THE TRANSIT OF VENUS EXPEDITION.

PART II.

DETERMINATIONS OF LONGITUDE AND LATITUDE.

INTRODUCTION TO THE LONGITUDES.

IN order that the reader may more easily follow the various operations detailed in this volume it may be well to begin with a general summary of the whole.

The problem was to determine the longitude of the station at Mauritius where the transit of Venus was to be observed. We very much desired to secure as accurate a result as possible, because the station was likely to become a central one, i.e. to be connected with many other transit of Venus stations.[1] Under these circumstances it was not thought desirable to rely solely upon observations of the moon; and, indeed, the experience of the Americans in determining the longitude of Washington (see Dr. Gould's 'Transatlantic Longitude') seemed to point to the impossibility of determining any longitude by means of observations of the moon without a possible error of two or three seconds of time. Accordingly, Lord Lindsay determined that an attempt should be made to connect Aden with Greenwich by telegraph, and Mauritius with Aden by chronometers.

For the first part of the operation, we knew that the British Government party intended to connect Greenwich and Suez by telegraph. It was also understood that Mr. Hunter (of the British Government party) would remain at Suez to exchange signals with Mr. Gill on his return to Aden after the transit, and that thus the longitude of Aden would be determined.

However, a very short time before Mr. Gill left England for Mauritius it was found that, as the arrangement of the mail steamers would not permit Mr. Gill to leave Mauritius before January 8, 1875, the British observers and their instruments could not be detained in Egypt so long as the end of January, and that therefore some other plan of determining the longitude of Aden must be devised. We at once put ourselves in communication with Professor A. Auwers, of Berlin (secretary to the German Transit of Venus Commission), and with Professor H. G. van de Sande Bakhuyzen, of Leyden, on behalf of the Dutch Government. A reply was

[1] The result has proved that the latter expectation was fully justified, for Belmont has actually been connected with five stations where the transit of Venus was observed, viz. :—

Rodriguez, the British Government station.
Pamplemousses (Mauritius), Dr. Meldrum's station.
Solitude (Mauritius), a German Transit of Venus Commission station.
Réunion, the Dutch Transit of Venus station.
St. Paul, a French Transit of Venus station.

received from Professor Auwers by return of post, to say that the German astronomers, who would leave for Mauritius by the mail following Mr. Gill, would have instructions to co-operate with Lord Lindsay's expedition in every possible way, and that one of the German astronomers would assist in the telegraphic connection of Suez with Aden on the return voyage. Professor Bakhuyzen also wrote to the effect that if the German astronomers could not co-operate in the telegraphic longitudes, one of the Dutch astronomers would certainly do so; and thus, so far, the matter was satisfactorily arranged.

Some months before this chronometers had been hired from the chief makers who had instruments at disposal, and these, to the number of fifty, were sent to the Liverpool Observatory, there to be tested by Mr. Hartnup, in order to determine their temperature coefficients.

On June 14, 1874, Mr. Gill went to Liverpool Observatory, made observations for time, compared the chronometers, and the following day conveyed them by railway to the Royal Observatory, Greenwich. The chronometers remained there until June 18, when they were conveyed by railway to Southampton, and duly mounted in their gimbals in a cabin of the Peninsular and Oriental Steam Navigation Company's steamer 'Mirzapore,' then lying in Southampton Docks.

On June 19 the 'Mirzapore' sailed from Southampton, and reached Malta on June 27. Mr. Gill addressed a letter from the telegraph office, Malta, to Professor Auwers at Berlin, pointing out the possibility of making an independent determination of the longitude of Suez viâ Malta, provided that the consent of the Eastern Telegraph authorities could be secured; and this, the officials at Malta assured Mr. Gill, there would probably be no difficulty in obtaining.

On July 1 the 'Mirzapore' reached Alexandria, and Mr. Gill at once visited Mr. Gibbs, chief of the Eastern Telegraph Company's Mediterranean stations. That gentleman entered with the utmost energy and goodwill into the whole matter, so that a second letter was sent to Prof. Auwers, confirming the possibility of making an independent determination of the longitude of Suez viâ Alexandria, Malta, and Berlin. The following evening the 'Mirzapore' sailed for Suez, where she arrived on July 5. An observing station was selected in an enclosure belonging to the Messageries Impériales.[2]

On July 6 the altazimuth and some chronometers were duly conveyed to this station, and on the 6th, 7th, and 8th observations for time were made; on the 7th and 8th observations were also made for latitude. After the time determination chronometers were transported by boat between the observing station and the ship.

