2. *Signals.—*In 1671 Picard determined the difference of longitude between Copenhagen and the site of Tycho Brahe’s observatory by watching from the latter the covering and uncovering of a fire lighted on the top of the observatory tower at Copenhagen. Powder or rocket signals have been in use since the middle of the 18th century; they are nowadays never used for this purpose, although several of the principal observatories of Europe were connected in this manner early in the 19th century.@@1

3. *Transport of Chronometers.—*This means of determining longi­tude was first tried in cases where the chronometers could be brought the whole way by sea, but the improved means of communication on land led to its adoption in 1828 between the observatories at Greenwich and Cambridge, and in the following years between many other observatories. A few of the more extensive expeditions undertaken for this object deserve to be mentioned. In 1843 more than sixty chronometers were sent sixteen times backwards and forwards between Altona and Pulkowa, and in 1844 forty chrono­meters were sent the same number of times between Altona and Greenwich. In 1844 the longitude of Valentia on the south-west coast of Ireland was determined by transporting thirty pocket chronometers via Liverpool and Kingstown and having an inter­mediate station at the latter place. The longitude of the United States naval observatory has been frequently determined from Greenwich. The following results will give an idea of the accuracy of the method.@@2

Previous to 1849, 373 chronometers . . . 5h 8m 12∙52s

Expedition of 1849, Bond’s discussion . . ιι∙205

„ „ Walker’s „ 12∙065

„ ,, Bond’s second result . 12∙26β ±0∙205

j, 1855, 52 chronometers, 6 trips,

Bond . 13\*49“ =t0∙19β

The value now accepted from the telegraphic determination is 5h 8m 12∙θQβ. The probable errors of the results for Pulkowa- Altona and Altona-Greenwich were supposed to be ≡fc 0\*039“ and ±0-042·. It is of course only natural that the uncertainty of the results for the transatlantic longitude should be much greater, considering the length of time which elapsed between the rating of the chronometers at the observatories of Boston, Cambridge Massachusetts) and Liverpool. The difficulty of. the method consists in determining the “ travelling rate.” Each time a chrono­meter leaves the station *A* and returns to it the.error is determined, and consequently the rate for the time occupied by the journeys from *A* to *B* and from *B* to *A* and by the sojourn at *B.* Similarly a rate is found by each departure from and return to *B,* and the time of rest at *A* and *B* is also utilized for determining the stationary rate. In this way a series of rates for overlapping intervals of time are found, from which the travelling rates may be interpolated. It is owing to the uncertainty which necessarily attaches to the rate of a chronometer during long journeys, especially by land, where they are exposed to shaking and more or less violent motion, that it is desirable to employ a great number. It is scarcely necessary To mention that the temperature correction for each chronometer must be carefully investigated, and the local time rigorously deter­mined at each station during the entire period of the operations.

4. *Telegraphic Determination of Longitude.—*This was first sug­gested by the American astronomer S. C. Walker, and owed its development to the United States Coast Survey, where it was em­ployed from about 1849. Nearly all the more important public observatories have now been connected in this way on the continent of Europe, chiefly at the instigation of the “ Europäische Grad­messung,” while the determinations in connexion with the transits of Venus and those carried out in recent years by the American, French, British and Colonial governments have completed the circuit of the greater part of the globe. The telegraphic method compares the local time at one station with that at the other by means of electric signals. If a signal is sent from the eastern station *A* at the local time .Γ, and received at the western station *B* at the local time 7∖, then, if the time taken by the current to pass through the wire is called z, the difference of longitude is

λ = 7,-Ti+x,

and similarly, if a signal is sent from *B* at the time T2 and received at *A* at *Tt,* we have λ = T\*3-T2-x,

from which the unknown quantity *x* can be eliminated.

