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DETERMINATION OF THE DIFFERENCE IN LONGITUDE BETWEEN EACH TWO OF THE STATIONS WASHINGTON, CAMBRIDGE, AND FAR ROCKAWAY

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ASSISTANTS
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CONTENTS.

	Page.
General statement	5
The broken telescope transit	6
The chronograph	10
Clocks	12
Description of stations	12
Adjustments of instruments	16
Observing methods	16
Star lists	19
Level values	20
Values of transit micrometer screws	21
Width of contact strips	21
Lost motion	22
Records and computations	25
Weights	27
Stability of the transits	27
Computation of time observations	29
Latitude with the broken telescope transit	40

ILLUSTRATIONS.

Fig. 1.	Broken telescope transit	facing 6
Fig. 2.	Broken telescope transit (another view)	facing 8
Fig. 3.	Chronograph	facing 10
Fig. 4.	Positions of relays on chronograph, and other method of wiring	11
Fig. 5.	Plan of United States Naval Observatory, Washington, D. C.	13
Fig. 6.	Plan of Harvard University Observatory	15
Fig. 7.	Connection of astronomic station at Far Rockaway with Greater New York triangulation	17
Fig. 8.	Correction for lost motion	23

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DETERMINATION OF THE DIFFERENCE IN LONGITUDE BETWEEN EACH TWO OF THE STATIONS, WASHINGTON CAMBRIDGE, AND FAR ROCKAWAY.

By Fremont Morse and O. B. French,
Assistants United States Coast and Geodetic Survey.

GENERAL STATEMENT.

Early in the year 1912 Dr. Helmert, director of the Royal Prussian Geodetic Institute, Potsdam, Germany, suggested to the Superintendent of the United States Coast and Geodetic Survey the desirability of making a direct connection between the longitude nets of the two countries. The improvements in portable transit instruments and in the methods of recording cable signals which have been introduced since former trans-Atlantic determinations make it quite certain that a new determination can be obtained with a probable error considerably less than that of the older ones. Using the four determinations made previous to 1900 Assistant Schott found the probable error of the weighted mean to be ± 0.050 seconds. There is little doubt that a determination may be made at the present time with a probable error of less than ± 0.005 seconds.

Another reason for desiring a new determination lies in the fact that a result of the order of accuracy indicated above will give in connection with future observations, if not with those of the past, data for the settlement experimentally of the question raised by geophysicists whether the distance between the two continents is constant.

A discussion of ways and means of making as accurate a determination as possible led to the plan of using the German cables which cross the Atlantic in two links, one extending from the island of Borkum, in the North Sea, to Fayal, in the Azores, and the other from Fayal to Far Rockaway, on the outer coast of Long Island, N. Y. It was arranged that the German observers should do the cable work, while the American observers should connect the station at the Far Rockaway end of the cables with the United States longitude net. The Borkum station had already been connected with the German net.

As the Harvard University Observatory at Cambridge, Mass., has been used as the initial station for all the United States longitudes, and the United States Naval Observatory at Washington, D. C., had been recently used for a wireless determination between the United States and France, these two stations were selected as the two points of the net to be connected with the Far Rockaway station. And, as the line Cambridge-Washington had been observed before the days of the transit micrometer, a new determination of this line was decided upon.

The plan of the entire work may be briefly outlined as follows: The German plan contemplated beginning observations on July 20, 1914. One observer was stationed at Borkum, a second was located at Fayal, while a third came to Far Rockaway. As these three stations were too far apart to permit the use of the same stars it was planned to exchange cable signals at a specified hour each night for 20 nights, regardless of the weather, and to make time observations whenever the weather permitted. The clock errors on nights when no observations could be obtained were to depend on the rates of the clocks. At the end of the 20 nights the observers at Borkum and Far Rockaway were to change stations, and a second series of exchanges was to extend over 20 nights. The observer at Fayal was to remain at his station during the entire period.

In passing, it may be noted that the German observations were unfortunately ended before the first series of exchanges had been completed by the cutting of the cable soon after the outbreak of the European war.

The American plan of work contemplated the determination of each of the three lines, Far Rockaway-Washington, Far Rockaway-Cambridge, and Cambridge-Washington, by a 10-night series of observations, with an exchange of observers after 5 nights, so as to eliminate personal equation.

While the plan of making the direct connection between Germany and this country was under discussion Dr. Helmert suggested that the entire instrumental outfit of all the parties should be alike, and recommended the use of the Bamberg or broken telescope transit, which had been in use in Germany for some time. Accordingly, two of these transits were purchased by the Coast and Geodetic Survey, together with two chronographs of the fillet type.

THE BROKEN TELESCOPE TRANSIT.

In this instrument the light coming through the objective is reflected at right angles by a prism set in the axis of the telescope, to the eye end, which is in the prolongation of the axis about which the telescope revolves, and outside of the wyes. (Figs. 1 and 2.) The

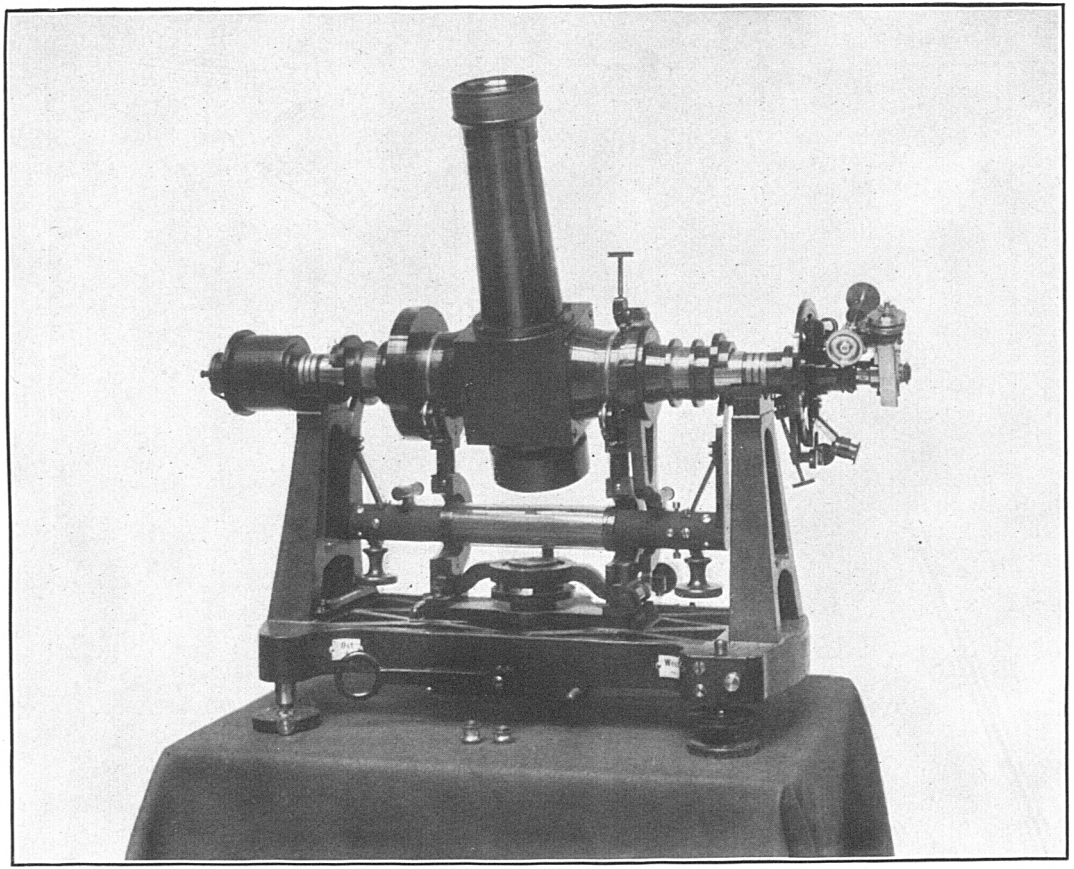

FIG. 1.—BROKEN TELESCOPE TRANSIT.

objective has a clear aperture of 7 centimeters and a focal length of 67 centimeters. The instrument is fitted with an ocular micrometer which records electrically the times of the passage of a star through the field. The micrometer screw has an equatorial value of about 10.5 seconds for one turn, and the head of the micrometer has an agate rim in which are set 10 equidistant metallic strips, each strip being about one one-hundredth of a turn in width. In addition to these 10 strips there are also 2 others, set one on each side of the zero strip and equidistant from it, to provide a means of identifying the marks of the record. A platinum point is pressed by a spring against the surface of the micrometer rim, and as the head is revolved this point makes a contact and completes a circuit each time one of the metallic strips passes under it, and a record is made on the chronograph.

At the opposite end of the telescope axis from the micrometer there is arranged a very small electric light for the illumination of the cross hairs, and the light from it is transmitted through the large prism to the eyepiece by means of a small prism not over one-third of a centimeter in size which is cemented with Canada balsam on the diagonal face of the large prism. The faces of the two prisms must be accurately parallel to allow the passage of the light.

A small setting circle, about 15 centimeters in diameter, is attached to the telescope axis back of the micrometer box at the eye end. This circle carries a movable vernier and level, and reads to 1′. The graduations of the circle are numbered from 0 to 360, and the zero is so placed that the circle reads zenith distances for stars $\frac{\text{north}}{\text{south}}$ of the zenith when the eye end is $\frac{\text{east}}{\text{west}}$; and explements of zenith distances for stars $\frac{\text{south}}{\text{north}}$ of the zenith when the eye end is $\frac{\text{east}}{\text{west}}$.

A reversing apparatus is provided, and attached to it are four friction wheels which run in two grooves cut in the axis of the telescope. These wheels, two of which form a sort of cradle, one on each side of the telescope tube, rest in turn on springs which are sufficiently strong to support the greater part of the weight of the telescope. Thus, only a small part of the burden of the telescope is borne on the pivots and wyes. This reduces flexure to a minimum and permits of the telescope being made heavier and more solid than would be desirable if all the weight were carried on the pivots.

Instead of the usual striding level the instrument is furnished with a hanging level, and to permit of its hanging directly below the axis of the telescope each standard of the reversing gear is cast with a semicircular arc at a point about halfway of its length. Two small cross levels are attached to the hanging level, one near each end, to indicate when it is in proper position for reading.

The frame of the instrument is skeletonized, but strength has not been sacrificed, nor has it been made too light in weight. In size it is 28 by 55 centimeters, with its top 8 centimeters above the top of the pier.

One peculiarity of the construction of the instrument is in the position of the foot screws. These are three in number, two being placed in line at the corners of the frame on the north side, and the third being at the middle of the opposite side. The west foot screw rests in a hole in a footplate; the south one rests on a plane surface of hardened steel on a second footplate, while the east one rests in a V-shaped groove in a third footplate. This groove is cut in a steel block, which is movable in the footplate by means of two abutting screws. The object of this motion is to provide means of setting the instrument in the meridian. When the abutting screws are turned, the whole instrument, frame and all, revolves horizontally about the hole in the west footplate as a center.

In addition to what has already been described, the instrument is provided with detachable twin levels for latitude work. When in use for latitude determinations a second micrometer is employed. This micrometer has no electric connections. It is arranged so that it can be used for time-work, either by the key method or by eye and ear.

The care taken to avoid flexure by supporting the telescope on friction wheels has been mentioned. As another means to this end the telescope is very efficiently counterpoised. Thus, as a balance to the telescope tube, a weight is attached to the opposite side of the axis; as a counterpoise to the ocular micrometer and setting circle the mounting of the illuminating lamp is made heavy; as a balance to the clamp a counterweight is provided on the opposite side; and, finally, when the latitude levels are in use, a counter-disk is attached opposite them.

There are two independent electric circuits in the instrument, one for the illumination of the field and the other for transmitting the record of the transit micrometer, and they are so arranged as to be effective in both positions of the telescope. There are only three wires for the two circuits, one wire being common to both. Hence, in making the connections, the central, or common, wire must be connected with like poles of the two batteries. The two circuits enter the instrument at the southwest corner, where there are four binding posts. Two switches are placed here, by means of which either circuit can be opened or closed. The three wires are insulated and lead along the frame of the instrument to three metal springs, which are fastened to a strip of hard rubber at the top of each standard. These springs press upward against three insulated metal bands in the

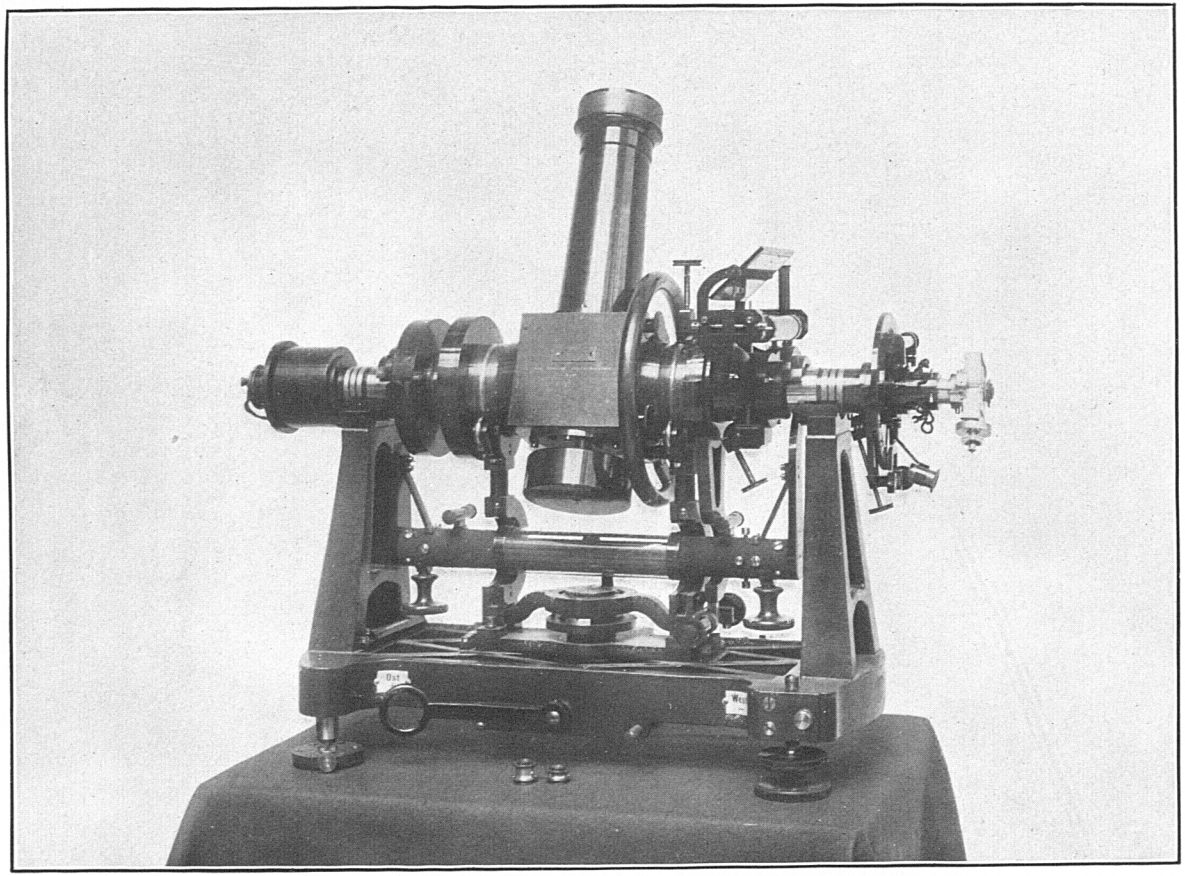

FIG. 2.—BROKEN TELESCOPE TRANSIT (ANOTHER VIEW).

axis just outside the pivots. The outer and middle bands are in the micrometer circuit, and the inner and middle ones are in the illuminating circuit.

