•circle) is generally founded on observations of four or five “ clock stars," these being standard stars not near the pole, ot 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 α or δ Ursae 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 cock 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 arc 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 formulae of reduction as developed by Hansen in the *Astronomische Nachrichten* (xlviii. 113 seq.) are given by Chauvenet in his *Spherical and Practical Astronomy* ii. 216 seq. (4th ed., Philadelphia, 1873) The subject has also been treated at great length by Döllen in two memoirs : *Die Zeitbestimmung vermittelst des tragbaren Durchgangsinstrument im Verticale des Polarsterns* (4t0, St Petersburg, 1863 and 1874).

*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, and Geodesy, 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 the first meridian that of Rhodes, where he ob­served; but Ptolemy adopted a meridian laid through the “ In­sulae 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 Uraniburg and that of San Miguel, one of the Azores, 29° 25' W. of Paris) continued to be used for a long time, that of Ferro, which received the authorization of Louis XIII. on the 25th of 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° W. 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 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 interfering with the use of local time. This proposal has, however, not been adopted, but instead of it the system of “ Standard Time ” (see below) has been accepted in most countries. Already in 1883 four standard meridians were adopted in the United States, 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. In Europe Norway, Sweden, Germany, Austro-Hungary, Switzerland and Italy use mid-European time, one hour fast on Greenwich. In South Africa the legal time is two hours fast on Greenwτch, &c.@@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 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 the 23rd of 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 ephemeris announced this to take place at midnight. This gave the longitude of his station as roughly equal to 5⅜ hours west of Cadiz. The instruments and the lunar tables at that time being very imperfect, the longitudes determined were very erroneous. 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 formulae see Chauvenet’s *Spherical and Practical Astronomy,* i. 518-542 and 550-557.

We now proceed to consider the four methods for finding the longitudes of fixed observatories, viz. by (r) moon culminations, (2) rockets or other signals, (3) transport of chronometers and (4) transmission of time by the electric telegraph.

I. *Moon Culminations.*—Owing to the rapid orbital motion of the moon the sidereal time of its culmination is different for different meridians. If, therefore, the rate of the moon’s change of right ascension is known, it is easy from the observed time of culmination at two stations to deduce their difference of longitude. In order to be as much as possible independent of instrumental errors, some standard stars nearly on the parallel of the moon are observed at the two stations; these “ moon-culminating stars ” are given in the ephemerides in order to secure that both observers take the same stars. As either the preceding or the following limb, not the centre, of the moon is observed, allowance must be made for the time the semi-diameter takes to pass the meridian and for the change of right ascension during this time. This method was proposed by Pigott towards the end of the 18th century, and has been much used; but, though it may be very serviceable on journeys and expeditions to distant places where the chronometric and telegraphic methods cannot be employed, it is not accurate enough for fixed observatories. Errors of four to six seconds of time have frequently been noticed in longitudes obtained by this method from a limited number of observations: *e.g.* 4·47’ in the case of the Madras observatory.@@4

@@@1 The probable error of a clock correction found in this way from one star is about = 0∙04', if a modem transit circle and chronograph is used

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

@@@3 For a complete list of the standard times adopted in all countries see *Publications of the U.S. Naval Observatory,* vol. iv. aρρ. iv. (Washington, 1906).

@@@4 For field stations the photographic method first proposed and carried out by Captain Hills, R.E., in 1895, may be found advan­tageous. A camera of rigid form is set up and some instantaneous moon-exposures are made, after which the camera is left untouched until a few exposures can be made of a couple of bright stars, which are allowed to impress their trails on the plate for 15 or 30 seconds. If the exact local time of each exposure be known, such a plate gives the data necessary for computing the moon’s position at the time of each exposure, and hence the Greenwich time and longitude *{Memoirs Roy. Asir. Soc.,* 1899, liii. 117).