On July 9 the 'Mirzapore' sailed from Suez, and reached Aden on July 15.

The chronometers were at once landed, and conveyed to the police station for safety. On the following day they were removed on board the 'Godavery,' a steamer of the Messageries Impériales about to sail for Mauritius, and mounted in their gimbals in one of the cabins. Cloudy weather prevented observations until July 18, when satisfactory time determinations were secured.

[2] This enclosure belonged formerly to the workshops of the company, and the buildings are still to some extent used as storehouses. Since the opening of the Suez Canal the tools have been removed to Marseilles.

The observing site was nearly opposite the Austrian Consulate, which opens into this enclosure, and the consul kindly undertook to have a brick foundation built to mark the spot, and to form the foundation of the pillar of the transit instrument which would be employed in the telegraphic operations for longitude on the return journey.

On July 19 the night was again cloudy, and on July 20 the 'Godavery' sailed for Mauritius. On August 3 the 'Godavery' reached Réunion, and dropped anchor the following day in the harbour of Port Louis, Mauritius. The same night the altazimuth was set up at Fort George, and an attempt was made to secure observations there, but without success. The night of August 5 was hopelessly cloudy; and on August 6 another attempt was made to determine time at Fort George, but with only partial success.

Seeing that the chances of observation were so precarious at Fort George, and the fatigue of going to and from Pamplemousses extreme, Mr. Gill had one box of the chronometers transported to Pamplemousses by hand, and on the night of August 7 secured observations with the transit instrument of the observatory there. Soon after Mr. Gill's arrival at Mauritius he met Lieutenant Neate, R.N., with the rest of a British Transit of Venus party, whose instructions were, if possible, to connect Rodriguez (their station), by means of chronometers, with Lord Lindsay's station. Application was made by Lieutenant Neate for the loan of Lord Lindsay's chronometers for this purpose, and it was arranged that, as soon as the clocks and transit instrument had been fairly established at Rodriguez, H.M.S. 'Shearwater' should return for the purpose of conveying Lord Lindsay's chronometers to Rodriguez and back. This arrangement was duly carried out, and forty-two of Lord Lindsay's chronometers were put on board the 'Shearwater' on September 8. Two double runs connecting Pamplemousses with Rodriguez were made, the details of which will be found in the account of the 'Rodriguez-Pamplemousses Longitude.' The operations connected with this run extended from September 8 till September 24.

Meanwhile the work of preparing the station at Belmont—levelling the rock, removing loose stones, and making paths between the observatories—had been in progress. Mr. Gill had also made a series of observations for determining the latitude of Pamplemousses. Before the completion of the Rodriguez-Pamplemousses longitude work, the transit hut and photographic room, which had been sent out by the September mail, were erected. After the transit of Venus had been observed, the operations in connection with the longitudes were resumed.

The first steps taken were for the determination of the difference of longitude between Belmont and Solitude (the German station). For this purpose a field telegraph (lent by H.M. War Office) was laid down between Belmont and Poudre d'Or (the nearest railway station), and between Solitude and its nearest station (Union Vale). By this means telegraphic signals were exchanged with Solitude between Dr. Copeland at Belmont and Drs. Löw and Pechüle at Solitude, and, as an additional check, thirty-six chronometers were also transported from Belmont to Solitude and back. The details of this operation will be found under the head of 'Belmont-Solitude Longitude.'

To complete the local longitudes in Mauritius, it still remained to connect Belmont with Pamplemousses. For this purpose the field telegraph which had been laid down between Belmont and Poudre d'Or railway station was utilised, and advantage taken of the railway telegraph wires connecting Poudre d'Or with Pamplemousses railway station, whence Dr. Meldrum's special wire completed the connection between the two observatories. On the evening of January 2, Mr. Gill left Belmont with two light spring carts (carioles), one carrying eight chronometers, the other the altazimuth. On arrival at Pamplemousses, the alt-

azimuth was set up, and observations for time were made the same night and on the night following.

At a prearranged hour the same evening seven rockets were discharged at an intermediate station, five of which were simultaneously observed at Belmont and Pamplemousses. Telegraphic signals were exchanged on January 2 and 3, and on January 4 Mr. Gill returned to Belmont, taking the chronometers with him, so that the transport of chronometers gave a third check on the longitude. The time determinations at Belmont were made by Dr. Pechüle, both Lord Lindsay and Dr. Copeland being prostrated at the time by fever. The details of the operations will be found under the head of 'Belmont-Pamplemousses Longitude.'