It is desirable to describe the micrometer and recording device more in detail. The micrometer screw, with its divided head and metallic strips already mentioned, is provided with a suitable train of beveled wheels, which are in turn connected with an axis located back of and above the micrometer box. This axis has a large milled head at each end for use, one with each hand, in following a star as it transits.

The back of the micrometer box is attached to a tube which fits accurately into the end of the telescope axis. A lug on the tube runs in a slot in the axis, and the slot is made larger than the lug, so as to allow the tube to be rotated through a small angle by means of two abutting screws for adjustment of the verticality of the movable wires. The focusing of the wires is done by moving the tube in or out as required, and a clamp is provided to hold the tube in place after the adjustment for focus is made.

The movable threads of the diaphragm are parallel and three in number. Two of them are placed close together, so that observations may be made by keeping the image of the star midway between them, and the third is separated from the pair by the space of about half a turn of the screw. Observations may be made with this thread by bisecting the star image.

There are six fixed wires in the micrometer. Two of these are intended to indicate the path through which the star transits and are placed about 50 seconds of arc apart and parallel. These are of course at right angles to the movable wires. The other four fixed wires are parallel to the movable wires. Two of them are close together and serve to define the line of collimation; the other two are placed one at each side of the field at a distance of five turns of the micrometer screw from the line of collimation and indicate where the observations on a star begin and end. A small scale on the outside of the micrometer box numbered from 0 to 10 indicates the position of the movable threads. On the west end of the frame of the instrument there is a small plate bearing the inscription "0 R," and on the east end a similar plate is inscribed "10 R." These are intended to remind the observer that in position ocular west the micrometer should be set at 0 revolutions in preparation for the approach of the star; while in position ocular east it should be set at 10 revolutions.

The transit described above can be used also for the determination of latitude by the Horrebow-Talcott method. (See p. 40.)

THE CHRONOGRAPH.

This differs from the ordinary style of chronograph (fig. 3) in being made to use with a fillet or tape. It is a very compact instrument, being mounted on a wooden base 18 by 30 centimeters. The clockwork is contained in a metallic box which measures 7 by 13 by 17 centimeters. It is driven by a weight which is hung in one loop of a sprocket chain, the other loop being occupied by a light counterweight. The chain goes over two sprocket wheels within the box. The speed of the tape is controlled by a fan governor which revolves about a vertical axis, the fans spreading out from the axis as the speed increases. Attached to the chronograph are three relays. One is a starting relay, which, when a switch is thrown, pulls a brake away from a drum on the governor axis and allows the chronograph to start and lets the brake return and stop the machine when the circuit is broken. The second is the micrometer relay, and it is connected by wires with points on the frame of the transit, which are in the micrometer circuit. The third is the clock relay. The micrometer and clock relays are side by side and actuate two armatures which carry needle points. These points puncture the paper fillet and leave a permanent record in the shape of a minute hole every time either circuit is made. The tape or fillet is wound on a reel that stands on top of the box containing the clockwork, and it is fed through a train of wheels by friction. One wheel of the train has a roughened surface, and a friction roller pressed by a spring against this surface causes the paper to be drawn through. There are on the roughened surface of this wheel two grooves cut close together, one to receive each of the two needle points, and thus prevent damage to the points. The starting relay is also so connected with the clock relay that when its circuit is closed that in the clock relay is closed too. All three relays were connected during observations with a double switch placed beside the observing pier, so that one motion set the chronograph going, the clock recording its beats on the tape, and put the micrometer in circuit. A second motion, turning another switch, lighted the lamp for illuminating the cross hairs.

Figure 4 shows the relative positions of the three relays on the chronograph and also the method of wiring the apparatus for this work. The *A* circuit is the one for stopping and starting the chronograph. The clock is connected with the *U* circuit. The *T* circuit is the one used for recording the star transits and the exchange of signals, and hence must include the transit, switchboard, local battery, and preferably the control switch, although the last is not required except for the purpose of making sure that the circuit is broken when desired without watching to see that the contact point is not touching

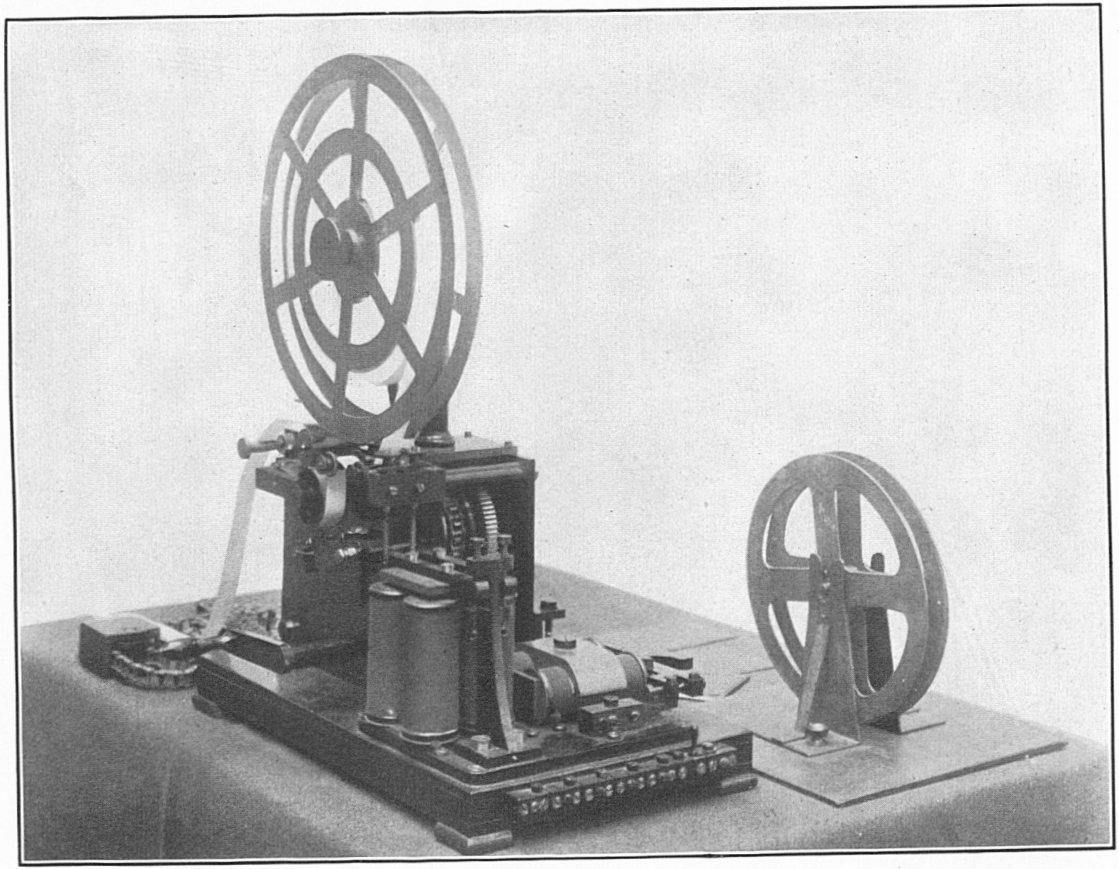

FIG. 3.—CHRONOGRAPH.

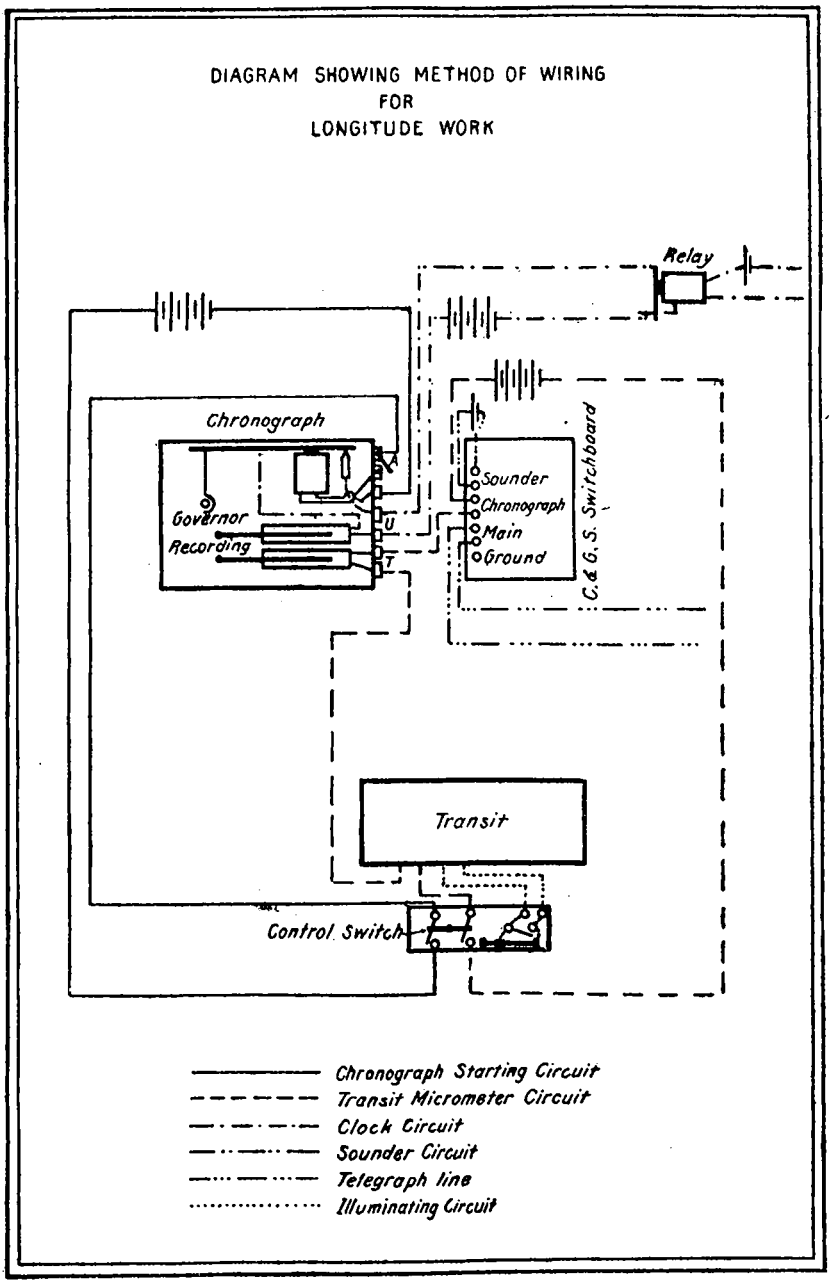

FIG. 4.—POSITIONS OF RELAYS ON CHRONOGRAPH, AND OTHER METHOD OF WIRING.

one of the metal strips. When exchanging signals the contact point was placed on a metal strip in order to complete the circuit, thus using identically the same local circuit for both the transits and signals. The regular Coast and Geodetic Survey switchboard was used in this work.

CLOCKS.

At the Naval Observatory, Washington, D. C., through the courtesy of its superintendent, the use of the standard Riefler sidereal clock was obtained. It is kept in a constant-temperature vault, and is in an air-tight case under constant pressure.

At Far Rockaway the German observer kindly arranged a double relay in connection with his sidereal clock, Dencker No. 27, which he had brought from Germany, so that the clock could be used without interference by both observers. It was hung in a small closet in the basement of the cable building and was under excellent temperature conditions, as was shown by the record of a thermograph kept in the same closet during the observation period.

At Cambridge the director of the Harvard University Observatory kindly had connections made so that the observers had the uninterrupted use of the observatory sidereal clock, Frodsham No. 1327. It is kept in a vault in the basement of the main office building of the observatory, where the temperature is fairly uniform.

DESCRIPTION OF STATIONS.

The Washington station is in the grounds of the United States Naval Observatory, and the observations were made in the eastern of two small houses that had been erected in 1913 for use by the French and United States naval observers in the determination of the difference of longitude between Paris and Washington by wireless telegraphy. Its location with respect to the other buildings in the grounds is shown on the map, figure 5, on which it is numbered "1." At "3" is shown the position of the pier used by the Coast and Geodetic Survey in in 1897 while determining originally the longitude of the Naval Observatory.

As the point of reference for all data at the observatory is the center of the clock room ("9" on map) the following measurements are here given for the reductions to the observatory meridian:

1897 station east of 1914 station 4.53 meters, or 0″.188, or 0.0125 second.
1897 station east of clock room, 0.0691 second.
1914 station east of clock room, 0.0566 second.
1914 station south of clock room 145.73 meters, or 4″.73, agreeing with the value obtained by the Naval Observatory.

