given by the observations x, the change of declination in half the interval ∆δ, and the observed altitude h, we have

sin h=sin φ sin (δ - ∆δ) + cos φ cos (δ - ∆δ) cos (t+x) and sin h=sin φ sin (δ + ∆δ) + cos φ cos (δ + ∆δ) cos (t -x),

whence, as cosx; may be put=1, sinx=x, and tan∆δ=∆δ,

X sin t tan t J

which, divided by 15, gives the required correction in seconds of time. Similarly an afternoon observation may be combined with an observation made the following morning to find the time of apparent midnight.

The observation of the time when a star has a certain azimuth may also be used for determining the clock error, as the hour-angle can be found from the declination, the latitude, and the azimuth. As the azimuth changes most rapidly at the meridian, the observa­tion is most advantageous there, besides which it is neither neces­sary to know the latitude nor the declination accurately. In the article Geodesy (vol. x. p. 166) it has been shown how the observed time of transit over the meridian is corrected for the deviations of the instrument in azimuth, level, and collimation. This corrected time of transit, expressed in sidereal time, should then be equal to the right ascension of the object observed, and the difference is the clock error. In observatories the determination of a clock’s error (a necessary operation during a night’s work with a transit circle) is generally founded on observations of four or five " clock stars,” these being standard stars not near the pole, of which the absolute right ascensions have been determined with great care, besides observation of a close circumpolar star for finding the error of azimuth and determination of level and collimation error.@@1

Observers in the field with portable instruments often find it inconvenient to wait for the meridian transits of one of the few close circumpolar stars given in the ephemerides. In that case they have recourse to what is known as the method of time deter­mination in the vertical of a pole star. The alt-azimuth is first directed to one of the standard stars near the pole, such as a or δ Ursæ Minoris, using whichever is nearest to the meridian at the time. The instrument is set so that the star in a few minutes will cross the middle vertical wire in the field. The spirit-level is in the meantime put on the axis and the inclination of the latter measured. The time of the transit of the star is then observed, after which the instrument, remaining clamped in azimuth, is turned to a clock star and the transit of this over all the wires is observed. The level is applied again, and the mean of the two results is used in the reductions. In case the collimation error of the instrument is not accurately known, the instrument should be reversed and another observation of the same kind taken. The observations made in each position of the instrument are separately reduced with an assumed approximate value of the error of collimation, and two equations are thus derived from which the clock error and correction to the assumed collimation error are found. This use of the transit or alt-azimuth out of the meridian throws considerably more work on the computer than the meridian observations do, and it is therefore never resorted to except when an observer during field operations is pressed for time. The formulæ of reduction as developed by Hansen in the Astronomische Nachrichten (vol. xlviii. p. 113 sq.) are given by Chauvenet in his Spherical and Practical Astronomy (vol. ii. pp. 216 sq., 4th ed., Philadelphia, 1873). The subject has also been treated at great length by Döllen in two memoirs, Die Zeitbestimmung vermittelst des tragbaren Durchgangs- instrument im Verticale des Polarsterns (St Petersburg, 1863 and 1874, 4to).

*Longitude.—*Hitherto we have only spoken of the de­termination of local time. But in order to compare ob­servations made at different places on the surface of the earth a knowledge of their difference of longitude becomes necessary, as the local time varies proportionally with the longitude, one hour corresponding to 15°. Longitude can be determined either geodetically or astronomically. The first method supposes the earth to be a spheroid of known dimensions. Starting from a point of departure of which the latitude has been determined, the azimuth from the meridian (as determined astronomically) and the distance of some other station are measured. This second station then serves as a point of departure to a third, and by repeating this process the longitude and latitude of places at a considerable distance from the original starting-point may be found. Referring for this method to the articles Earth (Figure of the), Geodesy, and Surveying, we

shall here only deal with astronomical methods of deter­mining longitude.

The earliest astronomer who determined longitude by astronomical observations seems to have been Hipparchus, who chose for a first meridian that of Rhodes, where he observed ; but Ptolemy adopted a meridian laid through the “Insulæ Fortunatae” as being the farthest known place towards the west.@@2 When the voyages of discovery began the peak of Teneriffe was frequently used as a first meri­dian, until a scientific congress, assembled by Richelieu at Paris in 1630, selected the island of Ferro for this purpose. Although various other meridians (*e.g.,* that of Uranienburg and that of San Miguel, one of the Azores, 29° 25' west of Paris) continued to be used for a long time, that of Ferro, which received the authorization of Louis XIII. on 25th April 1634, gradually superseded the others. In 1724 the longitude of Paris from the west coast of Ferro was found by Louis Feuillée, who had been sent there by the Paris Academy, to be 20° 1' 45”; but on the proposal of Guil­laume de Lisle (1675-1726) the meridian of Ferro was assumed to be exactly 20° west of the Paris observatory. Modern maps and charts generally give the longitude from the observatory of either Paris or Greenwich according to the nationality of the constructor; the Washington meri­dian conference of 1884 has recommended the exclusive use of the meridian of Greenwich. On the same occasion it was also recommended to introduce the use of a “uni­versal day,” beginning for the whole earth at Greenwich midnight, without, however, interfering-with the use of local time.@@3

The simplest method for determining difference of longi­tude consists in observing at the two stations some celestial phenomenon which occurs at the same absolute moment for the whole earth. Hipparchus pointed out how ob­servations of lunar eclipses could be used in this way, and for about fifteen hundred years this was the only method available. When Regiomontanus (*q.v.)* began to publish his ephemerides towards the end of the 15th century, they furnished other means of determining the longitude. Thus Amerigo Vespucci observed on 23d August 1499, some­where on the coast of Venezuela, that the moon at 7h 30m P.M. was 1°, at midnight 5½° east of Mars; from this he concluded that they must have been in conjunction at 6h 30m, whereas the Nuremberg ephemeris announced this to take place at midnight. This gave the longitude of his station as roughly equal to 5½ hours west of Nuremberg. The instruments and the lunar tables at that time being very imperfect, the longitudes determined were very er­roneous; see Navigation (vol. xvii. p. 251), to which article we may also refer for a history of the long-discussed problem of finding the longitude at sea. The invention of the telescope early in the 17th century made it possible to observe eclipses of Jupiter’s satellites ; but there is to a great extent the same drawback attached to these as to lunar eclipses, that it is impossible to observe with suffi­cient accuracy the moments at which they occur.

Eclipses of the sun and occultations of stars by the moon were also much used for determining longitude be­fore the invention of chronometers and the electric telegraph offered better means for fixing the longitude of observatories. These methods are now hardly ever em­ployed except by travellers, as they are very inferior as regards accuracy. For the necessary formulæ see Chau-

@@@1 The probable error of a clock correction found in this way from one star with the Dunsink transit circle was ±0s⋅052.

@@@2 This was probably first done in the first century by Marinus of Tyre.

@@@3 This proposal was chiefly dictated by a wish to facilitate the inter­national telegraph and railway traffic. In the United States, where the large extent of the country in longitude makes it impossible to use the time of one meridian, four standard meridians were adopted in 1883, viz., 75°, 90°, 105°, 120° west of Greenwich, so that clocks show­ing “ Eastern, Central, Mountain, or Pacific time ” are exactly five, six, seven, or eight hours slower than a Greenwich mean-time clock.