The last operations connected with longitude in Mauritius were made for determining the errors of the chronometers before starting on the homeward run, for an account of which the reader is referred to Chapter VIII.

The members of the German Transit of Venus Commission and Mr. Gill sailed from Mauritius in the Messageries steamer 'Dupleix' on the afternoon of January 8, and reached Réunion the following morning. Two chronometers belonging to the Dutch expedition were at once brought on board by Dr. Oudemans, and compared with Lord Lindsay's chronometers. The errors of the Dutch chronometers had been determined on the previous night. Thus the difference of longitude between Réunion and Belmont was determined. The same evening the 'Dupleix' left Réunion for Aden, taking the members of the Dutch expedition —Oudemans (chief), Kaiser, Bakhuyzen, jun., and Soeters—as passengers. On the evening of January 13 the 'Dupleix' dropped anchor off Mahé, Seychelles; but unfortunately was put in quarantine for having touched at Réunion, where several cases of measles were said to have broken out.

This unfortunate circumstance prevented any landing to determine time; and but for the energy of Captain Wharton, of H.M.S. 'Shearwater' (which happened to be at Seychelles at the time), the opportunity of fixing the longitude of this group of islands would have been lost, or at least could only have been determined with the limited accuracy of sextant observations with a sea horizon. At first all communication whatever with the island was strictly prohibited; but at last, after much negotiation, Captain Wharton obtained permission to receive two chronometers, provided they were previously disinfected and allowed to drift astern in a boat with the wind, a rope being attached to the boat to haul it back again. So the chronometers, having been duly sprinkled with vinegar, were put in the boat and drifted off to Captain Wharton, who conveyed them on board his ship, compared them with his own chronometers, and returned them to the boat, which was then hauled back. Captain Wharton and his officers had observed equal altitudes of the sun on that day, and did so on the following day. The very satisfactory results thus obtained will be found in the 'Seychelles-Aden Longitude.' The following morning the 'Dupleix' sailed from Seychelles, and on the evening of January 20 reached Aden. Some chronometers and instruments were landed, and time was determined on the same night.

At Aden it was found that the 'Dupleix' had orders to remain there for ten days, to wait for cargo, and then to proceed to Marseilles for repairs. Thus it became possible, if favoured by the weather, &c., to finish the necessary work at Aden during the stay of the 'Dupleix,' and then to proceed to Suez by the same vessel without transshipping the chronometers. Accordingly Dr. Löw (chief of the German Mauritius Transit of Venus Commission) left Aden on the fol-

lowing day (January 21) by another Messageries steamer, and reached Suez on January 27. He proceeded at once to build a pier for his transit instrument on the site of the foundation which had been arranged for by Mr. Gill, and carefully executed under the kind superintendence of the Austrian consul. On the evening of Saturday, January 30, all was in readiness, and Dr. Löw commenced observations. Meanwhile Mr. Gill had secured several series of observations for time at Aden, so that exchanges of signals for longitude were begun after midnight on Saturday, January 30. On the evening of Sunday, the 31st, signals were again exchanged between Aden and Suez, and again on the early morning of Monday. It was only on Sunday that it was possible to obtain the use of the telegraph cable, and even then it was often necessary to wait some hours for an opportunity to exchange signals. The weather at Aden was very cloudy, and opportunities for observing were few and unsatisfactory; so that it would have been very desirable, if an extremely precise longitude had been required, to wait for further exchanges. But this would have involved another week's delay as well as transshipment of the chronometers. During Mr. Gill's stay at Aden signals were also exchanged by him on Sunday evening and early the following morning with Mr. Chambers, jun., at Bombay. It so happened that Mr. Gill had met Mr. Chambers, of the Bombay Observatory, on the outward voyage as a fellow passenger in the 'Mirzapore,' and had suggested to him the possibility of making a determination of the longitude of his observatory by an exchange of signals with him when at Aden. It was thus that a correspondence was commenced between Mr. Chambers, Director of the Bombay Observatory, and Mr. Gill, which afterwards ended in the determination of the longitude above referred to. The details of these determinations will be found under the head of 'Bombay-Aden Longitude.'