The Cambridge station is located in the grounds of the Harvard University Observatory, north of Concord Avenue and between Bond and Madison Streets, Cambridge, Mass. The observatory used was

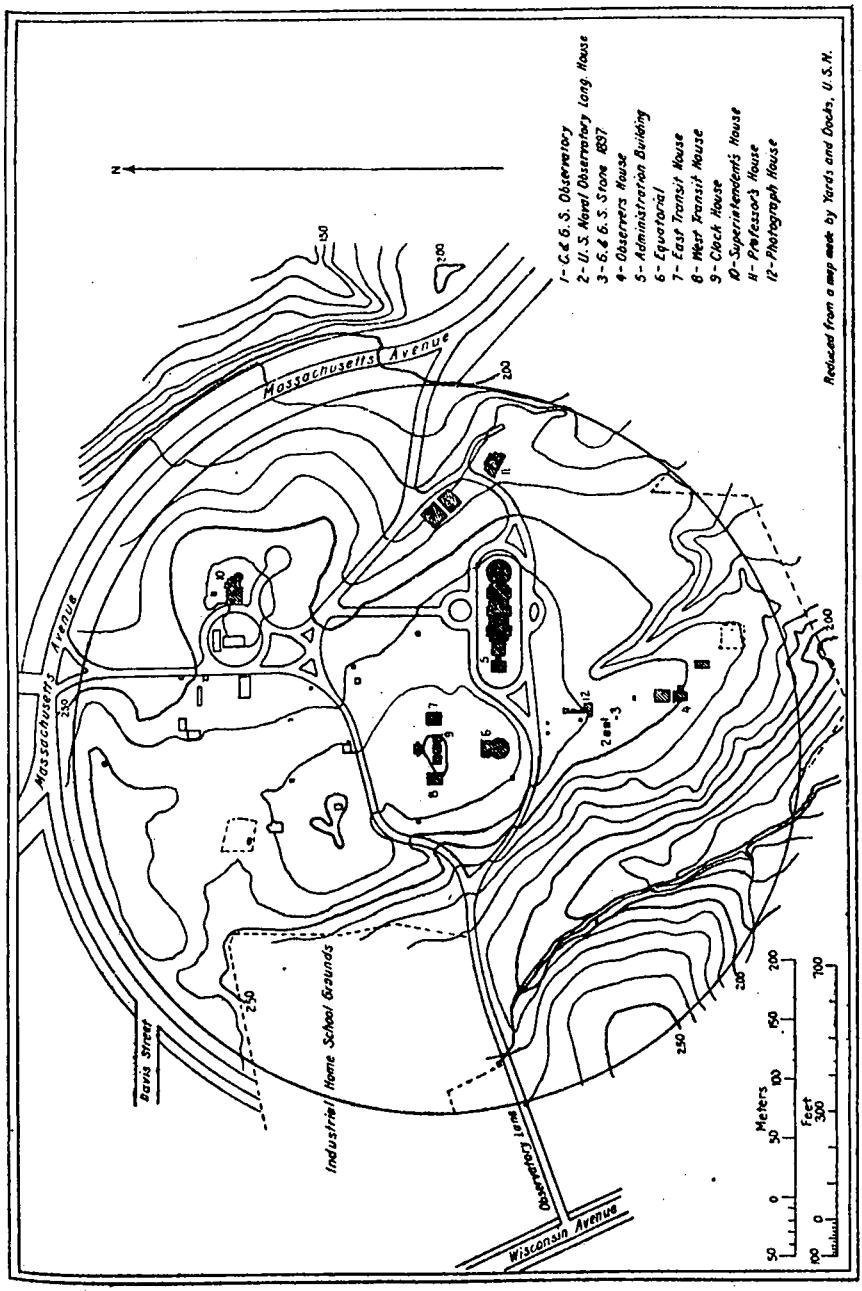

FIG. 5.—PLAN OF UNITED STATES NAVAL OBSERVATORY, WASHINGTON, D. C.

constructed in 1905 for the use of longitude observers. Its location with respect to other buildings in the observatory grounds is shown on the map (fig. 6), where it is numbered "1."

As the point of reference for Harvard College Observatory is the center of the large dome over the Sears equatorial in the middle of the main building, a trigonometric survey was made to connect the observing station with it. The results are as follows:

1914 station west of dome 37.836 meters, or 1″.654, or 0.1103 second.
1914 station north of dome 41.448 meters, or 1″.343.
1914 station west of Russian transit 24.23 meters, or 1″.059, or 0.0706 second.

The Russian transit is mounted on a pier which was erected on the same foundation as the pier used for the Coast and Geodetic Survey observations of 1869, and hence is probably within an inch or two of the old station. From the above figures the Russian transit is west of dome 0.0397 second, agreeing with the value originally obtained for the 1869 station, viz, 0.040 second. The distances for the 1914 station agree with those obtained by Dr. Klotz in 1905. (See Report of Chief Astronomer of Canada for 1905, p. 22.)

The Far Rockaway station is located to the northeast of the building where the cables, which are operated by the Commercial Cable Co., terminate in Far Rockaway, Long Island, N. Y. The building is a large two-story structure on the west side of Grand View Avenue, about half a mile southeast of the Long Island Railroad station at Far Rockaway, and about the same distance from the ocean beach. The observatory building was located just outside the cable company's inclosure on a lot owned by William Caffrey. It was a small shed 8 by 16 feet, with a partition in the middle dividing it into two rooms. The western room was used by the German observer and the other by the United States observers. The distance between the centers of the two observing piers is 2.44 meters, or 0″.1038, or 0.0069 second.

The following measurements were made from the center of the eastern pier:

	Meters.
Nearest corner of fence	9.29
Nearest corner of cable house	15.89
Second corner of cable house	22.28

Figure 7 shows the connection of the United States station with the triangulation of Greater New York, and, in the subsketch, the relative positions of the cable house and station, together with the measurements given above.

The geographic position of the station as deduced from the triangulation is: Latitude, 40° 36′ 00″.249; longitude ,73° 44′ 58″.628, or 4^h 54^m $59^s.9085$.

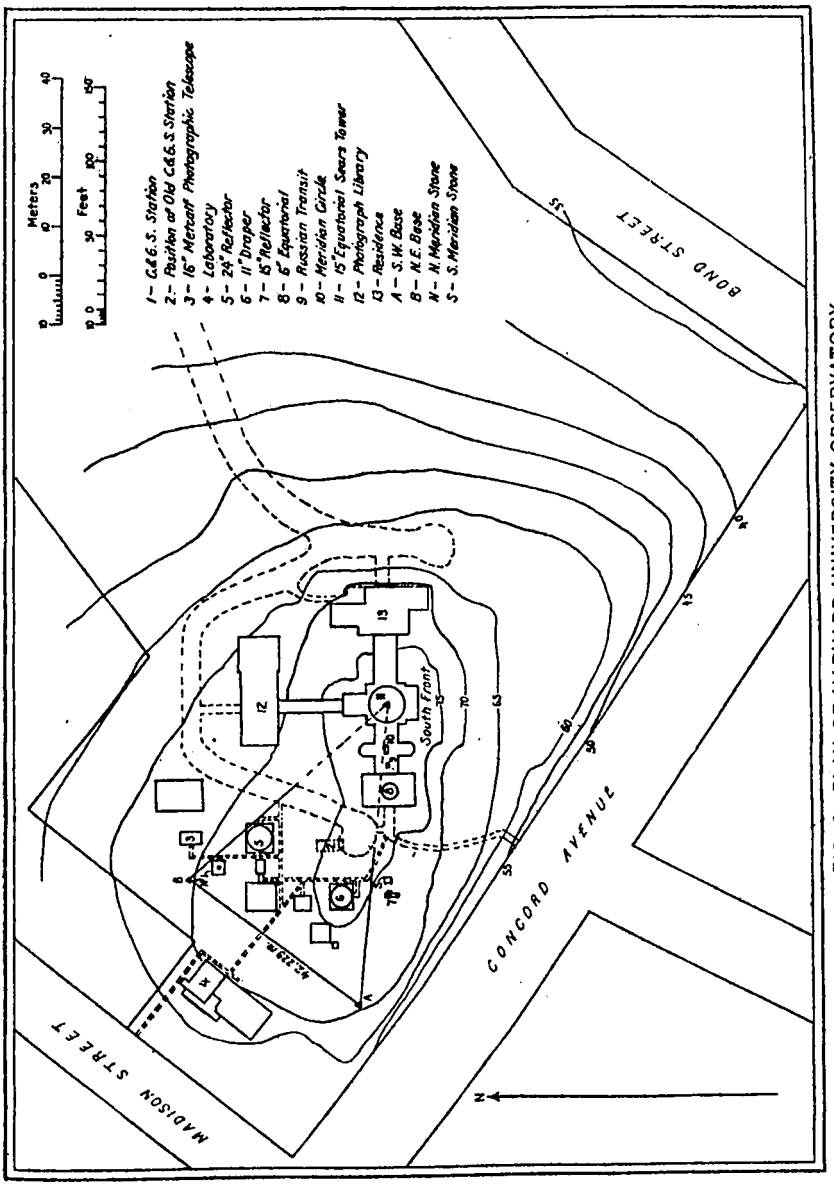

FIG. 6.—PLAN OF HARVARD UNIVERSITY OBSERVATORY.

ADJUSTMENTS OF INSTRUMENTS.

The adjustments of the transit are so similar to those described in Special Publication No. 14 that they need not be repeated here.

The chronograph adjustments are few and mostly obvious. The friction brake should be adjusted so that it barely touches the governor when acting as a brake, thus permitting the use of a weak current through the relay to start the chronograph and keep it going. The recording prick points should be made to fit into the grooves in the friction wheel, and to stand vertical with their tips just far enough from the paper to prevent touching when not recording. Changes in the adjustments of the relays should be avoided during observations and while exchanging signals. If, for any reason, an adjustment becomes necessary during an exchange, all signals sent previous to the adjustment should be rejected and a complete new exchange made.

OBSERVING METHODS.

Below is shown the arrangement of an observing list for one complete time set. In the use of the broken telescope transit the telescope was reversed on each star, thus practically eliminating the collimation correction and also the correction for pivot inequality, if any existed. This reversal made it necessary to set the telescope twice for each star, once for the pointing before reversal and the other after. The first setting given in the observing list is the one to be used when the eye end is in the position shown by the letter preceding it.

Washington, D. C. Latitude, 38° 55′ 14″.

Star No.	Magnitude.	Right ascension.	Declination.	Ocular.	Settings.	
		h m s	° ′		° ′	° ′
5431....	3.9	21 01 48	43 35	W	355 20	4 40
5450....	6.1	07 14	77 47	E	38 52	321 08
5469....	4.3	14 02	39 02	W	359 53	0 07
5512....	6.1	22 16	36 18	E	357 23	2 37
5523....	5.4	26 16	46 10	W	352 45	7 15
5546....	5.1	31 16	38 09	E	359 14	0 46
5567....	5.4	36 48	42 53	W	356 02	3 58

The observing practice was as follows: A short time before the star was due to enter the field, the telescope was set to the right zenith distance by means of the setting circle and level and clamped. Then, without disturbing the telescope, the circle was set for the required pointing after reversal, and the micrometer thread set at the proper side of the field. A few seconds before the star should appear in the field the switch controlling the illumination was thrown and watch was kept for the star. When it appeared the image was brought between the parallel lines defining the center of the field, and when it neared the movable thread the control switch was thrown to start

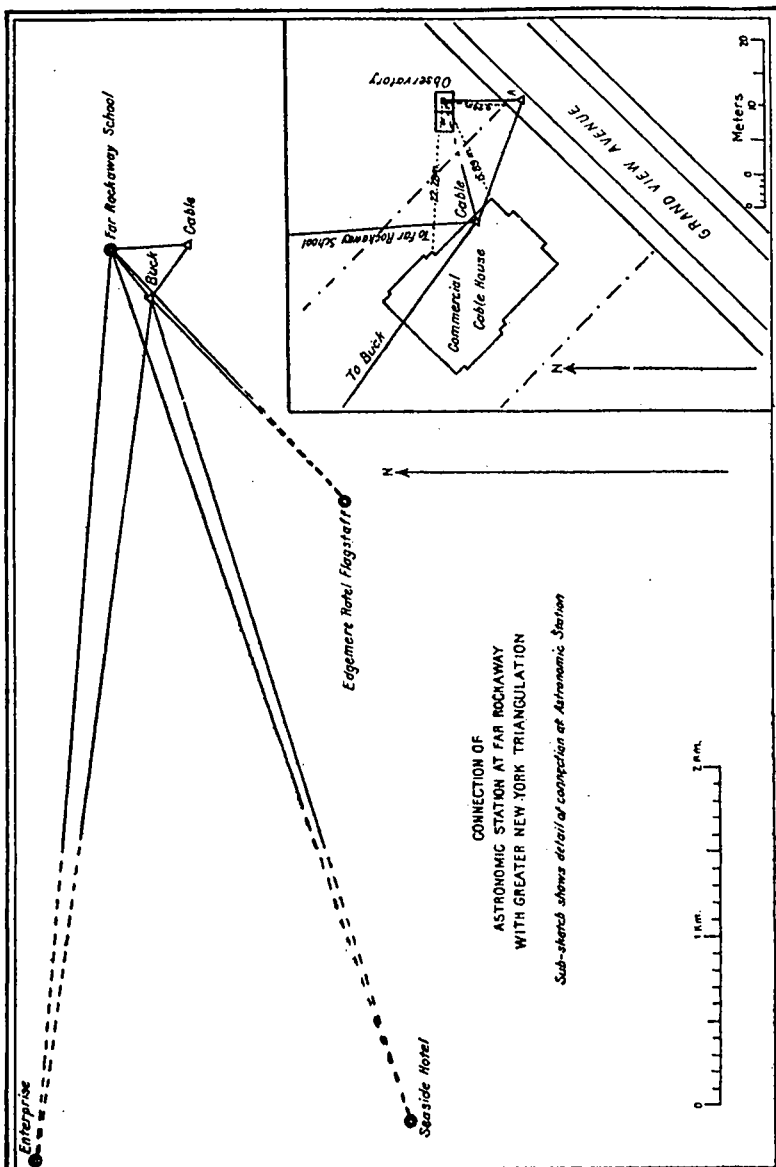

FIG. 7.—CONNECTION OF ASTRONOMIC STATION AT FAR ROCKAWAY WITH GREATER NEW YORK TRIANGULATION.

the chronograph, put the clock in action, and the micrometer in circuit. A note of the number of the star was then made on the fillet, after which the image was followed through about two revolutions of the screw, or sufficiently far to insure two records of the three lines defining the zero of the micrometer head. The two observers differed slightly in some respects in the manipulation of the instrument. Thus, one unclamped the telescope before beginning observations and applied a force of 4 or 5 pounds to the top of the axis just back of the clamp to insure that the pivots were not riding up on the sides of the wyes, while the other kept the telescope clamped. So, also they differed as to the time of making the level readings, one making them just before the passage of the star in each position of the clamp, and the other just after. After the star had been observed in the first position the telescope was reversed and the image followed as it passed the same portion of the micrometer screw as before, the recorded contacts being in reverse order. The illumination was turned off and the chronograph stopped between stars, except in some instances when the interval was short.

