be S A O, and the star will be seen in the direction of O S', and not O S; the difference between the angles S O H and S' O H is what is called atmospheric refraction, the amount of which is to be calculated for every observation, to reduce it to what it would have been had there been no atmosphere.

By determining the elevation of the Pole Star, and other stars situate near the Pole, above the horizon, both when above and below the Pole, the true place



of the Pole may be found; and, consequently, the north polar distance of all objects can be ascertained by adding to the true zenith distances the angular distance of the Pole from the zenith, or the co-latitude of the place.

The declination is found by taking the difference between the north polar distance and 90°. Thus, by the use of the transit instrument, one of the two elements to determine the place of a celestial object is obtained, and by the use of the mural circle, the other necessary element is determined. These being found—in the case of the old planets, are compared with their calculated places, and the differences between them, called errors of tables, form the basis of future calculations to free the tables of such errors. In the case of new planets and comets, their orbits are, in the first place, calculated from the observed right ascensions and north polar distances; and the results of such calculations remain for comparison with future observations, with the view to the improvement of the elements of their orbits.