On Monday afternoon, February 1, Mr. Gill sailed from Aden, and arrived at Suez on February 8. Here he found Dr. Löw. Observations were made the same afternoon and evening both by Dr. Löw and Mr. Gill for time and personal equation. Similar observations were made on the 9th, and on the 10th observations were made for personal equation in sending and receiving signals by an artificial cable.

On the 11th Dr. Löw was prostrated by illness, brought on by fatigue; so Mr. Gill undertook to connect the observing station in the enclosure belonging to the Messageries Impériales with the British Government station.[3]

Accordingly the altazimuth was conveyed to Mr. Hunter's station; and observing there with that instrument, and at the other station with Dr. Löw's transit instrument, Mr. Gill determined the difference of longitude between the two stations by transport of chronometers. The details of this operation are given in Chapter XV. Mr. Gill then left for Alexandria, and erected his instrument on the stone roof of the Hôtel de l'Europe, on the site occupied by Mr. Hunter's transit instrument when that gentleman was engaged in the telegraphic operations under Sir George Airy for finding the longitude of Alexandria and Cairo from Greenwich.

On February 19, 20, 23, 24, and 25 signals were exchanged between Suez and Alexandria, and then Dr. Löw came on to Alexandria. Here, on March 3, he again compared personal

[3] When Mr. Hunter arrived in Suez for the purpose of observing the transit of Venus, he did not consider the station selected by Mr. Gill for his longitude purposes a suitable site for observing the transit. He accordingly selected another station (near the flagstaff at the Governor's summer residence), and it was the longitude of this station which he determined.

equation with Mr. Gill, and Mr. Gill also observed to determine his difference of personal equation when observing with his own instrument and that of Dr. Löw.

Meanwhile, on February 27 and 28, signals had been nightly exchanged between Prof. Auwers at Berlin and Mr. Gill at Alexandria; but the weather was not favourable for getting accurate time.

On March 6, 7, and 10 signals were also exchanged between Prof. Auwers and Mr. Gill. By March 11 Dr. Löw had reached Malta and established his observatory there, and the same night signals were exchanged between Malta and Alexandria, and Malta and Berlin. On March 12, 13, and 14 signals were exchanged between Alexandria and Malta, Malta and Berlin, and Berlin and Alexandria direct. On March 15 the exchanges were confined to Malta-Berlin, and the same night Mr. Gill determined the latitude of the station at Alexandria. The following day Mr. Gill measured a series of azimuths of well-known points in the city, by which the position of the site could afterwards be exactly identified. This concluded the longitude operations as far as the connection of Mauritius with a known European longitude is concerned. The final result, however, rests on a wider basis.

Dr. Copeland observed a number of moon culminations at Mauritius with the reversing transit instrument, and a considerable number of occultations were observed by Lord Lindsay, Dr. Copeland, and Mr. Davis. The independent determination of the longitude of Rodriguez by altitudes and transits of the moon by the British Transit of Venus party, and the determination of the longitude of Rodriguez by occultations by the Dutch party, afford additional checks on the main longitude by the chronometric connection of these stations with Belmont or Pamplemousses.

Mauritius being the centre of a group of observing stations, we were anxious that the determination of its longitude should be as accurate as possible. As far as we were aware the observers at the neighbouring stations—Rodriguez (English), Réunion (Dutch), and Mauritius (German)—intended to rely solely on observations of the moon.

Looking to the experience of the Americans, we could not coincide in the opinion that by this method the longitude could be obtained within a second of time.

Dr. Gould, in his account of the transatlantic longitude, determined by submarine cable by the expedition of the Coast Survey in 1866,[4] gives the following note of previous determinations of the longitude of Washington :—

I. From Observations of Eclipses and Occultations.

	h.	m.	sec.
Walker (' Coast Survey Report,' 1851), from observations before 1843 . . .	5	8	11·14
Pierce (' Coast Survey Report,' 1861), from eclipse of 1851, July 28 . . .			11·57
Pierce (' Coast Survey Report,' 1861), from emersions of Pleiades, 1839, September 26			11·45 ± 0·3
Pierce (' MS. Coast Survey Report '), from emersions of Pleiades, 1856–1861 . .			13·13

II. From Moon Culminations.

	h.	m.	sec.
Walker (' Coast Survey Report,' 1851), from Cambridge observations, 1843–1845 .	5	8	10·01
Loomis (' Trans. Amer. Phil. Soc.' x.), from Hudson observations, 1838–1844 . .			9·3
Gilliss (' Wash. Obs.,' 1862, vii.), from Capitol Hill, 1838–1842			10·04
Walker (' Coast Survey Report,' 1851), from Washington, 1845. . . .			9·60
Newcomb (Wash. Obs.,' 1862, lii.), from Washington, 1846–1860 . . .			11·6 ± 0·4
Newcomb (' Wash. Obs.,' 1864), from Washington, 1862–1863			9·8

[4] *Smithsonian Contributions to Knowledge*, No. 223, vol. 16.