A complete night's observations consisted of three time sets with an exchange of signals between the first and second and between the second and third sets. The method of making the exchanges was practically the same as that heretofore followed by the Coast and Geodetic Survey and explained in Special Publication No. 14. When this work was begun the method of sending "breaks" over the telegraph wires was adopted, but on August 6 a trial of both "breaks" and "makes" was made (this being effected by reversing the armature points of the signal relay), which resulted in the use of "makes" for all exchanges subsequent to August 7. It was found that there was a difference of 0.02 second between the results of the "make" and "break" signals, and that the transmission time was about three times as great with the "breaks" as with the "makes." A later comparison of the longitude differences derived from the two sets of signals showed that the "make" results were nearer the final mean value. Hence, the decision to use the "make" signals was fully justified.

For the arbitrary signals the times of sending were regulated by a swinging plummet, so adjusted as to make approximately 58 swings per minute. Thus the arbitrary signals were distributed progressively among the clock signals and possible errors due to eccentricity or irregularity of the gear wheels of the clock were eliminated.

STAR LISTS.

In selecting the stars for these observations the method used by the German and other observers was employed. This consists in using only close zenith stars for the time stars and a circumpolar

for an azimuth star. A complete time set included five or six time stars and one azimuth star. Owing to the restriction of the time stars to those near the zenith and the extra time required in making a reversal on each star, it was necessary, in order to avoid long waits between stars and consequent undue lengthening of the time of observation, to have recourse to a more extended catalogue than that published in the American Ephemeris, and accordingly "A Preliminary Catalogue of 6,188 Stars, Epoch of 1900, by Lewis Boss," was used to supplement the American Ephemeris list. Such stars as were available were selected from the latter catalogue and the lists were then filled out from the Boss stars. This increased the amount of computation, since the apparent places of the Boss stars had to be computed. A slight correction was applied in every case to the American Ephemeris star places when they differed from the Boss values. No time star was selected which had an azimuth factor greater than 0.3, and each time set was so nearly balanced that the algebraic sum of the azimuth factors was less than 0.3. To make these conditions hold for both stations of a line (the same stars being observed at each) the number of available stars was necessarily limited, and hence more time was required for a complete set than would have been the case if such rigid conditions had not been imposed. The only conditions as to the azimuth star were that it should not be under 70° in declination, and preferably not over 80°, and that if practicable it should be chosen from the American Ephemeris list in order to insure the use of better determined stars and to avoid computation of apparent places.

The list of stars used at Washington while working on the Washington-Far Rockaway line is given on page 20. It differs from similar lists published in Special Publication No. 14 only in the introduction of the column headed "*l*." This gives the combined correction for width of contact strips and lost motion to be described later.

Star lists. Far Rockaway and Washington.

MEAN PLACES, 1914. WASHINGTON FACTORS.

Star.	Magnitude.	Right ascension.	Declination.	Zenith distance.	C	B	A	l	κ
		h m s	° ′ ″	° ′				s	s
I.									
*4403	5.8	17 17 26.453	32 34 39	S 6 20.6	1.19	1.18	+0.12½	+0.06	−0.02
4430	6.0	24 27.412	48 19 54	N 9 24.7	1.50	1.48½	− .24½	+ .07½	− .02½
4455	6.0	30 23.505	41 18 13	N 2 23.0	1.33	1.33	− .05½	+ .06½	− .02
*4479	3.8	37 02.178	46 03 05	N 7 07.8	1.44	1.43	− .18½	+ .07½	− .02½
*4504	5.0	43 27.906	72 11 29	N33 16.2	3.27	2.73	−1.79½	+ .16½	− .05
4522	5.2	50 30.067	40 01 25	N 1 06.2	1.31	1.30½	− .02½	+ .06½	− .02
*4538	4.0	54 25.351	29 15 23	S 9 39.8	1.14	1.13	+ .19½	+ .06	− .02
II.									
*4672	3.6	18 22 36.528	72 41 45	N 33 46.5	3.36	2.79½	−1.87	+ .17	− .05
4702	5.6	29 32.632	30 29 19	S 8 25.9	1.16	1.15	+ .17	+ .06	− .02
*4722	0.0	34 01.603	38 42 11	S 0 13.1	1.28	1.28	+ .00½	+ .06½	− .02
4742	5.8	40 37.756	31 50 30	S 7 04.7	1.18	1.17	+ .14½	+ .06	− .02
*4776	4.0	46 54.278	33 15 44	S 5 39.5	1.20	1.19	+ .12	+ .06	− .02
4811	6.0	52 31.032	48 45 05	N 9 49.8	1.51	1.49½	− .26	+ .07½	− .02½
4846	5.2	59 00.378	46 48 44	N 7 53.5	1.46	1.44½	− .20	+ .07½	− .02½
III.									
*4986	3.0	19 27 15.171	27 46 42	S 11 08.5	1.13	1.11	+ .22	+ .05½	− .02
*5014	4.5	34 08.090	50 01 17	N 11 06.0	1.56	1.52½	− .30	+ .08	− .02½
*5045	5.1	41 10.471	37 08 45	S 1 46.5	1.25	1.25½	+ .04	+ .06½	− .02
*5079	3.9	48 28.249	70 02 56	N 31 07.7	2.93	2.51	−1.51½	+ .15	− .05
5113	5.6	54 14.719	40 08 10	N 1 12.9	1.31	1.31	− .03	+ .06½	− .02
5137	5.3	58 55.604	49 51 53	N 10 56.7	1.55	1.52	− .29½	+ .08	− .02½
5157	5.7	20 03 10.062	35 44 06	S 3 11.1	1.23	1.23	+ .07	+ .06	− .02
IV									
*5280	6.6	20 30 23.416	72 14 25	N 33 19.2	3.28	2.74	−1.80	+ .16½	− .05
*5320	1.0	38 29.979	44 58 21	N 6 03.1	1.41	1.40½	− .15	+ .07	− .02½
*5336	2.5	42 43.867	33 38 51	S 5 16.4	1.20	1.19½	+ .11	+ .06	− .02
5365	5.1	47 01.583	43 44 05	N 4 48.8	1.39	1.38	− .11½	+ .07	− .02½
*5393	4.0	53 57.950	40 50 07	N 1 54.9	1.32	1.32	− .04½	+ .06½	− .02
5416	6.7	59 02.071	39 10 09	N 0 14.9	1.29	1.29	− .00½	+ .06½	− .02
*5433	5.5	21 03 02.490	38 19 33	S 0 35.7	1.27½	1.27½	+ .01½	+ .06½	− .02
V.									
5519	5.9	21 24 27.688	31 50 53	S 7 04.4	1.17½	1.17	+ .14½	+ .06	− .02
5539	5.8	29 54.230	49 35 45	N 10 40.5	1.54½	1.51½	− .28½	+ .08	− .02½
5557	7.0	34 19.067	38 55 46	N 0 00.5	1.28½	1.28½	.00	+ .07	− .02
5579	5.8	38 55.170	40 41 02	N 1 45.8	1.32	1.32	− .04	+ .07	− .02
5617	5.3	46 02.366	29 46 24	S 9 08.8	1.15	1.13½	+ .18	+ .06	− .02
*5640	6.9	51 47.079	73 17 43	N 34 22.5	3.48	2.87	−1.96½	+ .18½	− .05½
5669	5.7	59 28.345	44 14 05	N 5 18.8	1.39½	1.39	− .13	+ .07½	− .02½

*These stars are also in the American Ephemeris.

LEVEL VALUES.

The values of the hanging levels of the instruments were determined at the office both before and after the longitude observations. The two series of determinations differ slightly, but as the later determinations were made with the level vials mounted as in actual use and with the length of bubble as nearly as possible the same as

that used in the field they were deemed more nearly correct and hence were used in the final computations.

The adopted values for one division of the hanging levels are:

Transit No. 20, 1.″086±0.″004; 1/60=0.0181 second.
Transit No. 21, 1.″200±0.″002; 1/60=0.0200 second.

VALUES OF TRANSIT MICROMETER SCREWS.

Observations to determine the values of one turn of these screws were made several times during the season. As they are needed only for the purpose of finding the width of the contact strips and the lost motion of the screws, great accuracy is not required. Slow-moving stars were used in some cases and convenient time stars in others, the passage of the stars being followed through the field from the 0 to the tenth turn and in both directions, and the record made on the chronograph. Results obtained from time stars were quite as accordant as those from slow moving stars, and required much less time. The mean of all values obtained for each screw was adopted.

Equatorial value of one turn for transit No. 20=10.524 seconds±0.0006 second.
Equatorial value of one turn for transit No. 21=10.541 seconds±0.0006 second.

WIDTH OF CONTACT STRIPS.

The record on the chronograph is made the instant the electric circuit is closed as the micrometer screw is turned; that is, when the metal contact point touches the edge of a contact strip. As the telescope is reversed on each star, it is evident that the contact point touches the other edge of the strip first after reversal; hence the records are all made too early by one-half the time required for the point to cross the full width of the strip.

These widths are determined as follows: Having the instruments mounted and wired ready for observations, throw the control switch beside the transit pier on circuit and the small switch at *A* (fig. 6) off contact, thus breaking all the circuits except that of the micrometer. Then turn the micrometer screw very slowly, stopping the instant the click of the chronograph relay is heard. Note the reading of the micrometer and then move the contact point across the strip and bring it back into contact by turning the screw in the opposite direction, and again note the micrometer reading. The difference of the two readings is the effective width of the strip in terms of the screw. Each full determination consists of such readings for two complete revolutions of the screw.

Continued use of the micrometer with frequent sparking between the strips and the point causes a wearing of the edges. Hence frequent observations should be made. It was the practice for each observer to determine contact widths three times during each separate occupation of each station, once before beginning the longitude

work, again at about the middle of the observations, and finally at the end. The mean of all three was used for the computations during that period.

The correction l' to be applied to the mean of the star transits for error due to the width of the contact strips is

$$l' = 1/2\, Rs \sec. \delta, \qquad (1)$$

R being the equatorial value of one division of the micrometer screw,

s, the value of the width of the contact strip expressed in terms of one division of the screw; and

sec. δ, the correction for declination, or the C of the A, B, C factors used in time computations.

LOST MOTION.

In any screw working against a spring there is probably always a certain amount of lost motion. In this case, although the lost motion is small, it is usually in the same direction, and if neglected will cause a systematic error.

To determine its amount the movable wires of the micrometer were pointed upon the fixed wires at either side of the field and also on the fixed threads defining the line of collimation in order to get the value for different positions of the screw. Pointings were made first by turning the screw in one direction and then in the other. The difference of the readings is the lost motion in terms of the screw, and the correction to be applied to the mean of the star transits for error due to this cause is

$$l'' = 1/2\, Rm \sec. \delta, \qquad (2)$$

R being as before the equatorial value of one division of the screw,

m, the lost motion expressed in terms of one division of the screw, and

sec. δ, the correction for declination, as before.

To show how this correction is deduced, suppose that 1, 2, and 3 in figure 8 represent three successive recording positions of the movable thread while following a star going in the direction indicated by the arrow, before reversal of the telescope, and when the screw is being revolved so that it is compressing the opposing coiled springs. Suppose, further, that the thread is stopped at 4 after the record has been made. Now, let 4, 3, 2, and 1 represent like positions of the thread after reversal of the telescope on the assumption that there is no lost motion in the screw.

If there is lost motion, then, as the observer starts to follow the star (still going in the same direction), the movable thread will lag behind its proper position and instead of taking the positions 3, 2, and 1 it

will be at the points indicated by the dotted lines 3′, 2′, and 1′, and it is evident that all the observations after reversal will be recorded too soon by the time required by the star image to traverse the space 3–3′, 2–2′, or 1–1′, and the correction to be applied to the mean of the transits taken in both positions of the telescope will be one-half of this time. Hence equation (2). Similar reasoning shows that if the observations on a star are begun with the telescope reversed from the above position the same correction must be applied, the first half of the observations being made too soon.

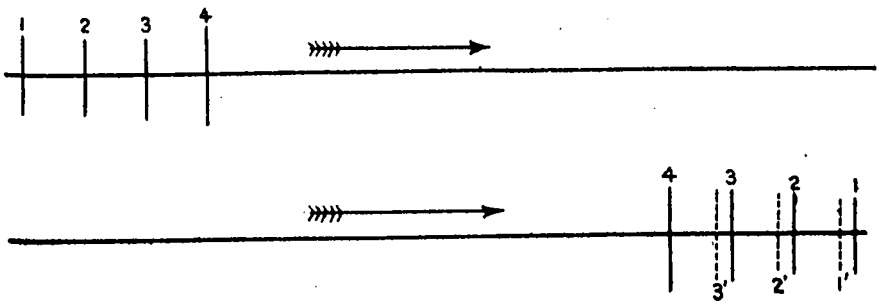

FIG. 8.—CORRECTION FOR LOST MOTION.

Adding equations (1) and (2), and letting $l'+l''=l$, we get as the expression for the combined corrections due to the errors caused by width of contact strips and lost motion,

$$l=1/2\ R(s+m)\ \sec.\ \delta \ldots\ldots (3).$$

An example of the record and computation for the determination of l is given below.

Observations for width of contact strip, transit No. 20, Cambridge, Mass. Observer, O. B. F.