The operations of a telegraphic longitude determination can be arranged in two ways. Either the local time is determined at both stations and the clocks are compared by telegraph, or the time determinations are marked simultaneously on the two chrono­graphs at the two stations, so that further signals forelock compari­son are unnecessary. The first method has to be used when the telegraph is only for a limited time each night at the disposal of the observers, or when the climatic conditions at the two stations are so different that clear weather cannot often be expected to occur at both simultaneously, also when the difference of longitude is so considerable that too much time would be lost at the eastern station waiting for the arrival of the transit record of one star from the

western station before observing another star. The independent time determination also offers the advantage that the observations may be taken cither by eye and ear or by the chronograph, but as the observations made with the chronograph are somewhat more accurate than those made by eye and ear, the chronograph should be used wherever possible. This method is the one generally adopted. The method of simultaneous registration at both stations of transits of the same stars has one advantage. Each transit observed at both stations furnishes a value of the difference of longi­tude, so that the final result is less dependent on the clock rate than in the first method, wrhich necessitates the combination of a series of clock errors determined during the night to form a value of the clock error for the time when the exchange of signals took place. When using this method it is advisable to select the stars in such a manner that only one station at a.time is at work, so that the in­tensity of the current can be readjusted (by means of a rheostat) between every despatch and receipt of signals. This attention to the intensity of the current is necessary whatever method is employed, as the constancy of the transmission time (x in the above equations) chiefly depends on the constancy of the current. The probable error of a difference of longitude deduced from one star appears to be@@3for eye and ear transits ±o∙o8β,

for chronograph transits ±0\*07·;

while the probable error of the final result of a carefully planned and well executed series of telegraphic longitude operations is generally between =fcoβ∙o 10 and=t0∙020β.

Wireless telegraphy was for the first time employed in 1906 in a determination of the difference of longitude between Potsdam and Brocken, the signals being sent from Nauen, 32 km. from the former and 183 km. from the latter station. The resulting clock-differences were found to be quite independent of the energy of the electric waves. Wireless telegraphy will no doubt in future be much used in places where it may be desirable to determine the longitudes of a number of stations at the same time.

It is evident that the success of a determination of longitude depends to a very great extent on the accurate determination of time at the two stations, and great care must therefore be taken to determine the instrumental errors repeatedly during a night’s work. But in addition to the uncertainty which enters into the results from the ordinary errors of observation, there is another source of error which becomes of special importance in longitude work, viz. the so-called personal error. The discovery of the fact that all observers differ more or less in their.estimation of the time when a star crosses one of the spider lines in the transit instrument was made by F..W. Bessel in 1820;@@4 and, as he happened to differ fully a second of time from several other observers, this remarkably large error naturally caused the phenomenon to be carefully examined. Bessel also suggested what appears to be the right explanation, viz. the co-operation of two senses in observing transits by eye and ear, the car having to count the beats of the clock while the eye compares the distance of the star from the spider line at the last beat before the transit with the distance at the first beat after it, thus estimating the fraction of second at which the transit took place. It can easily be conceived that one person may first hear and then see, while to another these sensations take place in the reverse order; and to this possible source of error may be added the sensible time required by the transmission of sensations through the nerves to the brain and for the. latter to act upon them. As the chronographic method of observing dispenses with one sense (that of hearing) and merely requires the watching of the star’s motion and the pressing of an electric key at the moment when the star is bisected by the thread, the personal errors should in this case be much smaller than when the eye and ear method is employed. And it is a fact that in the former method there have 'ne∖ur occurred errors of between half and a whole second such as have not infrequently appeared in the latter method.

In transit, observations generally this personal error does not cause.any inconvenience, so long as only one observer is employed at a time, and unless the amount of the error varies with the magni­tude of the star (which is often the case) ; but when absolute time has to be determined, as in longitude work, the full amount of the per­sonal equation between the two observers must be carefully ascer­tained and taken into account. And an observer’s error has often been found to vary very considerably not only from year to year but even within much shorter intervals; the use of a new instrument, though perhaps not differing in construction from the accustomed one, has also been known to affect the personal·error. For a number of years this latter circumstance was coupled with another which seemed perfectly incomprehensible, the personal error’appearing to vary with the reversal of the instrument, that is, with the position of the illuminating lamp east or west. But in 1869-1870 Hirsch noticed during the longitude operations in Switzerland that this was

@@@1 For instance, Greenwich and Paris in 1825 *(Phil. Trans.*, 1826). The result, 9m 21∙6∙, is only about 0\*6“ too great.

@@@2 Gould, *Transatlantic Longitude,* p. 5 (Washington, 1869).

@@@3 Albrecht, *Bestimmung von Längendifferenzen mit Hülfe des electrischen Telegraphen,* p. 80 (4t0 Leipzig, i86ÿ).

@@@4 Maskelyne had in 1795 noticed that one of his assistants observed transits more than half a second later than himself, but this was supposed to arise from some wrong method of observing adopted by the assistant, and the matter was not further looked into.