III. FROM CHRONOMETERS TRANSPORTED BETWEEN BOSTON AND LIVERPOOL.

	h.	m.	sec.
Indiscriminate [5] mean from 373 chronometers previous to 1849.	5	8	12·46
Bond's [6] discussion of 175 chronometers, expedition of 1849			11·14
Walker's [5] discussion of 175 chronometers, expedition of 1849			12·00
Bond's [7] discussion of 175 chronometers, expedition of 1849			12·20 ± 0·20
Bond's [8] discussion of 52 chronometers, 6 trips, expedition of 1855 . . .			13·43 ± 0·19

Dr. Gould remarks on these as follows (*loc. cit.* p. 5):—

'The discordance of results which individually would have appeared entitled to full reliance is thus seen to exceed four seconds; the most recent determinations, and those which would be most relied upon, being among the most discordant.'

The longitude of Washington deduced from telegraphic exchange is $5^h\ 8^m\ 12^s{\cdot}39$. Professor Newcomb assigned $5^h\ 8^m\ 11^s{\cdot}1$ as the most probable value indicated by the moon culminations observed at the Naval Observatory from 1846 to 1863 inclusive. The mean of the chronometric results is very nearly in accordance with the telegraphic result; nor, indeed, does the mean of the results deduced from occultations of stars differ much from the true result.

It would appear, therefore, that the transport of chronometers, and occultations of stars by the moon, afford, when telegraphic communication is not available, the methods least liable to systematic error for the determination of longitudes.

Considering the possibility of failure in securing a sufficient number of occultations so arranged as to eliminate the errors of diameter, due to irradiation and irregularities of the moon's limb, we were induced to attempt the chronometric connection of Aden and Mauritius, and to determine the longitude of the former station by exchange of telegraphic signals.

The method of determining differences of longitude by means of the transport of chronometers has been employed successfully in several great operations, notably in the following:—

1843 { By Struve, connecting Pulkowa and Altona, 68 chronometers, 8 double trips.
1843 { By Struve, connecting Altona and Greenwich.
1843 { By Airy, connecting Greenwich and Valentia.

1849, 1850, 1851 } By Bond, connecting Cambridge, U.S., and Liverpool.

1855. By Bond, connecting Cambridge, U.S., and Liverpool, 3 double trips.

Besides these there have been the later chronometric expeditions under Otto Struve for the determination of longitudes in various parts of Russia. From all these much valuable information was obtained.

The problem before us was, however, of a much more difficult character. True, the same precision is not demanded in this result, but the conditions under which the experiments had to be made were much less favourable.

In all the above-mentioned operations the chronometers were carried from station E. to station W., then from W. to E., then from E. to W., then W. to E., and so on, the journeys following each other as rapidly as possible.

Thus if the temperature is uniform and other conditions known to affect the rate remain unaltered, the rate is obtained from the time the chronometer leaves the station W. till it returns

[5] *Coast Survey Report*, 1851. [6] *Ibid.* 1850. [7] *Ibid.* 1854. [8] *Ibid.* 1856.

to W. again. Another determination of rate is obtained each time the chronometer leaves E. and returns to the same station: thus a series of overlapping rates is obtained, from which the rate for each journey can be interpolated with the greatest accuracy. Besides this the operations were conducted under conditions extremely favourable as to temperature; the temperature being nearly uniform throughout the journeys or slowly changing.

In arranging results derived from so many observations, it was thought best to adhere as closely as might be to chronological order, although it was first necessary to reduce all the telegraphic longitudes to find the rates of the chronometers during their transport between the stations whose longitudes had thus been determined. To this rule it is necessary to make an exception in the case of the chronometer trials, half of which were made after the return from Mauritius. Ample particulars of these trials, together with an explanation of the principles on which they were conducted, are given in the next chapter.