Sept. 29, 1914.		Oct. 3, 1914.		Oct. 12, 1914.	
Up.	Down.	Up.	Down.	Up.	Down.
d	*d*	*d*	*d*	*d*	*d*
9.1	0.1	9.2	0.1	9.1	0.1
19.1	90.1	19.2	90.1	19.1	90.1
29.1	80.2	29.1	80.2	29.1	80.2
39.1	70.2	39.1	70.2	39.2	70.2
49.2	60.2	49.1	60.1	49.2	60.2
59.2	50.1	59.2	50.1	59.2	50.1
69.2	40.1	69.2	40.1	69.2	40.1
79.2	30.1	79.2	30.1	79.2	30.1
89.2	20.1	89.2	20.1	89.2	20.1
99.2	10.1	99.2	10.1	99.1	10.1
9.1	00.1	9.2	0.1	9.1	00.1
19.1	90.1	19.2	90.1	19.2	90.1
29.1	80.2	29.1	80.2	29.2	80.2
39.1	70.2	39.1	70.2	39.2	70.2
49.2	60.2	49.1	60.2	49.2	60.2
59.2	50.2	59.2	50.1	59.3	50.2
69.2	40.1	69.2	40.1	69.2	40.1
79.2	30.1	79.2	30.1	79.2	30.1
89.2	20.1	89.2	20.1	89.3	20.1
99.2	10.1	99.2	10.1	99.2	10.1
9.16	10.135	9.17	10.125	9.185	10.135
Diff = +.975		+.955		+.950	

Final mean s = +.960.

Observations for lost motion, transit No. 20, Cambridge, Mass. Observer, O. B. F.

SEPTEMBER 29, 1914.

Lower wire.		Middle wire.		Upper wire.		
Up.	Down.	Up.	Down.	Up.	Down.	
d	*d*	*d*	*d*	*d*	*d*	
1.4	1.6	52.4	52.4	1.6	1.5	
1.4	1.5	52.4	52.4	1.5	1.6	
1.5	1.5	52.5	52.4	1.6	1.6	
1.4	1.4	52.4	52.4	1.6	1.6	
1.4	1.5	52.5	52.5	1.5	1.6	
1.5	1.4	52.4	52.5	1.5	1.6	
1.5	1.6	52.5	52.5	1.6	1.5	
1.5	1.6	52.5	52.5	1.5	1.6	
1.4	1.5	52.4	52.5	1.5	1.6	
1.5	1.5	52.5	52.5	1.6	1.7	
1.45	1.51	52.45	52.46	1.55	1.59	
+.06		+.01		+.04		Mean=+.037 *d*
OCTOBER 3, 1914.						
1.0	1.0	52.0	52.0	0.9	0.9	
1.1	1.0	51.9	52.1	0.8	1.0	
1.0	1.0	52.0	52.0	0.9	1.0	
1.0	1.1	51.9	52.1	0.9	1.0	
1.0	1.1	52.0	52.0	0.9	1.0	
1.1	1.1	52.1	52.1	0.8	0.9	
1.0	1,1	52.0	52.1	0.9	1.0	
1.0	1.1	52.0	52.0	0.9	1.0	
1.0	1.0	52.0	52.1	0.8	1.0	
1.0	1.1	52.0	52.1	0.9	1.0	
1.02	1.06	51.99	52.06	0.87	0.98	
+.04		+.07		+.11		Mean=+ .073 *d*
OCTOBER 12, 1914.						
1.2	1.3	52.4	52.3	99.6	99.8	
1.3	1.3	52.3	52.4	99.7	99.7	
1.2	1.3	52.3	52.4	99.6	99.8	
1.3	1.4	52.3	52.4	99.7	99.7	
1.3	1.4	52.3	52.5	99.7	99.8	
1.3	1.4	52.3	52.4	99.6	99.8	
1.2	1.4	52.4	52.4	99.6	99.8	
1.3	1.4	52.4	52.5	99.7	99.7	
1.2	1.4	52.3	52.4	99.6	99.7	
1.3	1.3	52.3	52.3	99.7	99.7	
1.26	1.36	52.33	52.40	99.65	99.75	
+.10		+.07		+.10		Mean=+ .090 *d*

Mean of three sets m	=+ .067
Mean value for width of contact strips	=+ .960
Sum, $s+m$	=+1.027
R	= .10524 *s*
Hence $l=1/2\ R\ (s+m)\ \sec\delta$	=+ .0540 $\sec\delta$ *s*

RECORDS AND COMPUTATIONS.

On pages 29 to 31 are shown the data obtained during the observations on August 15 at Washington, D. C., and also all the computations required to secure the clock correction from each star free from all determinable errors except the one due to the instrument's not being exactly in the meridian. On page 32 are the remaining computations necessary to obtain the clock correction from each set. These differ but little from those described in Special Publication No. 14, pages 20 to 27, after omitting that part in reference to determining the error of collimation. The elimination of the collimation by reversal on each star simplifies the computation greatly, besides reducing the number of stars required for a time set nearly one-half.

The inclination of the axis was determined for each star and a correction corresponding to that inclination was applied to each without taking any mean values or considering observations made on other stars.

As the fillet was read the time of transit of a star was placed in the first two columns under each star, the second column being in reverse order from the first, with both records of each contact strip placed on the same horizontal line in the two columns, so that their sum, recorded in the third column, is the sum of the two observations made by the same contact strip.

In the equations for the final computation of the clock corrections only two unknowns appear and there are two equations, so that the solution is simple and direct. All the time stars are used to form one equation and the azimuth star to form the other.

After completing the preliminary computations for clock corrections at both stations on each line all residuals obtained for each star by both observers were collected and a mean value deduced for each star, the object being to see what systematic errors might be found due to either star place or other causes. Many of the stars showed persistently large residuals of about the same size for both observers on nearly every night hence justifying the conclusion that better results would be obtained by applying corrections to the star places for such stars. Consequently, whenever the mean of the residuals on any star was 0.02 second or greater, it was applied as a correction to the star place. Since the residuals for each time set are balanced their means must also balance very nearly, being affected only by the loss of one or more stars in some of the observations. Hence, these star-place corrections did not affect the clock corrections except in those broken time sets where one or more of the lost stars had such corrections to be applied. Such broken sets were recomputed, using the corrected star places, and the revised clock corrections thus obtained were used in place of those originally

deduced. When the time sets were complete the effect of applying these star-place corrections is shown merely in the residuals. These are shown in the last column of the computation of clock corrections.

The probable error of a clock correction for a time set, r_0, or for a single star, r, was obtained from the revised residuals, using Peter's probable error formulas. The figures in parentheses following the probable errors represent the probable errors obtained from the residuals before applying the star-place corrections.

On page 32 is an example of the revised computation required by a broken time set. In this case the revised result has a larger probable error than the original, which might be expected when the original is small. Of the 162 time sets observed during the season, 25 had slightly larger probable errors after the application of the correction for star places, whereas 137 had their probable errors reduced, many of them to less than half their original size. Out of the 21 broken time sets only 5 had their probable errors increased by the corrections. In every case where the probable error was increased the original probable error was small, and hence the revised value is probably nearer the truth.

On pages 33 to 36 are all the clock corrections obtained during the season with the mean epoch for each, its probable error, r_0, and the probable error, r, of a result from a single star in each time set. Each mean T_0 and $\triangle T$, on the right-hand side of the pages, is the straight mean of the three preceding values for that date, each being given equal weight. The last column contains the rate per minute. Each quantity shown in parentheses was obtained for the period between the two dates where it is placed, and the values on the lines with the mean T_0 and $\triangle T$ were obtained from these values by interpolation for the date required. There were three exceptions to this method of computing the rate, due to the fact that the breaking of a weight cord stopped the Cambridge clock on October 9, thus causing a very unstable rate for a few days. On October 9 and 11 the clock rate was obtained in two different ways and their mean used for the computation of the longitude. The first method was by a least square computation from the results of the three time sets obtained that night; the second by taking the difference between the exchange of signals assuming the rate of the clock at the other end, Washington, to be known. For determining the rate on October 5 a combination of all three methods was used.

The clock rates given on pages 33 to 36 indicate that each clock had a very uniform rate during the observations made by each observer at a station. As these rates were so uniform when computed from the daily intervals it was concluded that they represented the actual rates better than those obtained by using merely the observations of one night for the rate on that night. As the rates

derived from the daily intervals are so uniform it is not likely that the actual hourly rates are much less so, since the clocks were kept under such constant conditions.

Pages 37 and 38 contain a record of the exchange of signals made on August 15. In computing the mean epoch only the first and last quantities in a column were used. The means at the bottom of the table on page 38 are the only ones used in the longitude determination for that night, being the means of all the signals on that date.

Pages 38 and 39 contain the final computation of the differences of longitude, each table containing all the data regarding one line. The explanation of the various steps may be found in Special Publication No. 14.

On page 39 is a summary of the final results showing the error of closure of the three lines and the adjustment for this error. On page 40 are the final longitudes based upon the longitude for Cambridge, Mass., as deduced by Mr. Schott in 1897.

The previous value for the difference of longitude between Cambridge and Washington agrees with the result of these observations within 0.001 second, but this agreement must be classed as accidental when it is considered that the two lines used for the old determination received corrections of −0.031 second and +0.010 second when that work was adjusted. It is very gratifying, however, to find that the old work, made with an exchange of observers and finally adjusted, accords so perfectly with results obtained with modern methods and instruments.

WEIGHTS.

All observations and results of a similar character have been given equal weights when combining them to secure mean values or to eliminate errors. When the question of using weights arose a careful investigation was made to determine whether the results would be made more accordant by assigning weights at any stage of the computations, but since no reasonable systematic method was found which would improve the agreement of the results, it was considered best to omit all weighting, thus conforming with the latest practice of the Coast and Geodetic Survey when determining longitudes.

STABILITY OF THE TRANSITS.

When the decision was made to use only close zenith stars for time stars on this work it was thought they were necessary owing to the uncertainty regarding the stability of the instrument during so many reversals of the telescope. As the highest degree of accuracy was desired, no experiments were attempted. After the completion of the work, however, the same observers determined several differences of longitude in the South, taking observations on only three nights

on each line, using two time sets and one exchange of signals per night, and selecting all the stars from the American Ephemeris according to the instructions given in Special Publication No. 14 except that all observations required merely for determining collimation were dropped. The results obtained are apparently of the same order of accuracy as those obtained on the work described herein, thus indicating that errors due to a changeable or unstable azimuth are of little consequence when these instruments are carefully handled.

COMPUTATION OF TIME OBSERVATIONS.

Station, Naval Observatory, Washington, D. C. Observer, French.

DATE, AUG. 15, 1914. TEMPERATURE, 74° F. CLOCK, STANDARD RIEFLER.

Star No. 4430			4455			4479			4504			4522			4538		
Level: W	E		W	E		W	E		W	E		W	E		W	E	
d	d		d	d		d	d		d	d		d	d		d	d	
50.3	15.0		14.0	49.5		50.5	14.8		13.9	49.8		50.8	14.8		13.8	49.9	
14.0	49.3		50.7	15.0		13.8	49.4		50.8	14.9		13.3	49.5		50.2	14.0	
+36.3	−34.3		+36.7	−34.5		+36.7	−34.6		+36.9	−34.9		+37.5	−34.7		+36.4	−35.9	
+2.0			+2.2			+2.1			+2.0			+2.8			+0.5		
b s +0.0362			s +0.0398			s +0.0380			s +0.0362			s +0.0507			s +0.0090		
h m 17 23	m 26	Sum	h m 17 29	m 31	Sum	h m 17 36	m 38	Sum	h m 17 42	m 45	Sum	h m 17 50	m 51	Sum	h m 17 54	m 55	Sum
s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s
58.4	00.5	118.9	59.1½	52.3	111.4½	37.2½	31.5	68.7½	7.9	51.1	119.0	10.6½	54.0½	04.7	16.4½	39.4	115.8½
59.9	59.1	9.0	00.5	50.9	.4½	38.8	30.0	8.8	11.4	47.4	8.8	12.0	52.6	.6	17.7	38.3½	6.0½
1.4	57.4	8.8	1.9½	49.6½	.6	40.5	28.5	9.0	15.1	43.9	9.0	13.4	51.2	.6	18.8	37.0½	5.8½
3.1	56.1	9.2	3.3	48.2	.5	42.0	26.9	8.9	18.3	40.6	8.9	14.7½	49.9	.6½	20.0	35.8½	5.8½
4.8	54.3	9.1	4.7	46.6	.3	43.5	25.2	8.7	21.9	37.1	9.0	16.0½	48.4	.4½	21.2	34.5½	5.7½
6.3	52.6	8.9	6.1	45.2	.3	45.0	23.9	8.9	25.4	33.8	9.2	17.6	47.2	.8	22.4	33.3½	5.7½
8.0	51.1	9.1	7.4½	43.9	.3½	46.4½	22.3½	8.8	28.5	30.0	8.5	18.9	45.8½	.7½	23.7	32.1	5.8
9.4½	49.4½	8.9	9.1	42.5	.6	48.0	20.7½	8.7½	32.0	26.4	8.4	20.3	44.6½	.9½	24.9	30.8½	5.7½
11.6	47.8	9.4	10.5	41.1	.6	49.5	19.2½	8.7½	35.1	23.2	8.3	21.7½	43.1½	.9	25.9	29.8	5.7
12.5½	46.4½	9.0	11.8	39.7	.5	51.1	17.7	8.8	39.3	19.7	9.0	23.0	41.8½	.8½	27.2½	28.5½	5.8
Sum		119.03	Sum		111.46	Sum		68.81½	Sum		118.81	Sum		04.72½	Sum		115.81½
Mean		59.51½			55.73			34.41			59.40½			02.36			57.91
l		+.07½			+.06½			+.07½			+.16½			+.06½			+.06
κ		−.02½			−.02			−.02½			−.05			−.02			−.02
Bb		+.05½			+.05½			+.05½			+.10			+.06½			+.01
R		+.00½			.00			.00			.00			−.00½			−.00½
t	17 24	59.62½		17 30	55.83		17 37	34.51½		17 43	59.62		17 51	02.46½		17 54	57.95½
α	17 24	29.76		17 30	25.98		17 37	04.60½		17 43	29.69		17 50	32.64½		17 54	28.10½
α−t		−29.86½			−29.85			−29.91			−29.93			−29.82			−29.85

Second time set.

DATE, AUG. 15, 1914.

4672			4702			4722			4742			4776			4811			4846		
Level: W.	E.		W.	E.		W.	E.		W.	E.		W.	E.		W.	E.		W.	E.	
d	d		d	d		d	d		d	d		d	d		d	d		d	d	
51.4	14.8		13.5	50.3		51.2	14.2		13.4	50.5		51.4	14.3		13.2	50.4		51.7	14.2	
13.4	50.0		50.9	14.0		13.2	50.1		51.0	13.9		13.2	51.4		51.5	14.1		13.5	51.0	
+38.0	−35.2		+37.4	−36.3		+38.0	−35.9		+37.6	−36.6		+38.2	−27.1		+38.3	−36.3		+38.2	−36.8	
+2.8			+1.1			+2.1			+1.0			+1.1			+2.0			+1.4		
b	s +0.0507		s +0.0199			s +0.0380			s +0.0181			s +0.0199			s +0.0362			s +0.0253		
h m 18 21	m 24	Sum	h m 18 29	m 30	Sum	h m 18 33	m 35	Sum	h m 18 40	m 41	Sum	h m 18 46	m 48	Sum	h m 18 52	m 54	Sum	h m 18 58	m 60	Sum
s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s
26.8	49.6	16.4	13.6	57.1	10.7	36.5½	31.6	68.1½	31.5½	49.2	20.7½	39.5	14.2½	53.7½	00.6	06.4½	07.0½	35.0½	30.7	65.7½
30.4	46.0	.4	14.9	55.8	.7	37.9	30.2	.1	32.7	48.0	.7	40.9½	13.2	4.1½	2.1½	4.8	6.9½	36.7½	.....	.....
33.8	42.7	.5	16.0	54.6	.6	39.5	28.9	.4	33.9½	46.8½	.8	42.1½	11.7	3.8½	3.7	3.3½	7.0½	38.1½	27.6½	.8
37.4	39.3	.7	.....	.....	.....	.....	.....	.....	35.2½	45.6	.8½	43.2½	10.3	.5½	5.3	1.7	.0	39.8	25.9½	.7½
40.9½	35.4	.3½	20.8½	49.6	.4½	43.3	24.9	.2	36.5	44.4	.9	44.6½	9.2	.8½	6.7½	0.0	6.7½	41.2	24.4½	.6½
44.6	31.9	.5	22.1	48.4½	.5½	.....	.....	.....	37.6½	43.1	.7½	46.1	8.0	4.1	8.5	58.4	6.9	42.8	22.9	.7
48.0	28.3	.3	23.3	47.2½	.5½	48.8	19.4	.2	38.8½	41.9½	.8	47.2	6.7½	3.9½	10.0	56.8	.8	44.2	21.3	.5
51.7	24.9	.6	24.6	46.1	.7	.....	.....	.....	40.2	40.4	.6	48.5	5.5	4.0	11.8	55.2	7.0	45.9½	19.7½	.7
55.3	21.1½	.4½	25.7	44.8½	.5½	52.9½	15.5½	.5	41.4	39.2	.6	49.7	4.1½	3.8½	13.2	53.5½	6.7½	47.4	18.3½	.7½
58.7	17.7	.4	.....	.....	.....	54.3	13.9	.2	42.7	38.2½	.9½	51.0	3.1	4.1	14.8	51.9	.7	48.8½	16.9	.7½
			31.8	38.8½	.6½	55.5	12.7	.2										50.5	15.4	.9
			33.0	37.5	.5	56.8	11.5	.3												
						68.3	9.9½	.2½												
Sum		16.46	Sum		10.59½	Sum		68.25	Sum		20.77	Sum		53.91½	Sum		06.89½	Sum		65.72½
Mean		08.23			05.30			34.12½			10.38½			26.96			03.45			32.86
l		+.17			+.06			+.06½			+.06			+.06			+.07½			+.07½
κ		−.05			−.02			−.02			−.02			−.02			−.02½			−.02½
Bb		+.14			+.02½			+.05			+.02			+.02½			+.05½			+.03½
R		+.00½			+.00½			.00			.00			.00			.00			−.00½
t	18 23	08.49½		18 30	05.37		18 34	34.22		18 41	10.44½		18 47	27.02½		18 53	03.55½		18 59	32.94
α	18 22	38.62½		18 29	35.48		18 34	04.36		18 40	40.62		18 46	57.14½		18 52	33.69½		18 59	03.09½
α−t		−29.87			−29.89			−29.86			−29.82½			−29.88			−29.86			−29.84½

Third time set.

DATE, AUG. 15, 1914.

4986			5014			5045			5079			5113			5137			5157		
Level.. W.	E.		W.	E.		W.	E.		W.	E.		W.	E.		W.	E.		W.	E.	
d	d		d	d		d	d		d	d		d	d		d	d		d	d	
13.2	51.1		52.0	13.9		13.0	51.1		52.0	13.7		13.0	51.3		52.0	13.5		12.7	51.2	
51.1	13.1		13.0	51.0		51.7	13.3		13.0	51.1		51.9	13.3		12.7	51.1		51.2	12.8	
+37.9	−38.0		+39.0	−37.1		+38.7	−37.8		+39.0	−37.4		+38.9	−38.0		+39.3	−37.6		+38.5	−38.4	
−0.1			+1.9			+0.9			+1.6			+0.9			+1.7			+0.1		
b	s −0.0018			s +0.0344			s +0.0163			s +0.0290			s +0.0163			s +0.0308			s +0.0018	
h m 19 27	m 28	Sum	h m 19 33	m 35	Sum	h m 19 40	m 42	Sum	h m 19 47	m 50	Sum	h m 19 53	m 55	Sum	h m 19 58	m 60	Sum	h m 20 02	m 04	Sum
s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s
00.0½	36.1	96.1½	39.1½	42.5	81.6½	50.0	.....	.....	23.0	38.4	01.4	51.8	43.0½	94.8½	26.9	29.7	56.6	50.5½	35.3	85.8½
1.2	34.9	.1	40.7	40.8½	.5½	51.2	.....	.....	26.1	35.1	.2	53.1	41.6	.7	28.6	28.0	.6	52.0	34.0	6.0
2.3½	33.8	.1½	42.3	39.0½	.3½	52.6	33.9½	86.5½	29.3	32.1	.4	54.6	40.1½	.7½	30.1½	26.4	.5½	53.1	32.7	5.8
3.7½	32.7	.4½	44.0	37.4	.4	54.0	32.6½	.6½	32.6	29.0½	.6½	55.8	38.8	.6	31.6½	24.6½	.3	54.4	31.5	.9
4.8	31.2½	.0½	45.6	35.9	.5	55.1	31.3	.4	35.5	26.1	.6	57.2	37.5	.7	33.3	23.0	.3	55.8	30.2	6.0
5.9	30.1½	.0½	47.2½	34.1	.3½	56.4	30.0½	.4½	38.6	22.9	.5	58.8	36.1½	.9½	35.1	21.4	.5	56.9	28.8	5.7
6.9	29.0½	5.9½	48.8½	32.5½	.4	57.8	28.8	.6	41.1½	19.5	.6½	0.2	34.9	5.1	36.6½	19.8	.4½	58.3	27.7	6.0
8.3½	27.6	.0½	50.5	30.8½	.3½	59.0	27.4	.4	44.4½	16.8	.2½	1.5	33.3	4.8	38.4	18.3	.7	59.6	26.3	5.9
9.6	26.5	6.1	52.2½	29.1	.3½	00.5	26.0	.5	47.7½	13.6½	.4	2.7	32.0½	.7½	39.9	16.5	.4	0.9½	24.9	.8½
10.7	25.4	.1	53.9	27.8	.7	1.8	24.7	.5	50.8	10.5	.3	4.1½	30.5	.6½	41.5½	14.9	.4½	2.3½	23.5	.8½
						.....	.....	.....												
						7.1	19.4½	.5½												
						8.3	18.1½	.4½												
Sum		96.10½	Sum		81.46	Sum		86.50½	Sum		01.33½	Sum		94.78½	Sum		56.48½	Sum		85.88½
Mean		48.05			40.73			43.25			00.67			47.39			28.24			42.94
l		+.05½			+.08			+.06½			+.15			+.06½			+.08			+.06
κ		−.02			−.02½			−.02			−.05			−.02			−.02½			−.02
Bb		.00			+.05			+.02			+.07½			+.02			+.04½			.00
R		+.00½			+.00½			.00			.00			.00			−.00½			−.00½
t	19 27	48.09		19 34	40.84		19 41	43.31½		19 49	00.84½		19 54	47.45½		19 59	28.33½		20 03	42.97½
α	19 27	18.23½		19 34	10.88½		19 41	13.45		19 48	30.90		19 54	17.69		19 58	58.48½		20 03	13.10
α−t		−29.85½			−29.95½			−29.86½			−29.94½			−29.76½			−29.85			−29.87½

COMPUTATION OF CLOCK CORRECTIONS.

Station, Naval Observatory, Washington, D. C. Observer, French.

DATE, AUG. 15, 1914.

Star No.	$\alpha-t$	δt	A	Aa	ΔT	v	ΔT_1	v_1
	s	s		s	s	s	s	s
4430.....	−29.865	+0.135	−0.245	−0.010	−29.855	−0.001	−29.855	+0.003
4455.....	.85	+0.15	−0.055	−0.002	.848	−0.008	.828	−0.024
4479.....	.91	+0.09	−0.185	−0.008	.902	+0.046	.902	+0.050
4504.....	.93	+0.07	−1.795	−0.074	.856	.....	.852	.....
4522.....	.82	+0.18	−0.025	−0.001	.819	−0.037	.819	−0.033
4538.....	.85	+0.15	+0.195	+0.008	.858	+0.002	.858	+0.006
					−29.856	0.094	−29.852	0.116

1, $\delta t-1.795a-0.07=0$
2, $5\delta t-0.315a-0.705=0$
3, $\delta t-0.063a-0.1410=0$
4, $-1.732a+0.0710=0$
$a=+0.0410$

5, $5\delta t-0.0129-0.705=0$
6, $5\delta t-0.7179=0$ s.
7, $\delta t=+0.1436$
8, $\Delta T=-29.856$
$r=\pm 0.014$
$r_0=\pm 0.006$

Star 4403 was lost in this set, and being one of the stars to which a correction was applied for error of star place, necessitated the following recomputation of this time set:

1, $\delta t-1.795a-0.07=0$
2, $5\delta t-0.315a-0.725=0$
3, $\delta t-0.063a-0.1462=0$
4, $-1.732a+0.0762=0$
$a=+0.0440$

5, $5\delta t-0.0139-0.725=0$
6, $5\delta t-0.7389=0$
7, $\delta t=+0.1478$
8, $\Delta T=-29.852$
$r=\pm 0.018$
$r_0=\pm 0.007$

The above table shows the results of this recomputation in the last two columns. All the other columns are unchanged except as required by a change of +0.02 second in the mean place of star 4455.

Second time set.

Star No.	$\alpha-t$	δt	A	Aa	ΔT	v	v_1
	s	s		s	s	s	s
4672.....	−29.87	+0.13	−1.87	−0.010	−29.860	.....	.....
4702.....	.89	+0.11	+0.17	+0.001	.891	+0.031	+0.011
4722.....	.86	+0.14	+0.005	0.000	.860	0.000	0.000
4742.....	.825	+0.175	+0.145	+0.001	.826	−0.034	−0.034
4776.....	.88	+0.12	+0.12	+0.001	.881	+0.021	+0.021
4811.....	.86	+0.14	−0.26	−0.001	.859	−0.001	+0.019
4846.....	.845	+0.155	−0.20	−0.001	.844	−0.016	−0.016
					−29.860	0.103	0.101

1, $\delta t-1.87\,a-0.13=0$
2, $6\delta t-0.02\,a-0.84=0$
3, $\delta t-0.003a-0.14=0$
4, $-1.867a+0.01=0$
$a=+0.0054$

5, $6\delta t-0.0001-0.84=0$
6, $6\delta t-0.8401=0$
7, $\delta t=+0.140$
8, $\Delta T=-29.860$
$r=\pm 0.016\ (\pm 0.016)$
$r_0=\pm 0.006\ (\pm 0.006)$

Third time set.

4986.....	−29.855	+0.145	+0.22	+0.013	−29.868	+0.010	−0.010
5014.....	.955	+0.045	−0.30	−0.017	.938	+0.080	+0.035
5045.....	.865	+0.135	+0.04	+0.002	.867	+0.009	−0.011
5079.....	.945	+0.055	−1.515	−0.087	.858	.....	.....
5113.....	.765	+0.235	−0.03	−0.002	.763	−0.095	−0.010
5137.....	.85	+0.15	−0.295	−0.017	.833	−0.025	−0.025
5157.....	.875	+0.125	+0.07	+0.004	.879	+0.021	+0.021
					−29.858	0.240	0.112

1, $\delta t-1.515\,a-0.055=0$
2, $6\delta t-0.295\,a-0.835=0$
3, $\delta t-0.0492a-0.1392=0$
4, $-1.4658a+0.0842=0$
$a=+0.0577$

5, $6\delta t-0.0170-0.835=0$
6, $6\delta t-0.852=0$
7, $\delta t=+0.142$
8, $\Delta T=-29.858$
$r=\pm 0.017\ (\pm 0.037)$
$r_0=\pm 0.007\ (\pm 0.015)$

Clock corrections and rates.

WASHINGTON. OBSERVER, FRENCH.

Date.	No. of stars.	T_0	ΔT	r	r_0	Mean. T_0	Mean. ΔT	Rate per minute.
		h m	s	s	s	h m	s	s
Aug. 7	6	17 36.20	−27.129	±0.006	±0.002			
	5	18 42.52	−27.111	± .015	± .007	18 40.79	−27.129	−0.000237
	5	19 43.65	−27.148	± .014	± .006			
								(− .000237)
Aug. 8	6	18 44.28	−27.472	± .012	± .005			
	6	19 46.99	−27.473	± .021	± .009	19 47.50	−27.486	− .000237
	6	20 51.23	−27.514	± .014	± .006			
								(− .000238)
Aug. 13	6	18 44.30	−29.178	± .043	± .018			
	5	19 50.87	−29.215	± .031	± .014	19 48.81	−29.202	− .000236
	6	20 51.26	−29.213	± .020	± .008			
								(− .000235)
Aug. 14	6	17 34.24	−29.524	± .019	± .008			
	6	18 44.31	−29.516	± .026	± .011	18 41.86	−29.525	− .000232
	6	19 47.02	−29.536	± .035	± .014			
								(− .000230)
Aug. 15	5	17 39.90	−29.852	± .018	± .007			
	6	18 44.32	−29.860	± .016	± .006	18 43.75	−29.857	− .000230
	6	19 47.03	−29.858	± .017	± .007			
				Av. ± .0204	± .0085			

FAR ROCKAWAY. OBSERVER, MORSE.

Date.	No. of stars.	T_0	ΔT	r	r_0	Mean. T_0	Mean. ΔT	Rate per minute.
Aug. 7	6	17 35.98	−13.762	±0.030	±0.012			
	6	18 44.05	−13.784	± .034	± .014	18 42.26	−13.783	−0.00022
	6	19 46.76	−13.802	± .028	± .011			
								(− .000216)
Aug. 8	6	18 44.05	−14.092	± .019	± .008			
	6	19 46.77	−14.116	± .028	± .011	19 47.28	−14.109	− .00021
	6	20 51.01	−14.120	± .040	± .016			
								(− .000192)
Aug. 13	6	18 44.07	−15.450	± .040	± .016			
	6	19 46.79	−15.518	± .032	± .013	19 47.30	−15.494	− .00020
	6	20 51.03	−15.514	± .023	± .010			
								(− .000199)
Aug. 14	6	17 36.01	−15.759	± .032	± .013			
	6	18 44.08	−15.776	± .021	± .009	18 42.30	−15.767	− .00020
	6	19 46.80	−15.767	± .033	± .013			
								(− .000207)
Aug. 15	5	17 39.67	−16.061	± .016	± .007			
	6	18 44.08	−16.060	± .035	± .015	18 43.52	−16.065	− .00021
	6	19 46.80	−16.073	± .030	± .012			
				Av. ± .0294	± .0120			

WASHINGTON. OBSERVER. MORSE.

Date.	No. of stars.	T_0	ΔT	r	r_0	Mean. T_0	Mean. ΔT	Rate per minute.
Aug. 22	6	18 43.35	+27.816	±0.019	±0.008			
	6	19 46.07	+27.739	± .032	± .013	19 46.58	+27.769	−0.00025
	6	20 50.31	+27.753	± .017	± .007			
								(− .00025)
Aug. 30	6	19 46.11	+24.863	± .023	± .009			
	6	20 50.36	+24.827	± .024	± .010	20 44.99	+24.840	− .00026
	6	21 38.49	+24.830	± .014	± .006			
								(− .00026)
Aug. 31	6	18 43.40	+24.512	± .030	± .012			
	6	19 46.12	+24.452	± .015	± .006	19 46.63	+24.476	− .00026
	6	20 50.36	+24.463	± .033	± .014			
								(− .00026)
Sept. 2	6	18 43.42	+23.762	± .020	± .008			
	4	19 38.85	+23.750	± .017	± .008	19 43.28	+23.732	− .00026
	3	20 47.56	+23.684	± .024	± .014			
								(− .00025)
Sept. 4	5	19 47.21	+22.956	± .035	± .016			
	6	20 50.39	+22.953	± .026	± .011	20 46.33	+22.962	− .00025
	5	21 41.40	+22.978	± .027	± .012			
				Av. ± .0240	± .0103			

Clock corrections and rates—Continued.

FAR ROCKAWAY. OBSERVER, FRENCH.

Date.	No. of stars.	T_o	ΔT	r	r_o	Mean. T_o	Mean. ΔT	Rate per minute.
		h m	s	s	s	h m	s	s
Aug. 22	6	18 44.12	−18.261	±0.020	±0.008			
	6	19 46.84	−18.280	± .014	± .006	19 47.35	−18.302	−0.00012
	6	20 51.08	−18.366	± .019	± .008			
								(− .00015)
Aug. 30	6	19 46.68	−19.965	± .017	± .007			
	6	20 51.10	−20.038	± .009	± .004	20 45.73	−20.007	− .00020
	6	21 39.24	−20.018	± .016	± .007			
								(− .00025)
Aug. 31	6	18 44.15	−20.330	± .013	± .005			
	6	19 46.87	−20.347	± .021	± .009	19 47.38	−20.351	− .00024
	6	20 51.11	−20.375	± .013	± .005			
								(− .00023)
Sept. 2	6	18 44.16	−20.994	± .027	± .011			
	6	19 46.88	−20.975	± .028	± .012	19 47.39	−21.005	− .00024
	6	20 51.12	−21.047	± .020	± .008			
								(− .00024)
Sept. 4	6	19 46.89	−21.695	± .011	± .005			
	6	20 51.13	−21.732	± .012	± .005	20 45.76	−21.714	− .00024
	6	21 39.27	−21.714	± .014	± .006			
				Av. ± .0170	± .0070			

FAR ROCKAWAY. OBSERVER, FRENCH.

Date.	No. of stars.	T_o	ΔT	r	r_o	Mean. T_o	Mean. ΔT	Rate per minute.
Sept. 12	6	19 45.50	−24.091	±0.018	±0.007			
	6	20 31.69	−24.096	± .018	± .007	20 51.04	−24.100	−0.00010
	6	22 15.94	−24.113	± .011	± .005			
								(− .000103)
Sept. 13	6	19 45.51	−24.257	± .031	± .013			
	6	20 31.69	−24.243	± .011	± .005	20 33.08	−24.246	− .00009
	6	21 22.05	−24.239	± .027	± .011			
								(− .000069)
Sept. 14	6	19 45.51	−24.339	± .021	± .009			
	6	20 31.70	−24.347	± .028	± .012	20 33.09	−24.346	− .00009
	6	21 22.05	−24.352	± .023	± .009			
								(− .000116)
Sept. 15	6	19 45.51	−24.501	± .034	± .014			
	6	20 31.70	−24.510	± .026	± .010	20 33.09	−24.513	− .00010
	6	21 22.05	−24.527	± .029	± .012			
								(− .000101)
Sept. 16	6	20 31.70	−24.663	± .035	± .014			
	4	21 18.52	−24.647	± .019	± .010	21 22.10	−24.664	− .00010
	6	22 16.08	−24.681	± .011	± .004			
				Av. ± .0229	± .0095			

CAMBRIDGE. OBSERVER, MORSE.

Date.	No. of stars.	T_o	ΔT	r	r_o	Mean. T_o	Mean. ΔT	Rate per minute.
Sept. 12	6	19 45.14	−01.798	±0.042	±0.018			
	6	20 31.32	−01.844	± .042	± .017	20 51.35	−01.844	−0.00080
	5	22 17.58	−01.890	± .030	± .012			
								(− .000755)
Sept. 13	6	19 45.15	−02.897	± .030	± .012			
	6	20 31.34	−02.884	± .062	± .022	20 32.73	−02.917	− .00072
	6	21 21.70	−02.971	± .052	± .021			
								(− .000676)
Sept. 14	6	19 45.17	−03.815	± .052	± .021			
	6	20 31.36	−03.925	± .022	± .009	20 32.75	−03.890	− .00075
	6	21 21.71	−03.930	± .045	± .018			
								(− .000827)
Sept. 15	6	19 45.18	−05.042	± .028	± .012			
	6	20 31.38	−05.073	± .039	± .016	20 32.76	−05.080	− .00093
	6	21 21.73	−05.126	± .012	± .005			
								(− .001036)
Sept. 16	4	20 33.73	−06.600	± .057	± .028			
	6	21 21.76	−06.597	± .033	± .013	21 23.76	−06.624	− .00100
	6	22 15.78	−06.676	± .040	± .016			
				Av. ± .0391	± .0160			

Clock corrections and rates—Continued.

FAR ROCKAWAY. OBSERVER, MORSE.

Date.	No. of stars.	T_0	ΔT	r	r_0	Mean. T_0	Mean. ΔT	Rate per minute.
		h m	s	s	s	h m	s	s
Sept. 20	6	20 31.88	−25.547	±0.035	±0.014			
	6	21 22.07	−25.574	± .012	± .005	21 23.30	−25.573	−0.000156
	6	22 19.96	−25.598	± .012	± .005			
								(− .000172)
Sept. 21	6	20 31.89	−25.812	± .023	± .010			
	6	22 16.09	−25.831	± .019	± .008	22 01.48	−25.827	− .000188
	6	23 16.47	−25.837	± .015	± .006			
								(− .000204)
Sept. 22	6	20 31.73	−26.117	± .024	± .010			
	6	21 22.08	−26.100	± .019	± .008	21 23.30	−26.114	− .000212
	6	22 16.10	−26.125	± .031	± .013			
								(− .000219)
Sept. 23	6	20 31.73	−26.418	± .018	± .007			
	6	21 22.08	−26.430	± .022	± .009	21 23.30	−26.429	− .000225
	6	22 16.10	−26.440	± .025	± .010			
				Av. ± .0212	± .0088			

CAMBRIDGE. OBSERVER, FRENCH.

Date.	No. of stars.	T_0	ΔT	r	r_0	Mean. T_0	Mean. ΔT	Rate per minute.
Sept. 20	5	20 46.47	−12.987	±0.021	±0.009			
	4	21 16.81	−13.035	± .028	± .014	21 24.92	−13.040	− .00114
	5	22 11.48	−13.098	± .012	± .005			
								(− .001140)
Sept. 21	6	20 31.53	−14.625	± .035	± .014			
	6	22 15.91	−14.783	± .023	± .009	22 01.25	−14.722	− .00114
	6	23 16.30	−14.758	± .017	± .007			
								(− .001141)
Sept. 22	6	20 31.56	−16.261	± .033	± .013			
	6	21 21.92	−16.324	± .021	± .008	21 23.14	−16.322	− .00113
	6	22 15.94	−16.382	± .019	± .008			
								(− .001108)
Sept. 23	5	20 32.10	−17.885	± .025	± .011			
	6	21 21.95	−17.921	± .008	± .003	21 30.05	−17.928	− .00111
	5	22 36.09	−17.979	± .034	± .015			
				Av. ± .0230	± .0097			

WASHINGTON. OBSERVER, MORSE.

Date.	No. of stars.	T_0	ΔT	r	r_0	Mean. T_0	Mean. ΔT	Rate per minute.
Oct. 1	6	21 21.92	+11.902	±0.022	±0.009			
	6	22 29.92	+11.885	± .016	± .006	22 28.39	+11.880	−0.00028
	6	23 33.32	+11.854	± .027	± .011			
								(− .000285)
Oct. 2	6	21 21.93	+11.490	± .020	± .008			
	6	22 29.93	+11.474	± .009	± .004	22 29.09	+11.469	− .00030
	5	23 35.42	+11.442	± .029	± .013			
								(− .000310)
Oct. 5	6	21 21.95	+10.138	± .020	± .008			
	6	22 29.95	+10.137	± .016	± .007	22 28.41	+10.127	− .00030
	6	23 33.34	+10.107	± .014	± .006			
								(− .000300)
Oct. 9	6	21 21.96	+08.408	± .016	± .006			
	6	22 29.98	+08.424	± .016	± .006	22 28.44	+08.397	− .00030
	6	23 33.37	+08.359	± .016	± .007			
								(− .000311)
Oct. 11	6	21 21.99	+07.516	± .020	± .008			
	6	22 29.99	+07.524	± .022	± .009	22 28.46	+07.500	− .00031
	6	23 33.39	+07.461	± .014	± .006			
				Av. ± .0185	± .0076			

Clock corrections and rates—Continued.

CAMBRIDGE. OBSERVER, FRENCH.

Date.	No. of stars.	T_0	ΔT	r	r_0	Mean. T_0	Mean. ΔT	Rate per minute.
		h m	s	s	s	h m	s	s
Oct. 1	6	21 21.61	+30.630	±0.006	±0.003			
	6	22 29.61	+30.602	± .013	± .005	22 28.07	+30.590	−0.00091
	6	23 33.00	+30.539	± .016	± .006			
								(− .000904)
Oct. 2	6	21 21.63	+29.343	± .025	± .010			
	6	22 29.63	+29.308	± .018	± .007	22 28.10	+29.288	− .00090
	6	23 33.03	+29.213	± .023	± .010			
								(− .000871)
Oct. 5	6	21 21.70	+25.573	± .017	± .007			
	6	22 29.70	+25.545	± .016	± .007	22 28.16	+25.526	− .00090
	6	23 33.09	+25.469	± .029	± .012			
								(*)
Oct. 9	6	21 22.18	−03.787	± .033	± .014			
	5	22 30.47	−03.748	± .020	± .009	22 28.74	−03.772	− .000000
	6	23 33.58	−03.781	± .046	± .019			
								(*)
Oct. 11	6	21 22.18	−03.725	± .016	± .007			
	5	22 33.75	−03.741	± .025	± .011	22 29.84	−03.768	− .00070
	6	23 33.58	−03.838	± .022	± .009			
				Av. ± .0217	± .0091			
WASHINGTON. OBSERVER, FRENCH.								
Oct. 21	6	22 30.30	−10.972	±0.008	±0.003			
	6	23 33.70	−11.059	± .010	± .004	23 36.67	−11.033	−0.00065
	6	0 46.00	−11.067	± .017	± .007			
								(− .000660)
Oct. 22	6	22 30.32	−11.906	± .024	± .010			
	6	23 33.71	−12.023	± .024	± .010	23 36.68	−11.984	− .00067
	6	0 46.02	−12.024	± .020	± .008			
								(− .000682)
Oct. 23	6	22 30.33	−12.871	± .028	± .012			
	6	23 33.73	−13.019	± .024	± .010	23 36.70	−12.966	− .00069
	6	0 46.03	−13.009	± .020	± .008			
				Av. ± .0191	± .0080			
CAMBRIDGE. OBSERVER, MORSE.								
Oct. 21	6	22 30.07	+02.891	±0.015	±0.006			
	6	23 33.47	+02.859	± .014	± .006	23 36.44	+02.862	−0.00032
	6	0 45.77	+02.835	± .016	± .006			
								(− .00032)
Oct. 22	6	22 30.08	+02.433	± .012	± .005			
	6	23 33.47	+02.392	± .009	± .004	23 36.44	+02.402	− .000315
	6	0 45.78	+02.382	± .011	± .004			
								(− .00031)
Oct. 23	6	22 30.08	+01.956	± .014	± .006			
	5	23 36.82	+01.943	± .021	± .008	23 37.56	+01.954	− .00031
	6	0 45.78	+01.964	± .016	± .006			
				Av. ± .0142	± .0057			

* Computed from these three time sets and exchange of signals.

EXCHANGE OF ARBITRARY SIGNALS.

Station, Naval Observatory, Washington, D. C. Observer, French.

DATE, AUG. 15, 1914.

From Washington to Far Rockaway.			From Far Rockaway to Washington.		
Washington record.	Far Rockaway record.	Difference.	Washington record.	Far Rockaway record.	Difference.
h m s	h m s	m s	h m s	h m s	m s
18 01 30.29	18 14 32.17	13 01.88	18 02 14.16	18 15 16.00	13 01.84
32.22	34.14	.92	15.11	16.93	.82
34.42	36.33	.91	16.28	18.11	.83
36.53	38.45	.92	18.42	20.26	.84
38.54	40.46	.92	20.51	22.34	.83
40.76	42.67	.91	22.70	24.53	.83
42.90	44.80	.90	24.82	26.66	.84
45.07	46.97	.90	26.99	28.84	.85
47.17	49.10	.93	29.14	30.98	.84
49.33	51.27	.94	31.29	33.10	.81
51.47	53.37	.90	33.36	35.22	.86
53.58	55.50	.92	35.55	37.40	.85
55.73	57.66	.93	37.66	39.50	.84
57.80	59.74	.94	39.77	41.60	.83
59.91	15 01.86	.95	41.98	43.82	.84
02 02.07	03.99	.92	44.11	45.95	.84
04.21	06.13	.92	46.28	48.12	.84
03 22.93	16 24.86	.93	48.39	50.23	.84
24.91	26.83	.92	50.56	52.40	.84
26.69	28.58	.89	52.74	54.57	.83
28.04	29.97	.93	54.80	56.63	.83
29.23	31.16	.93	56.83	58.70	.87
31.30	33.23	.93	58.96	16 00.83	.87
33.38	35.30	.92	03 01.20	03.04	.84
35.45	37.36	.91	03.24	05.05	.81
37.63	39.56	.93	05.48	07.35	.87
39.76	41.67	.91	07.51	09.37	.86
41.89	43.82	.93	09.72	11.56	.84
43.99	45.90	.91	11.91	13.76	.85
46.08	48.00	.92	14.11	15.96	.85
48.26	50.17	.91			
50.35	52.26	.91			
52.49	54.42	.93			
54.58	56.51	.93			
56.74	58.66	.92			
58.78	17 00.67	.89			
04 00.90	02.83	.93			
03.03	04.95	.92			
18 02 46	18 15 48	13 01.9187	18 02 44	18 15 47	13 01.8410
Mean.....			18 02.75	18 15.80	13 01.8798

SECOND SET.

19 01 42.49	19 14 44.37	13 01.88	19 02 28.18	19 15 30.00	13 01.82
43.70	45.66	.90	29.15	31.97	.82
45.71	47.57	.86	30.33	32.14	.81
47.82	49.72	.90	32.35	34.15	.80
49.96	51.86	.90	34.50	36.33	.83
52.02	53.94	.92	36.64	38.45	.81
54.19	56.08	.89	38.77	40.57	.80
56.33	58.24	.91	40.91	42.70	.79
58.52	15 00.43	.91	43.03	44.84	.81
02 00.58	02.48	.90	45.23	47.04	.81
02.71	04.58	.87	47.31	49.10	.79
04.78	06.69	.91	49.48	51.28	.80
06.96	08.85	.89	51.67	53.49	.82
09.03	10.94	.91	53.70	55.53	.83
10.98	12.90	.92	55.93	57.74	.81
13.29	15.20	.91	58.02	59.84	.82
15.52	17.37	.85	03 00.30	16 02.08	.78
17.63	19.52	.89	02.42	04.23	.81
19.93	21.83	.90	04.54	06.36	.82
03 39.43	16 41.28	.85	06.73	08.54	.81
41.38	43.23	.85	08.84	10.64	.80
42.20	44.07	.87	10.93	12.74	.81
43.63	45.53	.90	13.13	14.95	.82

EXCHANGE OF ARBITRARY SIGNALS—continued.

Station, Naval Observatory, Washington, D. C. Observer, French—Continued.

SECOND SET—Continued.

From Washington to Far Rockaway.			From Far Rockaway to Washington.		
Washington record.	Far Rockaway record.	Difference.	Washington record.	Far Rockaway record.	Difference.
h m s	h m s	m s	h m s	h m s	m s
03 45.76	16 47.66	01.90	03 15.28	16 17.08	01.80
47.93	49.83	.90	17.38	19.16	.78
50.09	51.98	.89	19.52	21.34	.82
52.17	54.05	.88	21.49	23.30	.81
54.35	56.24	.89	23.75	25.57	.82
56.48	58.36	.88	25.95	27.76	.81
58.55	17 00.45	.90	28.03	29.85	.82
04 00.59	02.47	.88	30.22	32.03	.81
02.86	04.75	.89			
04.96	06.84	.88			
07.06	08.97	.91			
09.17	11.07	.90			
11.30	13.17	.87			
13.44	15.34	.90			
19 02 58	19 16 00	13 01.8908	19 02 59	19 16 01	13 01.8094
Mean			19 02.98	19 16.01	13 01.8501
Mean of both sets			18 32.86	18 45.90	13 01.8650

Transmission time, first set = 0.0388 sec.
Transmission time, second set = .0407 sec.

Mean of both exchanges.. .0398 sec.

Computation of difference of longitude.

FAR ROCKAWAY, N. Y., AND WASHINGTON, D. C.

Date.	T_0		ΔT		Difference ΔT.	Difference of signals.	Personal equation.	$\Delta\lambda$	v	Transmission time.
	Far Rockaway.	Washington.	Far Rockaway.	Washington.						
	Morse.	French.								
1914.	h m	h m	s	s	s	m s	s	m s	s	s
Aug. 7	18 44.62	18 31.58	−13.784	−27.127	+13.343	13 02.358	−0.021	13 15.680	−0.032	0.0558
8	19 48.36	19 35.32	−14.109	−27.483	+13.374	13 02.293	− .021	13 15.646	+ .002	.0284
13	19 49.78	19 36.75	−15.494	−29.199	+13.705	13 01.955	− .022	13 15.638	+ .009	.0263
14	18 43.85	18 30.82	−15.767	−29.522	+13.755	13 01.909	− .022	13 15.642	+ .005	.0264
15	18 45.90	18 32.86	−16.065	−29.854	+13.789	13 01.865	− .022	13 15.632	+ .015	.0308
	French.	Morse.								
22	19 48.24	19 34.21	−18.302	+27.772	−46.074	14 01.701	+ .021	13 15.648	− .001	.0282
30	20 50.49	20 36.48	−20.008	+24.842	−44.850	14 00.482	+ .022	13 15.654	− .006	.0246
31	19 48.05	19 34.04	−20.351	+24.479	−44.830	14 00.466	+ .022	13 15.658	− .010	.0300
Sept. 2	19 47.02	19 33.02	−21.005	+23.735	−44.740	14 00.357	+ .021	13 15.638	+ .009	.0308
4	20 49.82	20 35.82	−21.715	+22.965	−44.680	14 00.297	+ .022	13 15.639	+ .009	.0286

Mean..... 13 15.6475±0.0028
Reduction to center of clock room at Washington..... +.0566

Difference of longitude, Far Rockaway and Washington..... 13.15.7041±0.0028

Computation of difference of longitude—Continued.

CAMBRIDGE, MASS., AND FAR ROCKAWAY, N. Y.

Date.	T_0		ΔT		Difference ΔT.	Difference of signals.	Personal equation.	$\Delta\lambda$	v	Transmission time.
	Cambridge.	Far Rockaway.	Cambridge.	Far Rockaway.						
	Morse.	French.								
1914	h m	h m	s	s	s	m s	s	m s	s	s
Sept. 12	20 48.28	20 38.18	−01.842	−24.099	+22.257	10 06.668	+0.001	10 28.926	−0.006	0.0481
13	20 38.86	20 28.78	−02.921	−24.246	+21.325	10 07.603	+ .001	10 28.929	− .009	.0443
14	20 37.64	20 27.49	−03.894	−24.345	+20.451	10 08.469	+ .001	10 28.921	− .001	.0386
15	20 37.39	20 27.24	−05.084	−24.512	+19.428	10 09.504	+ .001	10 28.933	− .013	.0456
16	21 29.58	21 19.40	−06.630	−24.664	+18.034	10 10.858	+ .001	10 28.893	+ .027	.0376
	French.	Morse.								
20	21 31.43	21 21.16	−13.047	−25.573	+12.526	10 16.404	− .001	10 28.929	− .009	.0378
21	22 18.82	22 08.52	−14.742	−25.828	+11.086	10 17.838	− .001	10 28.923	− .003	.0300
22	21 30.16	21 19.84	−16.330	−26.113	+09.783	10 19.147	− .001	10 28.929	− .009	.0398
23	21 30.67	21 20.32	−17.929	−26.428	+08.499	10 20.403	− .001	10 28.901	+ .019	.0300

Mean ..... 10 28.9204 ± 0.0031
Reduction to Sears dome at Cambridge ..... +.1103

Difference of longitude, Cambridge and Far Rockaway ..... 10 29.0307 ± 0.0031

CAMBRIDGE, MASS., AND WASHINGTON, D. C.

Date.	T_0		ΔT		Difference ΔT	Difference of signals.	Personal equation.	$\Delta\lambda$	v	Transmission time.
	Cambridge.	Washington.	Cambridge.	Washington.						
	French.	Morse.								
1914.	h m	h m	s	s	s	m s	s	m s	s	s
Oct. 1	22 39.67	22 16.24	+30.579	+11.883	+18.696	23 25.881	+0.004	23 44.581	−0.010	0.0785
2	22 39.38	22 15.94	+29.278	+11.473	+17.805	23 26.758	+ .004	23 44.567	+ .004	.0813
5	22 39.48	22 16.00	+25.516	+10.131	+15.385	23 29.197	+ .004	23 44.586	− .015	.0868
9	22 38.56	22 14.62	−03.772	+08.401	−12.173	23 56.718	+ .004	23 44.549	+ .022	.0998
11	22 38.82	22 15.38	−03.774	+07.504	−11.278	23 55.847	+ .004	23 44.573	− .002	.0808
	Morse.	French.								
21	23 46.48	23 22.50	−11.039	+02.866	−13.905	23 58.484	− .004	23 44.575	− .004	.0676
22	23 46.60	23 22.62	−11.991	+02.406	−14.397	23 58.969	− .004	23 44.568	+ .003	.0670
23	23 46.42	23 22.43	−12.973	+01.959	−14.932	23 59.508	− .004	23 44.572	− .001	.0050

Mean ..... 23 44.5714 ± 0.0024
Reduction to Sears dome at Cambridge ..... +.1103
Reduction to clock room at Washington ..... +.0566

Difference of longitude, Cambridge and Washington ..... 23 44.7383 ± 0.0024

Summary of longitude differences and adjustment.

	Unadjusted.	Correction.	Adjusted.	Probable error.
	m s	s	m s	s
Far Rockaway to Washington	13 15.7041	+0.0012	13 15.7053	±0.0028
Cambridge to Washington	23 44.7383	− .0012	23 44.7371	± .0024
Cambridge to Far Rockaway	10 29.0307	+ .0011	10 29.0318	± .0031
Error of closure	.....	.0035		

Using the longitude for Cambridge as deduced by Mr. Schott and published in Coast and Geodetic Survey Report for 1897, Appendix 2, the following longitudes west of Greenwich are obtained:

	h	m	s
Cambridge, center Sears dome	4	44	31.0460
Cambridge to Washington		+23	44.7371
Washington, center of clock room, Naval Observatory	5	08	15.7831
Cambridge to Far Rockaway		+10	29.0318
Far Rockaway, center of east pier	4	55	00.0778

The previous value of the longitude of Washington is $5^h\ 08^m\ 15^s.784$.

LATITUDE WITH THE BROKEN TELESCOPE TRANSIT.

This transit may be used for the determination of latitude by the Horrebow-Talcott method in the same manner as a zenith telescope except in some minor details. The latitude levels, being independent of the setting circle, must be brought to the horizontal position with their clamp and tangent screw after the telescope has been set for the star with the setting circle and its level. Owing to the method of reversal between stars it is difficult to keep the instrument so that the latitude levels will come back after the reversal to the same reading that they had before, thus requiring the use of the axis tangent screw to prevent the introduction of large level corrections.

The approximate values of the latitude micrometer screws are as follows:

	″
One turn of latitude micrometer, transit No. 20	78.9
One turn of latitude micrometer, transit No. 21	79.0

The values obtained for one division of the latitude levels are:

		″
Transit No. 20, level numbered	0 to 40	1.358±0.006
	50 to 90	1.312±0.007
Transit No. 21, level numbered	0 to 40	1.316±0.006
	50 to 90	1.256±0.005

Owing to the manner in which this type of instrument is used the formula for the computation of the latitude, given on page 116 of Special Publication No. 14, requires some modification before it can be used here. Using the letters E and W as subscripts to indicate that the quantities to which they are attached are obtained when the ocular is in the east or west position, respectively, and letting the other symbols remain as in the above-mentioned formula, then the following is the complete formula for use with the new transit:

$$\phi=\tfrac{1}{2}(\delta_S+\delta_N)+\tfrac{1}{2}R(M_E-M_W)+\tfrac{1}{4}d[(N+S)_E-(N+S)_W]+\tfrac{1}{2}(r_S-r_N)+\tfrac{1}{2}(m_S-m_N).$$